REVIEW ARTICLE

Predictors of cardiac arrest in children

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Summary

The incidence of cardiac arrest (CA) in pediatric patients is lower than in the adult population. The unique anatomical and physiological characteristics of children contribute to differences in CA etiology and resuscitation outcomes. Key factors for surviving a life-threatening event include the rapid recognition of CA and the prompt initiation of effective resuscitation. Therefore, identifying predictors of CA is crucial, as they indicate the potential for such an event and help differentiate affected patients from others. It is possible to prevent CA by appropriate treatment in these situations. Moreover, there are significant differences in the approach, implementation of resuscitation procedures, treatment, outcomes, and education regarding CA events in children, whether they occur in-hospital or out-of-hospital.

Keywords: children, cardiac arrest, cardiopulmonary resuscitation, first aid

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INTRODUCTION

Cardiac arrest (CA) in children is the absence of mechanical cardiac activity, characterized by loss of consciousness, absence of a central pulse, and cessation of breathing. The causes of cardiac arrest in children are different from those described in the adult population. The success and outcome of resuscitation depend on the early recognition of respiratory and circulatory problems, a quick response, and the quality of resuscitation procedures. Predictors of cardiac arrest are extremely important, especially in the category of in-hospital cardiac arrests, when CA can be avoided by recognizing high-risk patients and undertaking adequate medical procedures (1). In the case of out-of-hospital cardiac arrests in children, preventive measures are crucial. These include creating a safe environment for children, educating caregivers about basic cardiopulmonary resuscitation (CPR) techniques, developing a pediatric emergency medical service, and informing parents about sudden infant death syndrome (SIDS). The concept of modern pediatric CPR was established in 1988 with the development of specific protocols, known as *Pediatric Basic Life Support (PBLS)* and *Pediatric Advanced Life Support (PALS),* along with a structured *Chain of Survival* for both in-hospital and out-of-hospital CA cases in children (2). The key to success and a good outcome in the treatment of cardiac arrest is time and good organization throughout all phases of resuscitation **(Figure 1)** (3,4).

World associations for resuscitation release new guidelines every 5 years, which are essential for improving resuscitation outcomes (4). These guidelines recommend maintaining registries on CA, as they help enhance preventive measures and resuscitation techniques. Currently, only 40% of European countries have organized and well-managed registries for pediatric cardiac arrest outcomes following resuscitation (5).

The American health care system is well-organized, which makes its pediatric CA data more reliable. Each year in the United States, approximately 15,200 in-hospital CAs and over 20,000 out-of-hospital CAs occur among children (6). To ensure consistency in international registries, it is recommended to use the pediatric version of the Utstein template, established in 1991, and the Pediatric Core Outcome Set for Cardiac Arrest (P-COSCA) score (7,8). The survival rate for CA in childhood remains low. Among other things, it depends on the place where the CA takes place. Children who experience in-hospital CA have a better chance of a good outcome than victims of out-of-hospital CA. There are also differences in CA treatment outcomes among hospitalized patients, depending on whether cardiac arrest occurred

