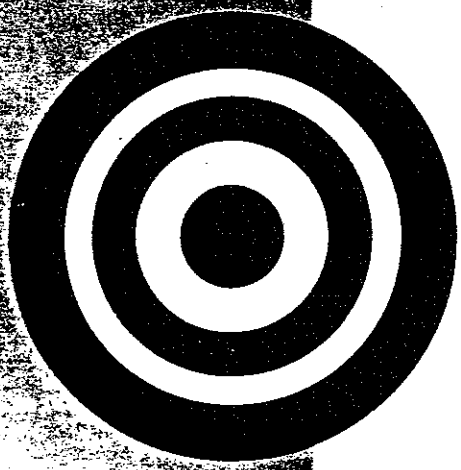
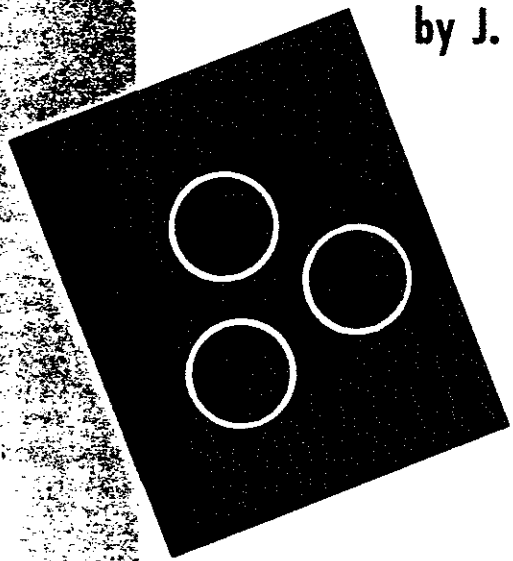
1994



Life-threatening injuries in children:

What have we learned and what are the challenges?

by J. Alex Haller, Jr., MD, FACS,
Baltimore, MD



What follows is my attempt to speak for the general surgeons of the United States and Canada who take care of children with life-threatening injuries. I will outline where I think we are in the management of serious injuries in children, and then will suggest some of the challenges that I believe lie ahead. I do this recognizing full well that there are many in American surgery who have contributed importantly to the management of life-threatening injuries in children. I believe we have learned a great deal over the last several years; but there still lie ahead for us some important challenges, both in the area of surgical care and in the organization of our trauma systems.

Brief resumé of trauma care: 1940-1990

Whence have we come in trauma care? I would like us to focus on the 1940s and 1950s, when we began to amass a body of knowledge about the pathophysiology of trauma. Much of it came from the military battlefields; some of it came from the civilian battlefields of our inner cities. Then, between 1955 and 1970, systems of trauma care developed in which we attempted to emulate military transport experience and identify ways in which patients could be brought most rapidly to the appropriate medical centers. The first regional trauma centers then came into being.

But as far as I am concerned, the Advanced Trauma Life Support® (ATLS®) course may stand as the single most important contribution of the American College of Surgeons to the care of injured children and adults. Bringing it into existence was an enormous task, and the ATLS course brought together dedicated individuals from rural, urban, and other walks of life to collate a body of knowledge that could be used for teaching continuity of trauma care.

Are injured children different from adults?

Within that ATLS course, we attempted to identify some of the special needs of children and teenagers, but constantly there arose the question, "Are infants and children different from adults? Do we need to look upon them in a special way because they are less mature and are smaller human beings?"

One of our approaches to answering this question was to identify the factors responsible for and patterns in most of the serious injuries in children. In so doing, we became aware that in pediatric age groups trauma was the number one killer of American children.[1] Not only was trauma responsible for most of the deaths, but between ages 1 and 14, unintentional injuries, crashes of various kinds, and burns from fire were responsible for 50 percent of the mortality in children. The chart (Figure 1) on page 10 was made in 1965, almost 30 years ago, when I first became aware of this impact of injury on children. The right side of this pie chart shows many of the other causes of death in children. Remarkable advances have been made in these other areas. For example, striking improvement has occurred in the management of malignancies in children; this includes both solid tumors and the leukemias. Many complicated congenital malformations have now yielded to management by pediatric surgeons and by neonatologists with a significant degree of success.

