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Neuropsychological, Academic, and Adaptive Functioning in Children Who Survive in-Hospital Cardiac Arrest and Resuscitation

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Children suffering cardiac arrest (CA) are not uncommon in certain pediatric populations. Due to the increasing survival rates of child CA patients, there is a growing interest in, and concern for, their long-term intellectual, academic, emotional, and adaptive functioning. This article describes the possible neurologic sequelae of CA in children and presents standardized assessment results on 25 children, 2 to 15 years of age, who survived a CA while in the hospital. A majority of these children exhibited low-average to deficient levels of performance on neuropsychologic, achievement, and adaptive behavior measures. Duration of cardiac arrest and a medical risk score were significantly correlated with decreased functioning in child CA patients. Children who suffer a cardiac arrest are at high risk for academic struggles, and many may need special education services.

Cardiac arrest (CA) occurs far less in children than in adults. However, children experiencing CA are not rare in certain pediatric populations. There is a growing body of medical literature concerning CA and related resuscitation techniques in children. Cardiac arrest in children is rarely a primary event; it is more often a sequelae to respiratory failure. Children suffering from insults to, or disorders of, the following systems are at risk for CA: cardiovascular (e.g., congenital heart disease, CHD); respiratory (e.g., pneumonia); central nervous system (CNS) (e.g., hydrocephalus, brain tumors, head injury); and gastrointestinal (e.g., hepatic disease) (Debard, 1981; Ehrlich, Emmett, & Rodriquez-Torres, 1974; Friesen, 1982; Ludwig, Kettrick, & Parker, 1984; Minter & Torphy, 1983).

To address CA in children, the medical profession has adapted cardiopulmonary resuscitation (CPR) techniques (Friesen, 1982) developed for adults. As a result, the rate of children surviving in-hospital CA and returning home ranges from 20% to 47% (Ehrlich et al., 1974; Nichols, 1984). Children who experience a CA outside of a hospital setting have lower survival rates. Because of the possibility of increasing survival rates for young CA patients, there is growing interest in, and concern for, the long-term functioning of CA survivors (Lasky et al., 1983; Mullie et al., 1980; O'Dougherty, Wright, Garmezy, Loewenson, & Torres, 1983).

In medical terminology, *cardiac arrest* denotes the functional cessation of the pumping action of the heart. Cardiac arrest can occur for a variety of reasons, all of which emcompass three main pathophysiologic pathways: hypoxia (lack of oxygen), hypoperfusion (lack of blood flow), or hemorrhage (inadequate red blood cell mass to carry oxygen to the tissue). The main deleterious effects of CA on the brain are caused by a combination of insufficient cerebral blood flow (CBF), decreased oxygenation, and anemia. During the acute phase of CA, as cerebral blood flow drops to nearly zero, the oxygen available to the brain is depleted within a few seconds (Frost, 1981; White, Wiegenstein, & Winegar, 1984). As the blood flow stagnates in the brain, oxygen is depleted. The resultant condition is termed *ischemic anoxia* or *hypoxic/ischemic* (H/I) damage, implying no oxygen and no blood flow. In this environment, normal brain chemistry and physiology undergo radical changes (Frost, 1981; White et al., 1984), which can lead to irreversible brain damage.

Early experiments with animals led researchers to believe that irreversible brain damage occurs within 4 to 6 minutes of H/I damage (Weinberger, Gibbon, & Gibbon, 1940). Later research (Ames & Guarian, 1963; Hassman, 1983; Hassman & Kleihues, 1971) suggested that CNS neurons can withstand 20 to 60 minutes of H/I without irreversible injury (White et al., 1984). However, the fact that clinically significant neurologic deficits still occur following H/I insults of much shorter duration has led investigators to search for their causes.