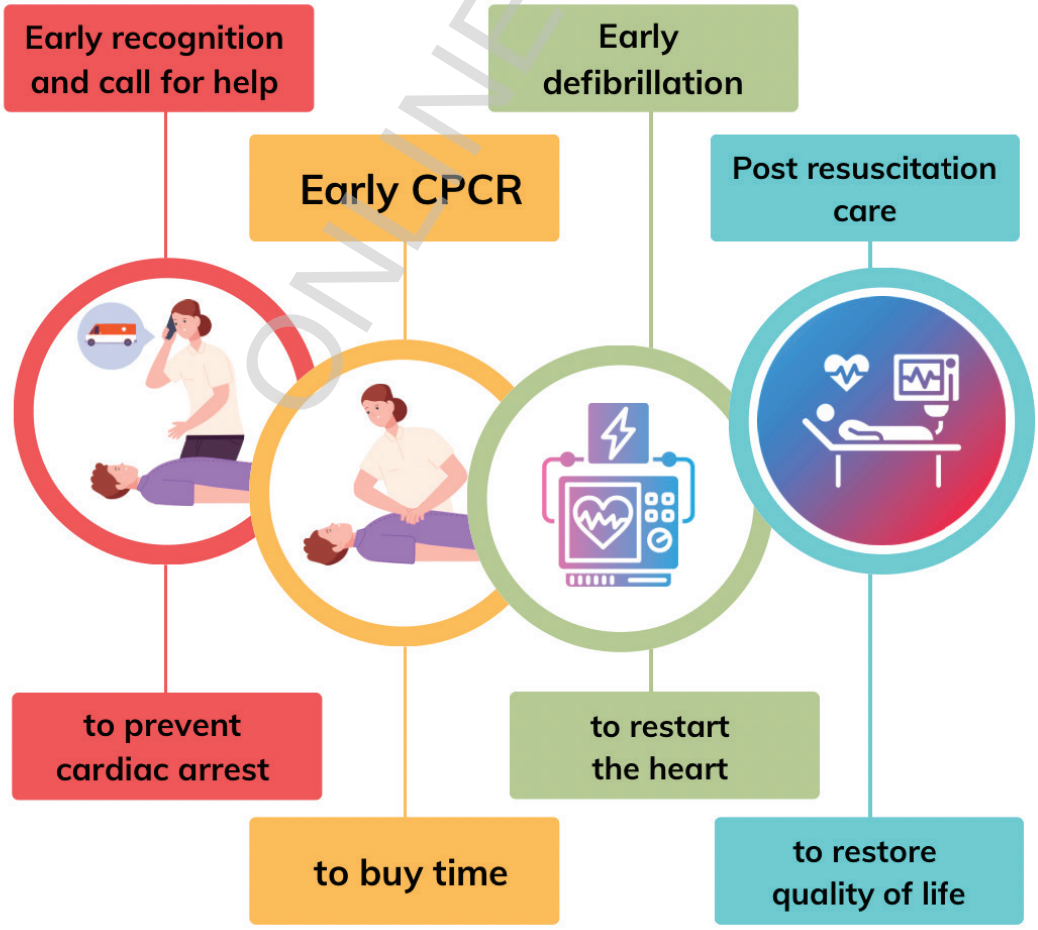

Figure 1. Chain of survival in childhood

in the emergency room, on the ward, in the intensive care unit, or during surgery in the operating room.

METHODS

A narrative review of the literature was conducted to identify relevant studies on predictors of CA in children. Electronic databases, including PubMed, Scopus, and Web of Science, were searched for English-language articles published from 2000 to 2025. Priority was given to systematic reviews, meta-analyses, clinical trials, and large observational studies.

The following keywords were used: "pediatric cardiac arrest", "in-hospital cardiac arrest in pediatric patients", "perioperative cardiac arrest in children", and "pediatric early warning scores".

ETIOLOGY OF CARDIAC ARRESTS IN CHILDREN

Children are not just smaller versions of adults; they have anatomical and physiological differences. As a result, the causes of CA in children differ from those in adults. In children, respiratory issues are the primary cause of CA, accounting for 75.8% of cases (9). The remaining cases are due to shock caused by sepsis or trauma, as well as cardiac diseases. The pathology of the respiratory system that can lead to CA in children includes bronchiolitis, pneumonia, status asthmaticus, aspiration of foreign bodies, smoke suffocation, and strangulation (10). Cardiac arrest can result from various conditions affecting the heart's structure and function. These include congenital structural abnormalities, complications following cardiac surgery, primarily electrical heart diseases, such as Wolff-Parkinson-White syndrome and long QT syndrome. Genetic syndromes like Marfan syndrome, hypertrophic cardiomyopathy, dilated cardiomyopathy, and arrhythmogenic right ventricular cardiomyopathy are also contributors. Other factors include myocarditis, arteriosclerosis, heart injuries, and drug-induced heart failure. In some cases, the cause of sudden cardiac events, such as those seen in Sudden Infant Death Syndrome (SIDS), remains undetectable (11).

IN-HOSPITAL CARDIAC ARREST (IHCA)

The incidence of in-hospital cardiac arrest (IHCA) among children admitted to pediatric intensive care units (PICUs) is approximately 1.8% (12). In the United States, the rate of hospital CA in children is 12.66 cases per 1,000 hospital admissions, with a survival rate for discharge to home at 41.1%. Among these survivors, 47% exhibit varying degrees of neurological damage (13). It is estimated that 90% of hospitalized children initially respond to resuscitation efforts; however, only about half of them survive the event and are discharged home (14). Around 90% of CA occur in PICUs, where the most critical pediatric patients are treated. Research conducted by Gardner and colleagues indicates that children who undergo cardiac surgery and receive treatment in the PICU have a higher chance of surviving CA compared to those with non-surgical heart diseases or non-cardiogenic CAs (12). The survival rate for heart failure in the emergency department is approximately 19%, while in the PICU, it rises to about 40% (15).