But very little has changed on the other side of this pie chart. In 1994, one in every two children who died in the United States died as a result of serious injuries. So trauma remains the number one cause of death in children.

Most children's injuries result from blunt forces such as crushing, compressing, or decelerating in relationship to a motor vehicle, which is the most common vector for serious injuries in children (see Figure 2, p. 10). School-age children are usually injured as pedestrians. In addition, falls are a frequent cause of blunt injury. The photograph (Figure 3) on page 11 reads "children can't fly" in two languages. Spanish is the common language where this scene is depicted, Harlem, New York City. Many children were falling out of tenement houses in the summertime when the windows were open. Fortunately, a good preventive measure was available. With window restraints, it was possible to decrease the number of injuries resulting from falls in that particular urban area.

The third major cause of death, burns, is shown on page 11 (Figure 4). We are beginning to collect data in different age groups and different regions of the country, so that we can accumulate information that may be helpful to us in both prevention and acute care. In age group 5-9

that particular five-year period in Maryland, a sizable percentage of children (nearly a fourth) died as a result of house fires.

Motor vehicle-related injuries, falls, and house fires are three very important causes of serious injury and death in children. So there are differences in the causes of children's trauma when compared with adult trauma.

Severity of injury/resuscitation response

The next question we asked ourselves was, "Does a child respond differently to the same severity of trauma?" We recognized early that the basic ABCs of management, *airway, breathing,* and *circulation,* were not only as appropriate for children as for adults, but were nothing new. These were basic ingredients in the management of any patient with serious injuries. But there were differences in the skills necessary for performing the ABCs.

The *airway*, for example, in a small child was much different anatomically than an adult's. Once the tongue is retracted in an adult, you are practically looking down the larynx. In an infant, on the other hand, the tongue is relatively so much larger, and the larynx is so much further anterior, that it requires special skills to intubate a small baby. Those skills can only be learned under good supervision and retained with constant practice.

Breathing and ventilation were also significantly different in that a child's mediastinum is not fixed and is very mobile all through childhood. Therefore, any degree of pneumothorax with a rapid shift of the mediastinal structures can be catastrophic to a small child. Also, the compliant chest wall with cartilaginous ribs could be so compressed that there could be a serious injury to the underlying parenchyma of the lung without a rib fracture. Therefore, some of the diagnostic features of adult trauma were not present in the early management of children with serious injuries to the chest. The indications for endotracheal intubation became clearer as we recognized that we might not be able to ventilate a child with a bag mask, particularly during transport when ensuring the airway was so critical. Therefore, indications for earlier endotracheal intubation were present, especially in those children who were unconscious. They could not protect their airways, and if they had associated

Figure 1

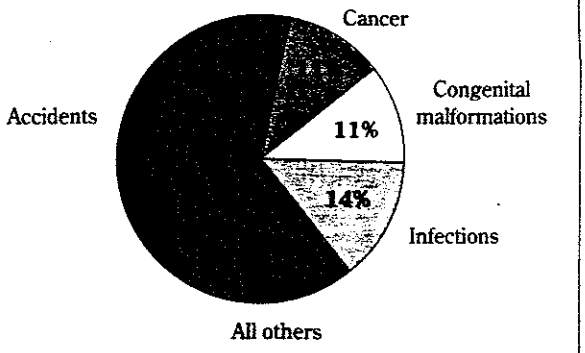
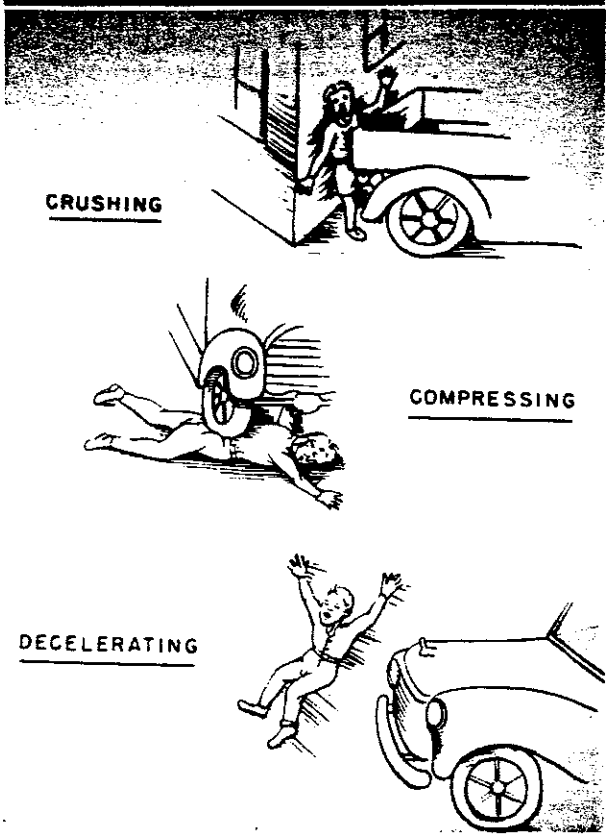