The adverse effects of acute anoxia on animals are well known (O'Dougherty, Wright, Loewenson, & Torres, 1985). Specific pathologic changes include edema (brain swelling) and widespread CNS damage, particularly to the basal ganglia, cerebral white matter, and brainstem, with sites of lesions related to the degree and duration of the anoxia (Hill & Volpe, 1981; Myers, 1975; Volpe, 1976). Unfortunately, the cited animal studies may not directly apply to or explain the pathology caused by brain HII in children (O'Dougherty et al., 1985). For example, CNS lesions following perinatal anoxia in human infants vary greatly; and damage to brainstem nuclei caused by anoxia is rare (Friede, 1975; Rorke, 1982).

The few studies relating to CA in children tend to indicate that brain damage is a correlate of H/I damage. In an extensive study of 406 children, Pampiglione, Chaloner, Harden, and O'Brien (1978) investigated the relationship between electroencephalographic (EEG) data and recovery from CA. One consistent finding was that patients suffered neurologic damage as a result of brain HlI that occurred during CA. Sixteen percent (n=19) of the children who survived at least 2 weeks (*n* =118) evidenced severe neurological sequelae as measured by a neurologic exam.

Our research at Egleston Children's Hospital at Emory revealed that some children suffering CA do have neurologic symptoms that are almost always indicative of brain damage. Most patients who died (75%) were in coma until death. On the other hand, of those patients surviving at least 6 months postarrest, more than 80% appeared to have survived without an obvious neurologic deficit on neurologic exam.

The foregoing observations tend to support the contention that CA may cause brain damage in some children but not in others. However, these studies only used a neurologic exam to detect CNS injury, and it is possible that survivors judged to be neurologically intact had actually sustained injury affecting academic and adaptive functioning only.

There are no previous prospective studies that assess the life quality of children following CA using a multivariate standardized assessment approach including measures of intellectual/cognitive functioning, academic achievement, relating to peers, social adjustment, or self-care and independent living skills. It is important to begin to describe the functioning of such children, and to describe factors that may predict their functional outcome. This is particularly crucial for ensuring that proper medical treatment protocols, academic programs, and sound counseling are delivered to the child's family and teachers as soon as possible after CA. The following study was undertaken to gather such information.

Method

Subjects

Subjects were children who were participants in the Pediatric Resuscitation Study carried out at Egleston Children's Hospital at Emory (Walter, 1989; Wright, Ahmann, Davies, & Carrigan, 1986). Patients meeting the following criteria participated in the study: (a) having parents' or guardians' permission, (b) history of only one CA, (c) at least 1 year post-CA, (d) not institutionalized, (e) no evidence of CNS infection or head trauma, and (f) no history of mental retardation or neurologic disability before the CA.

Of the 52 surviving subjects in the original Pediatric Resuscitation Study, 30 agreed to participate in this project. Of those 30 children, 5 were excluded from the study based on the above inclusion criteria. Four subjects were excluded because of CNS involvement prior to their CA. One subject had been diagnosed as mentally retarded before her CA. Of the 25 subjects remaining, 14 had cyanotic congenital heart disease (cCHD), 6 had a heart disease that did not produce cyanosis (acyanotic CHD = aCHD), and 5 had no heart disease (non-CHD = nCHD). Demographic characteristics for the 25 subjects were included in the data analyses (see Table 1). Socioeconomic status (SES) was based on Hollingshead's criteria.

Procedure

Subjects were given a standard neurologic examination by a pediatric neurologist or intensivist at the time of their follow-up evaluation. Thereafter, they were administered a battery of neuropsychologic and achievement tests (see Table 2). Measures in the neuropsychologic and achievement battery assessed the following constructs: (a) intelligence, (b) memory functioning, (c) visual-perceptual and visual-perceptual-motor (VPM) functioning, (d) verbal functioning, (e) problem solving and executive functioning, (f) motor functioning, and (g) achievement. Because of the age ranges covered by some measures, all items were not completed by all subjects. The parents or guardians of the children were also interviewed and completed a questionnaire regarding medical history and demographic data, the Vineland Adaptive Behavior Scale (Sparrow, Balla, & Cichetti, 1984), a behavioral checklist-the Child Behavior Checklist (CBCL) (Achenbach & Edelbrock, 1983)-and several measures of family functioning.