Predictors of CA can occur some time before the actual event. CA may be anticipated in various pathological conditions, including hypoxia, hypovolemia, acidosis, potassium imbalance, hypothermia, or disorders in glucose regulation. In children, hypoxia and hypovolemia are the predominant conditions leading to CA (16). Hypoxia manifests clinically with several symptoms, including increased respiratory effort, agonal breathing, cyanosis, tachycardia, impaired breathing mechanics, airway obstruction, abnormal auscultatory findings, desaturation, or an increased need for oxygen therapy. It is crucial to identify these signs during the compensation phase, employ appropriate maneuvers and equipment to maintain airway patency, administer oxygen therapy, and monitor oxygenation levels, ensuring that the minimum acceptable saturation level of 94% is maintained. In severe cases, it is crucial to perform lung ventilation with an Ambu balloon, along with oxygen therapy and various modes of non-invasive and invasive ventilation. In children, hypovolemia is most commonly caused by dehydration or acute bleeding, which can lead to shock and potentially to CA. Disorders of potassium homeostasis, which often contribute to CA, can occur in conditions associated with renal and gastrointestinal diseases. For patients with these problems, continuous electrocardiographic monitoring (ECG) and more frequent checks of laboratory and gas analyses are crucial for diagnosing this pathological condition.

Additionally, respiratory and/or metabolic acidosis, caused by various factors, can trigger CA. It is crucial to quickly identify the cause of acidosis and take appropriate therapeutic actions. Hypothermia can significantly reduce the success of resuscitation, and it is important to consider that during these procedures, the patient may be exposed to severe hypothermia. Therefore, maintaining normothermia during resuscitation is essential, and in some cases, Extracorporeal Membrane Oxygenation (ECMO) may be necessary as a warming measure.

Hypoglycemia can harm the developing brain; therefore, in critical pre-arrest situations, it is essential to monitor blood glucose levels. If necessary, administer sugar solutions either intravenously or intraosseously. In patients undergoing mechanical ventilation or those who have suffered trauma, tension pneumothorax should be anticipated; this condition rarely occurs spontaneously

without underlying lung pathology; therefore, appropriate radiological diagnostics are essential. In this situation, continuous clinical observation of the patient, frequent lung auscultation, and monitoring of saturation and hemodynamics are mandatory. To prevent CA, thoracic puncture and drainage may be required as therapeutic interventions.

Cardiac tamponade can result from trauma, surgery, infections, malignancy, or autoimmune diseases. The acute onset of tamponade can lead to circulatory shock, so it is essential to monitor the ECG, perform frequent ultrasound examinations, auscultate the heart, and perform pericardial drainage. In children, poisoning is common, especially among infants due to accidents, and in adolescents with suicidal intent. The toxic substances involved are often medications such as tricyclic antidepressants, calcium channel blockers, β-blockers, and digoxin, as well as illicit drugs like opiates and cocaine in teenagers. Additionally, thrombosis of the coronary blood vessels or pulmonary embolism can occur in children. Pediatric patients often experience damage to coronary blood vessels due to Kawasaki disease or congenital thrombophilia.

These conditions are referred to by acronyms "H" and "T," which are recognized in resuscitation manuals as reversible causes of cardiac arrest. Therefore, seriously ill children should be closely monitored and transferred to the PICU promptly. Vital signs must be assessed using both non-invasive and invasive methods, and the underlying medical problems should be diagnosed and treated with appropriate medications or surgery to prevent A.

It is crucial to identify potentially vulnerable children among all hospitalized patients. Special attention should be given to those exhibiting clinical signs such as hypoxia, tachycardia, acidosis, and hypotension. These signs are typically late indicators and often precede CA with asystole or Pulseless Electrical Activity (PEA) (17). Sepsis and septic shock are significant contributors to CA in children, particularly in newborns, where symptoms can present dramatically. Initial tachycardia may serve as an early warning sign, along with a discrepancy between heart and respiratory rates, elevated body temperature, behavioral changes, and poor peripheral perfusion. All these clinical signs indicate that the patient may be at risk (18). In over 50% of cases, poor peripheral perfusion accompanied by bradycardia occurs before asystole, whereas only 10% show an initially shockable rhythm leading up to asystole (19). In potentially life-threatening conditions, medical documentation, anamnesis from the parent or caregivers, laboratory analyses, and a clinical examination are essential for quickly assessing the severity of a child's condition.