Figure 2



Blunt forces which are responsible for serious injuries in children.

Figure 3

Windows in high-rise tenement house in New York, NY. Note protective guard rails over lower windows.

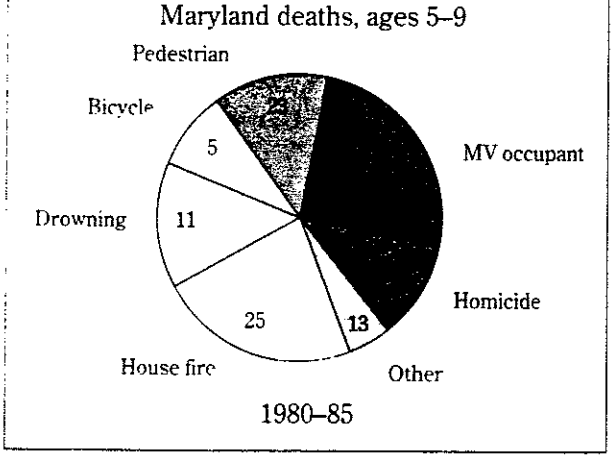
brain injury, hyperventilation became one of the important components of the overall management of that young child.

In the evaluation of the *circulation* of a child with hemorrhagic shock (hypovolemia), there was obviously the primary need for local control of bleeding, but the initial evaluation of the child in shock was more difficult. Capillary refill was useful. The central nervous system function was indicative of poor profusion of the brain, but in the small infant was not easy to characterize. One of the most important features of blood loss in a child was that the blood pressure was not an early reflection of intravascular volume loss, so that a child might lose 25 to 30 percent of his or her blood volume and still have a normal blood pressure. But the pulse always went up! So, close monitoring of the pulse became the standard of evaluating a young child with hypovolemia. The urinary output was also important, and we soon recognized the variation in output of the different age groups (for example, an infant has a different urinary output per pound or kilogram when compared to a preschool child or an adolescent). Change in urinary output is a very sensitive monitor of the adequacy of intravascular volume.

Under the options for vascular access, to the traditional approach of peripheral venous cannulation and cut downs, which we all learned as residents in surgery, was added an important new skill—intraosseous infusion, which none of us as surgeons had learned in the course of our training (see Figure 5, p. 12). But pediatricians had been using this technique for vascular access for more than 30 years in the management of infants with near sudden infant death syndrome (SIDS) and with overwhelming sepsis. By working with them, we became aware of this important skill that could not only be taught to surgeons, but could also be taught to emergency medical technicians and paramedics who could begin intraosseous infusion of crystalloid in the field with more success than with intravenous access in small children. So the ABCs of trauma management had some real differences in children.

There were others as we proceed into the Ds

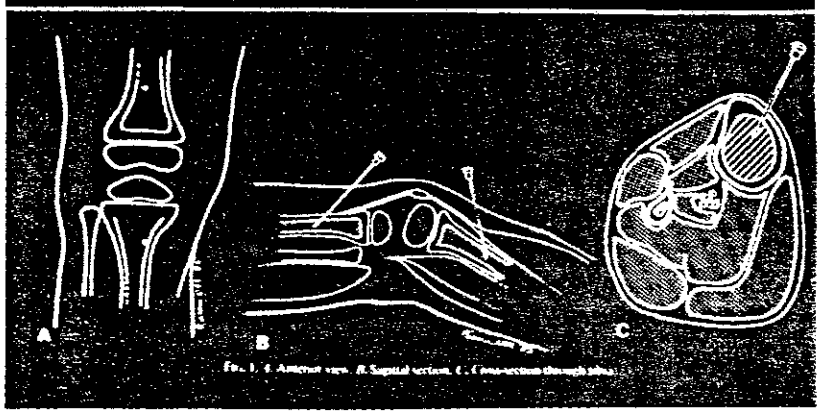
Figure 4



and Es because D, being a neurologic evaluation, also had to reflect the fact that a child does not have a fully mature neurologic system. In addition, the E[2] emphasized that a child in a cold environment will rapidly become hypothermic because there is not a matured central control of temperature. The environment has an even more important impact on the young infant.

We began to document that blunt injuries to the abdomen might result in very serious injuries to solid organs. In some recent series, 90 to 92 percent of the serious injuries to abdominal organs resulted from blunt forces. The spleen clearly was the organ most frequently injured. We learned early in the 1960s that the spleen not only functioned as a sieve within the bloodstream, but that it was the site of the production of an important antibody, now called tuftsin, which was necessary for breaking down the capsules of incapsulated organisms such as the *pneumococcus*. This finding is not new information to this audience, but some of the younger surgeons may not be aware of the background that finally led to recognizing that the spleen had an important immunologic function that was quantitative as well as qualitative. In other words, the spleen plays a major role in protecting the young infant.

Figure 5



Anatomy of intraosseous access for infusion in children.

With that information, the ball came back to our side of the net with the question, "Can you suture the spleen?" Most of us had been taught that it could not be sutured. We were told, "It is like wet toilet paper!" But using mattress sutures that cardiac surgeons had already been using on the myocardium, it was possible to control the bleeding to preserve the spleen and its function. Thus, when a child (such as represented by the photographs [Figure 6 and 7] on page 13 of an 11-year-old boy who was injured in a sledding accident) was being observed in the pediatric intensive care unit and began to deteriorate, that child went quickly to the operating room. Through a left upper quadrant incision, you can see the fracture in the spleen, the old blood clot, and the fresh hemorrhage. That spleen would have been removed a decade earlier, but by the 1970s we knew how to suture the spleen, to use some coagulant powder on the surface to control capillary bleeding, and this child has a functioning spleen today.[2]

In 1971, just about the time some of us had accepted this new approach to the management of splenic trauma, came the remarkable report from the Hospital for Sick Children in Toronto, ON (Table 1, p. 14). In black and white, the researchers showed us that they had nonoperatively managed many children with blunt injuries to the spleen if the patients did not require more than 40 percent of blood volume replacement.[3] This management was real heresy for many surgeons. A prospective study soon followed from that very fine children's hospital. If very careful protocols were followed, and if management was by surgeons in an intensive care environment, we could safely manage children nonoperatively if they remained hemodynamically stable, if they had received no more than 40 cc of blood volume replacement, and if they had diagnostic studies (such as CT scans) to identify associated injuries. Based on this experience, the algorithm (Figure 8) on page 14 was derived in which a child with blunt trauma could be managed in an intensive care environment unless the child was unstable, which would require immediate operative intervention. Otherwise, the

Figure 6

Operative photograph showing torn spleen in 11-year-old—injured in sledding accident—failed nonoperative management.

Figure 7

Splenic laceration secured with mattress sutures with functioning spleen thereafter.

child could be diagnosed in an appropriate environment, and if the child remained stable, nonoperative management was preferable. Note that this is *not* nonsurgical management, but rather nonoperative management. Clearly the surgeon needed to be a constant member of this team, because at any moment clinical deterioration demands a quick trip to the operating room. Nevertheless, it was appropriate to include nonsurgeons in the overall management. This team was led by a surgeon who had to call the shots and remain intimately involved in the continuing management of the child in a pediatric intensive care unit.

By the 1980s, the Golden Hour concept had become well accepted. The longer the patient remains hypovolemic and unresuscitated, the greater will be the cascade effect of metabolic deterioration, superimposed sepsis, which leads inexorably to organ failure and perhaps organism failure. What we recognized as we accumulated more data was that children have a Platinum Half-Hour. They deteriorate even more rapidly and do not have the reserves to withstand continuing insults as do their older counterparts. So if the Golden Hour concept underlined the importance of systems that brought patients into appropriate trauma hospitals, the same was also true for infants and young children—perhaps even more so because they did not have as much leeway for delay in their initial evaluation and resuscitation.