The Pediatric Early Warning Score (PEWS) assesses a patient's condition by monitoring factors such as behavior, cardiovascular and respiratory status, frequency of nebulizer use, and episodes of vomiting. While the PEWS can suggest that a patient may need monitoring in the PICU, it is not an entirely reliable indicator of the severity of the child's condition. Instead, it serves as an auxiliary tool to support clinicians' decision-making. The PEWS is analogous to the Modified Early Warning Score (MEWS) and the National Early Warning Score (NEWS), which are used for adult patients **(Table 1)** (20).

Given the above, more frequent medical visits and real-time assessments for life-threatening patients in the PICU are essential, as suggested by Dewan et al. (21). The advancement of predictive analytics, computing technology, and artificial intelligence enables clinicians to predict CA several hours in advance. This foresight enables healthcare providers to identify potential CA patients and implement preventive measures promptly.

These predictive patterns are derived from analyses of laboratory and physiological variables, including re-

Table 1. Pediatric Early Warning Score (PEWS) Adapted from Gold DL, Mihalov LK, Cohen DM. Evaluating the Pediatric Early Warning Score (PEWS) system for admitted patients in the pediatric emergency department. Academic Emergency Medicine. 2014;21(11):1249–1256. (20)

PEWS	**PAEDIATRIC EARLY WARNING SCORE**			
	0	**+ 1**	**+ 2**	**+ 3**
Behaviour	Appropriate Playing Sleeping	Irritable but consolable	Irritable AND unconsolable Restless OR pain	Lethargic OR confused Reduce response to voice or pain
Respiratory	Room air Within normal parameters No retractions	> 10 above baseline Mild contractions OR + 30% FiO_2 OR Up to +2L/min	> 20 above baseline Moderate contractions OR + 40% FiO_2 OR Up to +4L/min	> 30 above baseline Grunting Severe contractions OR + 50% FiO_2 OR Up to +5L/min
Cardio Vascular	Pink OR Cap Ref 1-2 s.	Pale OR Cap Ref 3 s.	Grey OR Cap Ref 4 s. OR Tachy of + 20 over normal rate	Grey & mottled OR Cap Ref > 5 s. OR Tachy of + 30 over normal rate OR Brachy
Other	+ 2 for nebulizer use OR suctioning OR persistent vomiting post surgery			
Total Score	**< 2 points** **LOW**	**3-4 points** **INTERMEDIATE**	**5 points** **HIGH**	**6 + points** **VERY HIGH**

spiratory and cardiovascular instability, the need for intubation, and the use of vasoactive-inotropic drugs (as reflected in the vasoactive-inotropic score). This data comes from hundreds of CA patients and their behavioral patterns before CA. For example, the AMP3D'CoMET model, developed by Nihon Kohden's risk prediction system, assesses a patient's risk of CA based on the respiratory and cardiovascular instability within a three-hour window (22). Additionally, some models can predict potential clinical deterioration 8 to 16 hours in advance. Research has also been conducted in the pediatric population, highlighting the importance of early detection in identifying potential cardiac arrest victims (23).

Perioperative Cardiac Arrest

Perioperative CA refers to cardiac arrest that can occur at any stage during the operative or diagnostic process. This includes the premedication phase, the induction of anesthesia, intraoperatively, upon awakening from anesthesia, and during the immediate postoperative period, which can extend up to 48 hours (24,25). The Pediatric Perioperative Cardiac Arrest (POCA) Registry is maintained for pediatric cases of perioperative CA. A study conducted between 1988 and 2005 aimed to investigate the anesthesiological causes of these CAs, and it offered suggestions for prevention methods and therapeutic approaches (24). In the complex field of anesthesiology, the causes of CA can include human error, administered medication, equipment failure, the patient's complexity and age, or the nature of the surgical procedure itself. It has been estimated that the incidence of anesthesiological causes of CA in pediatric surgical patients ranges from 0.027% to 0.229%, or approximately 2.7 CAs per 10,000 anesthesia administrations (26,27). Approximately 83% of children who experience an initial CA survived the event when resuscitation efforts lasted for more than 20 minutes, while only 41% were discharged from the hospital. In infants, the incidence of perioperative CA is about 1 in 500, with 83% surviving the event, but only 37% leaving the hospital with major or minor neurological sequelae (28). A more recent pediatric study using the Wake-Up Safe database reports a higher incidence of intraoperative cardiac arrest at 0.053% (5.3 per 10,000 anesthesia administrations) (29).

Predictors of perioperative CA in children include age (particularly in those under one year old), comorbidities (approximately one-third of children have heart disease), emergency surgeries, prematurity, ASA classifications III and IV, and the presence of sepsis. Studies have shown that children who experience CA intraoperatively have better outcomes compared to those who undergo surgical procedures during the recovery phase (30). In non-cardiosurgical operations, warning signs of CA include severe hypoxemia (22%), bradycardia (11%), and uncontrolled hemorrhage (8.6%). Anesthetic drugs and airway manipulation most frequently cause bradycardia. Patients undergoing cardiac surgery often experience complications such as severe hypotension (16%) and cardiac tamponade (11%) (28).

The surgical specialties in which CA is most prevalent among pediatric patients include cardiac surgery, ear, nose, and throat (ENT) surgery, and interventional cardiology. According to a study by Oglesby et al., around 62% of children were well-prepared for surgery, while only 1% had inadequate preparation (28). This study also examined age-specific factors related to the presentation, causes of CA, types of surgery, and locations of occurrence **(Table 2)**. Furthermore, CA occurs more frequently with general anesthesia than with regional anesthesia, and it tends to occur more often during the day. In 5.8% of cases, the patient's condition was underestimated according to the ASA classification (31).

Excessive doses of propofol in ill children can lead to hypotensive CA. Additionally, using high concentrations of volatile anesthetic agents during inhalational inductions can result in bradycardia. There is a notable lack of invasive arterial blood pressure monitoring, especially in patients undergoing cardiac catheterization. It is also essential that at least two consultants be present during the induction of anesthesia. Furthermore, having senior personnel readily available could have prevented deterioration and CAs in several cases. This is particularly critical, as failure to establish an airway accounts for 14% of all pediatric CA (32).

OUT OF HOSPITAL CARDIAC ARREST (OHCA)

The incidence of out-of-hospital CA in children under 18 years of age in the USA ranges from 7.5 to 11.2 per 100,000 persons per year, which translates to approximately 20,000 cases annually (33). About 60% of out-of-hospital CAs occur at home, with infants being the most affected. In contrast, adolescents typically experience these incidents outside the home and account for one-third of all deaths among young victims under 50 years of age. Of those patients who are resuscitated, approximately 8.4-11.4% are discharged home (17.3% are adolescents, 14.7% are children, and 6.6% are infants) (34). In the past three decades, the survival rate for out-of-hospital CA has increased threefold. Progress was made by enhancing early recognition and initiating resuscitation measures.

The latest ERC 2025 guidelines recommend that adults caring for children be educated to recognize critical situations early by using the BBB triangle tools: Behavior, Breathing, and Body Color. This is especially important for parents and guardians of children with chronic illnesses, those who are tracheostomized and on home ventilation, children with heart diseases, children with malignant diseases, or premature infants (4).

It is essential to support bystanders who are resuscitating a child by providing telecommunication guidance

Table 2. Presentation and cause of CA, areas of surgery, and location in the pediatric population, depending on age and typical clinical signs (27)

Age	Presentation CA	Cause CA	Area of surgery	Location of CA
neonate	• bradicardia > 60% • severe hypotension • hypoxemia • hemorrhage	• patient > 90% • surgery > 40% • anesthesia > 25%	• cardiac surgery • general surgery • interventional cardiology	• theatre > 45% • remote location > 15% • PICU 30%
28.d to 1 year	• hypoxemia > 40% • bradicardia • severe hypotension	• patient > 85% • surgery > 45% • anesthesia > 30%	• cardiac surgery • ETN surgery interventional cardiology	• theatre > 30% • remote location 14% • PICU > 40%
older than 1 year	• hypoxaemia > 40% • bradycardia • severe hypotension	• patient in 85%, • surgery > 35% • anesthesia > 35%	• cardiac surgery • ENT surgery • spinal surgery • interventional cardiology	• theatre 60%, • remote location 15% • PICU in 20%
children with congenital heart disease (CHD)	• severe hypotension • bradycardia • cardiac tamponade • major haemorrhage	• patient in > 90%, • surgery 55% • anaesthesia > 20%.	• cardiac surgery, • interventional cardiology • diagnostic cardiology	• theatre > 25%, • remote location 25% • PICU in > 40%.
children without CHD	• hypoxaemia > 20% • bradycardia > 10% • haemorrhage < 10% • hypotension 5%	• patient in > 85%, • surgery 33% • anaesthesia > 35%.	• ENT surgery • abdominal surgery • radiological procedures.	• theatre >60%, • remote location 8% • PICU in > 20%.