Trauma systems, dedicated to the care of children, began to

Table 1

Transfusion requirements for patients with splenic injuries

Grouped according to whether they were treated operatively or nonoperatively

	Nonoperative	Operative
Total no.	44	19
No. transfused	16 (36%)	19 (100%)
Pre-op. vol. (ml/kg)	—	80.4 ± 10.1*
Total vol. (ml/kg)	31.2 ± 5.3*	174.7 ± 23.3*

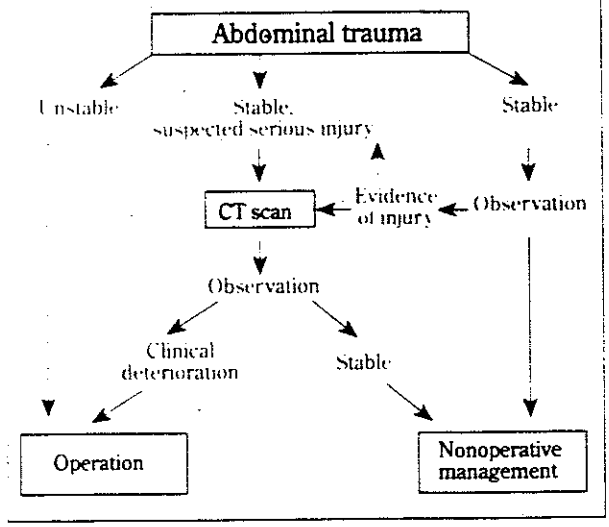
*Mean ± SEM

From initial report of nonoperative management of splenic trauma from Hospital for Sick Children, Toronto, ON.

evolve as we recognized that children's trauma was different because of the different forces and different responses of children due to their immaturity and because of their small size. We began to incorporate this information into the ATLS course.

In 1979, the first edition of the ATLS course did not have anything in it regarding pediatric trauma. A chapter on pediatric trauma did not appear until 1983. Some of our adult trauma surgeons proposed using a photograph of an infant stabbed with a butcher knife to introduce this chapter. It was not appropriate for a pediatric trauma section because it is a penetrating injury rather than a blunt one. A different photograph of a child with multiple blunt trauma from a motor vehicle accident should have been used for that first chapter on pediatric trauma. The little boy pictured on page 15 (Figure 9) would have been a better example. He is almost two years old, and was injured when he was standing with his brother on the curb, waiting for the school bus. His brother got on the school bus and this little boy stepped off the curb and was caught up in the back wheels of the school bus. He was crushed and burned against the exhaust system, and was brought in with multiple injuries. Fortunately, the boy was brought quickly into a resuscitation unit that was dedicated to the care of children. He was successfully treated, but his crushed pelvis, open fractures, and pneumothorax all could have been responsible for that child's death.

Figure 8



Algorithm for safe nonoperative management of blunt abdominal injuries in children.

Several important dicta came from the ACS Committee on Trauma as the ATLS course matured in the 1980s. You know these phrases as well as I: "Trauma is a disease of modern society." "Trauma is a surgical disease." "Surgical management is more than an operation."

These tenets were correct, but I believe we made two errors in judgment as surgeons caring for children and adults with trauma. First, we thought we could do it all ourselves. We had no partners. As a matter of fact, when the ATLS course was first given only surgeons were allowed to take it. Only after further evolution did we recognize that our emergency department physician counterparts needed those skills and that information, and then they could become a part of the management of the total patient. However, as a result of that initial exclusive approach, there was fragmentation of our emergency medical services systems. The American College of Emergency Physicians began developing its own course in the management of the injured patient.

Our second error was that *prevention* was not part of our protocols at that time. Most surgeons

are not involved in disease prevention, but that is a way of life of the pediatrician. The American Academy of Pediatrics appropriately posited that if trauma is really a disease, as we had stated, then what is the epidemiology and what are the preventive measures?

Pediatric surgeons finally became a part of the ATLS course in the early 1980s. With that background, our pediatric emergency colleagues asked, "Can't you help us with an advanced pediatric life support (APLS) course, modeled after your ATLS course, that will address not only injuries, but also illnesses?" For the first time, pediatric surgeons and pediatric emergency physicians, through the Committee on Pediatric Emergency Medicine of the American Academy of Pediatrics, began designing a more comprehensive course for life-threatening conditions in children. A number of us had to ask ourselves, "Should pediatricians be involved in the management of children with serious injuries?" It seems to me that if trauma is the most lethal disease of childhood, those physicians who normally care for children need some of those same skills, just as emergency department physicians need them.

Contributions of pediatricians

Were there any criteria to suggest that pediatricians might be effective? It was a pediatrician who first described the battered child syndrome or child abuse in Denver, CO.[5] It was a pediatrician who emphasized that while some of the objective features of intentional trauma, such as multiple fractures, could be taught and could be learned by surgeons, some of the more subtle signs, signs of physical neglect and the withdrawn child who was whimpering and unusually fearful, were not signs that most surgeons dealt with on a day-to-day basis. Therefore, the pediatrician became an important ally in the early determination of child abuse and the overall management of the battered child.

Who was it that conceived and introduced child car restraints? It was a pediatrician in Tennessee who suggested restraints as an important preventive measure. Shortly following the introduction of child restraints, we began having more and more legislation to champion seat belts that protected the older child and adults. I need only remind this audience that it is the child who often asks if the parents' seat belt is buckled. Universal use of seat belts was a natural evolution from child restraints.

Multiple systems injuries in two-year-old who was crushed by a school bus.

Injury prevention and control came out of a pediatric background, since pediatrics focuses on preventing illness. It was therefore natural for bicycle helmets to be a part of one of the important priorities of injury control developed by the American Academy of Pediatrics.

Building an integrated system

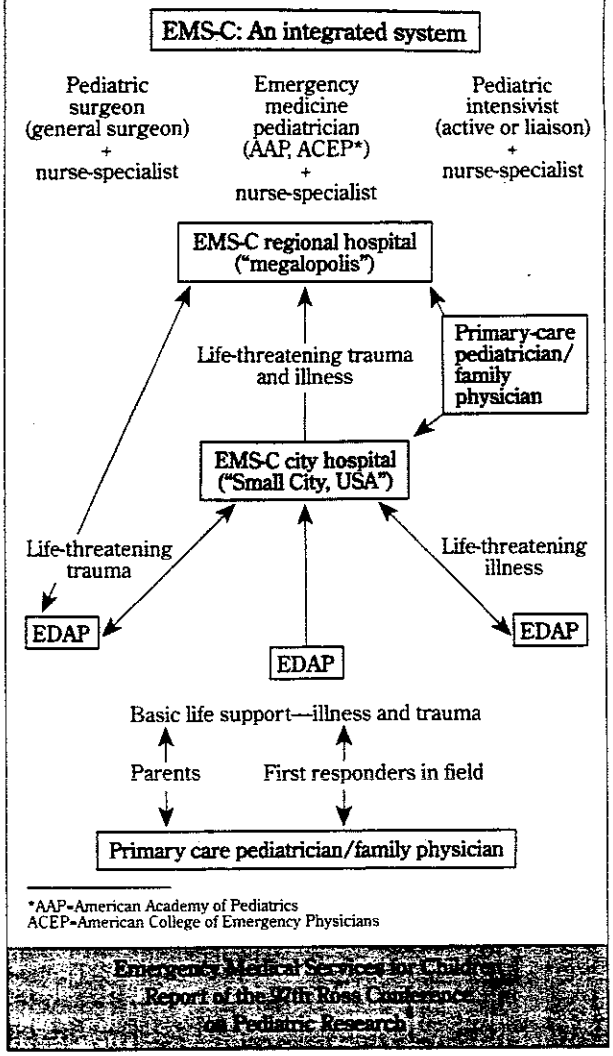
In 1988 we had a stroke of luck. The Ross Laboratories hold annual or semi-annual conferences on important issues in pediatrics. Some of us were asked to plan and participate in a Ross