from the ambulance service dispatcher (35). The dispatcher, an experienced medical professional, aims to promote early recognition of CA and encourage resuscitation for children over one year, until a specialized medical team arrives (34,36). The strategy for recognizing CA and initiating CPR through telecommunication with emergency services has been well established in adult medicine in developed countries. However, the development of pediatric emergency services in telecommunications related to resuscitation procedures lags. Typically, when an emergency call is made, the dispatcher identifies the patient's address and location. Then, the dispatcher asks two crucial questions: Is the child conscious? Is the child breathing normally? If the answer to either question is negative, the dispatcher begins to provide instructions for PBLS.

The first instruction is to place the child on their back on a hard surface. For children aged 0 to 8 years, CPR should start immediately with a compression-to-ventilation ratio of 30:2, as respiratory problems are often the cause of CA in this age group.

Chest compressions for children vary by age: performed with two fingers for infants under 1 year old, with the palm for children aged 1 to 8 years, and with both hands for children over 9 years old. If there's reason to believe that respiratory distress is causing CA in an older child, artificial ventilation should also be initiated alongside compressions.

During CPR, the rescuer should count loudly so that the dispatcher can hear. It is important to monitor the situation continuously, follow the dispatcher's instructions, and remain connected to the dispatcher until emergency services arrive. A study conducted at a pediatric emergency service in Washington from 2013 to 2019 revealed several interesting findings. Out of all emergency calls, 82% were made via telecommunications, and nearly 90% of CAs were correctly identified by dispatchers (37). The time from the call to recognition of a CA was 59 seconds, while the interval from recognition to the start of basic life support (BLS) measures was 58 seconds. Notably, the study found that children aged 9 to 17 were resuscitated in only 70% of cases, compared to younger children, even though the BLS protocol for this age group involves only compressions. In adolescents, causes such as hanging and strangulation are more common, complicating patient positioning and causing witnesses to be less likely to intervene in the resuscitation. Distribution of CPR may vary based on whether it is administered without the dispatcher's telecommunication assistance, with the dispatcher's guidance, or not undertaken due to the child's age **(Figure 2)** (37).

Two-thirds of CA in children occur during exercise or physical activity (38). We should be particularly concerned about this in obese children, if the child has hypertension, is exposed to toxins, drugs, or infectious agents, has experienced chest trauma, or has a family history of sudden death in a young person. In these children, warning signs are present in 30-50% of cases, but they are often ignored or misunderstood by parents or pediatricians (39). These warning signs include chest pain during physical activity, recurrent syncope (fainting), occasional convulsions, palpitations, rapid heart rate, shortness of breath, recent viral infections accompanied by chest pain, a noticeable decline in fitness, the onset of a new heart murmur, previously treated heart disease, and gastrointestinal symptoms such as nausea and vomiting, weakness, and abdominal pain, which can occur in about 20% of affected children (40). The outcome of CA depends on several factors: whether a shockable rhythm was identified, whether CPR was initiated immediately, and whether a rhythm was established before emergency services