Conference on Pediatric Trauma, but we were able to re-direct the emphasis into a more comprehensive study of emergency medical services for children.[6] A new concept came out of that Ross Conference, which addressed emergency medical services for children, including trauma and illness. The 1988 Ross Conference report was the first to focus on the fact that the essential features of emergency care for life-threatening illness in children are exactly the same ones that we had grown up with in children's trauma. All of the ingredients were there. So it seemed to me and to other pediatric surgeons working with pediatricians that we had a responsibility to help them build a strong integrated system in which parents had an important role, and which included injury control and illness prevention. We concluded that we could establish comprehensive systems that would address both illness and trauma. A systems algorithm might look like the one on this page (Figure 10). At the bottom are the entry sites of this overall system—emergency departments appropriate for pediatrics (EDAPs), a term originated by James Seidel, MD, an emergency pediatrician in Los Angeles, CA, both for trauma and for illness.[4] A sick or injured child would then move up the echelons of care into those special institutions that would have the personnel and facilities to care for life-threatening trauma and illness.

Shortly following that conference, federal monies became available to initiate the development of emergency medical services for children (EMS-C) through the Department of Maternal and Child Health with the strong leadership of a pediatrician from Hawaii, Cal Sia, MD, and his friend, Sen. Daniel Inouye.[7] Those first demonstration grants were important incentives, and this last year the 35th state received EMS-C enhancement money to bring forward new concepts in the management of life-threatening illnesses and trauma in children.

What about pediatric surgeons? How far behind were they lagging during this period of learning? In 1973, the first pediatric trauma centers came into being. There was a superb pediatric trauma center under Kiwanis support in Boston, MA, at the New England Medical Center, one in Ann Arbor, MI, at the Mott Childrens Hospital, one in Baltimore, MD, at Johns Hopkins Hospital, one at the Washington National Children's Medical Center, and one in the Hospital for Sick Children in Toronto, ON. We finally recognized that these pediatric trauma centers were critical components of an overall system for trauma care. (Notice I am not talking about illness at this point. I am suggesting that what we have learned in our pediatric trauma centers, which are a component of overall general trauma systems, is that surgeons can offer leadership in extending this into the area of illness at all ages.)

Figure 10



When a trauma center like ours at Johns Hopkins has a landing pad to deliver a child with serious injury, that same landing pad and that same helicopter can bring in a child with Reye's syndrome, or with overwhelming sepsis, or with some other life-threatening illness. The same is true for older children who are sometimes called adults.

From our pediatric trauma centers, we also learned a number of things about the initial assessment and what we were overlooking. These have become important concepts; for example, hypotension with head trauma means hidden bleeding somewhere. You can't bleed that much into your skull to become hypotensive. As we looked at our trauma centers and their performance, we recognized that a system of management did improve outcome, and we began to collect some data that would indicate that trauma centers have a positive impact.

Standards of care and prevention programs

Standards of care for the injured child were first enunciated in 1982. Max L. Ramenofsky, MD, FACS, was the lead author of a document, subsequently referred to as Appendix J of the ACS document, then titled *Hospital and Prehospital Resources for the Optimal Care of the Injured Patient*. This document became a guide for overall management of the seriously injured child.[8] In 1984, the National Pediatric Trauma Registry came into being. It now lists more than 65,000 injured children to give us a database from which we can conduct clinical research and identify trends that may be helpful to us in strategies for injury prevention. The development of pediatric trauma severity scores was an important step, and the Pediatric Trauma Score, introduced by Joseph Tepas, MD, FACS, was an important advance in evaluating injury severity.[9] Added to this were the sophisticated CT scans and sonography, which David E. Wesson, MD, FACS, has emphasized to me were an important evolution in our management of blunt trauma in children.

Trauma prevention programs became part of our way of life as pediatric surgeons. Most of us had to learn from pediatric epidemiologists, from pediatric statisticians, and from pediatricians who studied injury control. Some of us learned faster than others.

Barbara A. Barlow, MD, FACS, introduced a number of locally sensitive prevention programs in her area of Harlem in New York.[10] In some local school yards she envisioned areas where children could be safe; teachers and pupils constructed wall murals and drawings done in different pastels by those who played there. Under her leadership, abandoned fields of rubble in New York City were converted into gardens where children can be a part of blooming flowers, attempting to decrease some of the violence in their lives. Dr. Barlow has played a very significant leadership role in developing this urban initiative.

But there are other things to do. Playground safety is often overlooked. There is a sliding board in an elementary school yard within a half-mile of my house in Maryland that is 14 feet high. To a six-year-old who goes up there, you say "be careful." That is 14 feet high! If it were an American workman up on that slide, he would have OSHA regulations requiring a net and a hard hat, and yet our six-year-old on the playground is admonished to "be careful." The sliding board can be designed to be just as exciting with less danger. Mounted on a platform with one-foot graduated step-offs, a safe sliding board can still be 14 feet high. But if that child falls, he won't have a subdural hematoma; he'll have a bumped head and can run to his mom or dad for a hug.

There are other more sensitive areas that we have not addressed. In 1990, more than 12,000 Americans died as a result of handgun injuries. Is this important to children? You bet it is. Children find guns in the home. Loaded guns look like toys yet they can be responsible for the deaths of family members, and children can be caught in the crossfire.

In 1988, approximately 138,000 Americans were shot by children under six years of age. Children are not felons and they are not criminals. They find these unprotected guns in their homes. It is not because the gun itself kills, but because those adults who own it are irresponsible. This situation is a public health issue and I think that we as dedicated physicians need to push for more effective control of handguns in our homes, playgrounds, and schools.

Seizing leadership opportunities

We now have a second chance for leadership to form an *inclusive* emergency medical system. We have a model for that system from the 1993 Institute of Medicine report on emergency medical systems for children.[11] The Institute of Medicine is a study arm of the National Academy of Sciences in Washington, DC, that makes independent studies of major medical issues. This report focuses on the special needs of children in EMS.

We also have a recent track record of joint congressional efforts toward trauma funding in 1993, in which many of you participated. The leadership came from the American College of Surgeons; but I must emphasize to you that funding would not have been passed by Congress had the American Academy of Pediatrics not come forward, belatedly, and the American College of Emergency Physicians, and finally, squirming, dragging their feet, the American Medical Association. That unique coalition was responsible for the funding of our trauma programs and the extension of EMS systems, and it was *surgical leadership* that brought us through.

As noted previously, the 1993 Institute of Medicine report on EMS-C is a model upon which we can build a more comprehensive system because pediatricians and surgeons are working together in the management of life-threatening injuries and illness. I would like to suggest that what pediatric surgeons have learned from their pediatrician colleagues about children's needs may be important guidelines for adult EMS systems as well. The emergency medical services for children model is one which I think can be used for adults. Pediatric surgeons can now offer leadership for comprehensive care because from our trauma experience we can design comprehensive, interspecialty types of EMS-C, which will work for illness as well as trauma. We have earned the credibility to work closely with our pediatric colleagues. There is now greater recognition and acceptance of the need for such comprehensive programs for children.

We have learned that children have similarities with and differences from adults. Those critical differences require different personnel working in specially designed systems because children, for example, are much more likely to have respiratory problems causing cardiopulmonary arrest than heart disease. Airway control is more important than cardiac drugs. We must remember that children can't vote, and we are therefore politically responsible for their health and emergency care.

I will end by emphasizing that surgeons are grown children. They must offer mature leadership for EMS for all our citizens. They can do so because they don't only *operate* on trauma victims, they lead in the total management of this disease. We have identified our standard of care, the *Resources for Optimal Care of the Injured Patient*. I would like to see it changed in 1995 to read *Resources for Optimal Care of the Injured* ***and Ill*** *Patient*. This proposed new standard of care would list the American College of Surgeons at the bottom, with the American College of Emergency Physicians and American Academy of Pediatrics as collaborators. I think that is our greatest challenge. We need to offer critical leadership at the national level just as A. Brent Eastman, MD, FACS, our former Committee on Trauma Chairman, has emphasized. This time, our system must be *inclusive*. But if surgeons don't lead, there will not be an inclusive system for the care of life-threatening illness and injury for all. Ω

This article is an edited version of Dr. Haller's Scudder Oration on Trauma, which he presented at the 80th annual ACS Clinical Congress in Chicago, IL.

References

1. Haller JA: Pediatric trauma: The number 1 killer of children. *JAMA*, 249:47, 1983.

continued on page 43

Dr. Haller *is professor of pediatric surgery, pediatrics and emergency medicine, The Johns Hopkins University, and associate medical director, Children's Programs, Maryland Emergency Medical Services, University of Maryland, Baltimore, MD.*