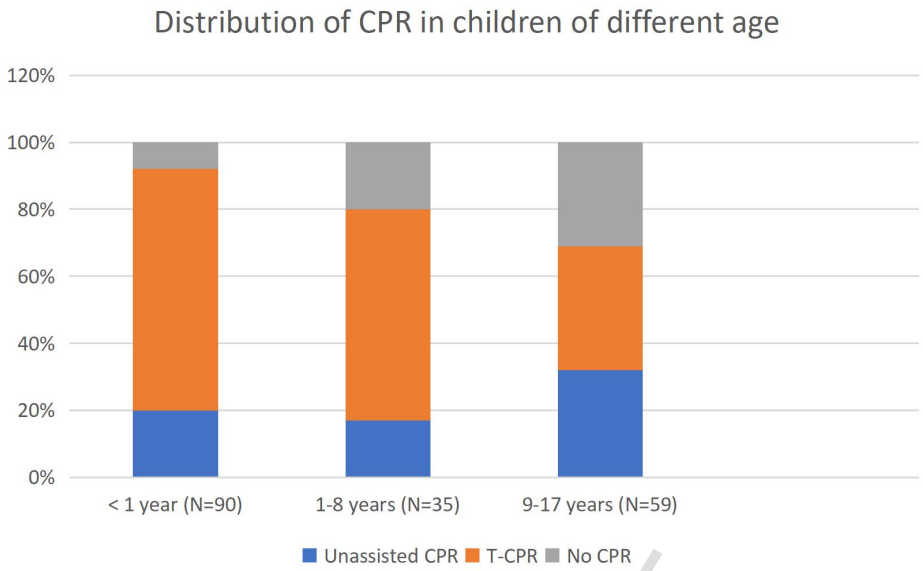

Figure 2. Distribution of cardiopulmonary resuscitation (CPR) in children of different ages

arrived. Asystole and PEA are the most common forms of arrhythmia, whereas ventricular fibrillation, which has a higher survival rate, occurs in only 10% of cases (41,42).

EDUCATION

Statistics show that education is crucial for CA progress and survival rates with good outcomes. The health system must identify weaknesses in the survival chain for both in-hospital and out-of-hospital CA. In hospital settings, early identification of potential CA victims requires continuous medical staff education, an effective notification system, and transportation of patients to PICUs or operating rooms equipped with advanced monitoring, diagnostic tools, and resuscitation and post-resuscitation treatment facilities (43). Perioperative CAs represent a distinct category of emergencies (44). Health workers need to be aware of the potential for these situations, recognize them early, and respond promptly with appropriate therapies. Modern simulation centers are vital for training medical resuscitation teams that specialize in treating children of all ages.

The most significant challenge facing the health system is in the management of OHCA. This includes educating the public about preventing CAs in children, emphasizing the importance of quickly implementing PBLS measures, improving telecommunications systems, and ensuring an efficient pediatric emergency service (45). It is also crucial to establish internationally recognized registries for pediatric CAs to enable thorough data evaluation. This approach is essential for advancing medical progress in this field.

CONCLUSION

The key to successful resuscitation is time. In healthcare settings, medical professionals are trained to identify these situations and provide patients with modern resuscitation techniques. Predictors of cardiac arrest in children are primarily related to respiratory and circulatory deterioration, with hypoxia, hypovolemia, and hemodynamic instability being the most significant warning signs. Early identification of these predictors, both in hospital and out-of-hospital settings, is crucial for preventing CA and improving survival outcomes. The use of structured assessment tools, continuous monitoring, and predictive models may further enhance early recognition. The healthcare system should educate the broader community, particularly caregivers of children, on PBLS skills. Additionally, improvements should be made to the pediatric emergency service system to offer telecommunication support to bystanders until the emergency response team arrives. This also includes ensuring appropriate transport for the child and ensuring PALS measures are available before the victim reaches the nearest children's hospital.

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PREDIKTORI SRČANOG ZASTOJA KOD DECE

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Sažetak

Incidenca srčanih zastoja (SZ) u pedijatrijskih bolesnika je manja odnosu na adultnu populaciju. Anatomske i fiziološke specifičnosti dečijeg doba doprinose da su uzroci SZ i ishodi reanimacije takođe drugačiji. Ključni faktori koji doprinose preživljavanju životno ugrožavajućeg događaja su brzo prepoznavanje i promptno preduzimanje kvalitetne reanimacije. Zato je prepoznavanje prediktora SZ veoma važno, jer oni nagoveštavaju razvoj nemilog događaja i izdvajaju bolesnika od ostalih. Pružanjem adekvantih mera lečenja u ovakvim situacijama moguće je prevenirati nastanak SZ. U odnosu na mesto dešavanja krucijalne razlike su u pristupu, sprovođenju reanimacionih postupaka, ishodu lečenja i edukaciji između vanbolničih i bolničkih dešavanja SZ koji se dešavaju u dečijem uzrastu.

Ključne reči: deca, srčani zastoj, kardiopulmonalna reanimacija, prva pomoć

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