Medical Data

Subjects underwent neurologic exams at 6, 12, and 24 hours post-CA. The data from these exams were used to derive a CA-related neurologic severity score based on the Toronto Hospital for Sick Children's Coma Scale. To classify subjects' post-CA functional outcomes, the Glasgow-Pittsburgh Cerebral Performance Categories (CPC) (Safar, 1989) were used.

A cumulative medical-problem risk score was also derived. A patient received a positive score for each of the

TABLE 1
Demographic Characteristics of Subjects *(N = 25)*

Age (months)	
Mean	67
Median	55
Range	21-179
Sex	
Male	36%
Female	64%
Race	
White	72%
Black	28%
Medical status	
eCHO	56%
aCHD	24%
nCHD	20%
SES[a]	
Group 1	20%
Group 2	24%
Group 3	40%
Group 4	16%
Group 5	0%

Note. eCHO = cyanotic congenital heart disease; aCHD = acyanotic CHD; nCHD = non-CHD.
[a]Socioeconomic Status-Hollingshead: Group 1, Professional and Technical; Group 2, Managerial, Clerical, and Sales; Group 3, Skilled Workers; Group 4, Semi-Skilled Workers; Group 5, Unskilled Workers.

TABLE 2
Standardized Assessment Battery for Children Following in-Hospital Cardiac Arrest

A. Intelligence
    Stanford-Binet Intelligence Scale (4th ed.) (SB-IV) (Thorndike, Hagen, & Sattler, 1986) or Bayley Infant Scale
B. Memory functioning
    Verbal Memory I subtests standard score of the McCarthy Scales of Children's Abilities (McCarthy, 1972) (ages 2.5-8.5)
C. Visual-spatial and Visual-perceptual-motor functioning
    Developmental Test of Visual-Motor Integration standard score (Beery, 1967) (ages 4-13)
    Gestalt Closure subtest standard score of the K-ABC (Kaufman & Kaufman, 1983) (ages 2.5-12.5)
D. Verbal functioning
    Peabody Picture Vocabulary Test-Revised standard score (Dunn & Dunn, 1981) (ages 2.5-adult)
    Faces and places subtest of the K-ABC standard score (ages 2.5-12.5)
    Rapid Automatized Naming Test standard score (Denckla & Rudel, 1976) (ages 3-8)
E Executive functioning
    Hand Movement subtest of the K-ABC, standard score (ages 2.5-12.5)
F. Motor functioning
    Timed Motor Exam standard scores (Denckla & Rudel, 1974) (ages 3-12)
    Purdue Pegboard Test standard score (Purdue Research Foundation, 1948) (ages 2-15)
    Motor Battery of the McCarthy, standard score (ages 1-adult)
G. Achievement functioning
    Woodcock-Johnson Psycho-Educational Battery (Woodcock & Johnson, 1977)
H. Adaptive and behavioral functioning
    Vineland Adaptive Behavior Scales (Sparrow, Balla, & Cichetti, 1984) (ages 1-adult)
    Child Behavior Checklist, Parent's Questionnaire (Achenbach & Edelbrock, 1983) (ages 2-16)

following conditions: medical disease pre-CA (such as CHD or congenital heart failure), weight less than 5th percentile for age, age of less than 6 months at time of CA, seizures, CA-related stroke, or age of less than 16 months at time of surgery. Length of CA was also included in the data base. CA was determined as the need for chest compressions in the resuscitative phase. Patients who responded to airway management alone were excluded.

Data Analysis

All statistical procedures were performed using SAS (SAS Institute, Inc., 1985). All standardized test data results were transformed to standard scores (55) (mean = 100, SD = 15). The Shapiro-Wilk statistic was utilized to assess the probability that the distribution of values of the variable in question was from a normal distribution. The Wilcoxon two-sample test was performed to test for differences among various groups of subjects.

Results

It was predicted that children surviving CA would show deficits (standard scores at or below 1 SD below the normative population mean) on IQ, visual-perceptual and VPM skills, executive functioning, memory functioning, motor functioning, academic achievement measures, adaptive behavior measures, and parent behavior rating scales, even though this sample of children appeared to represent the general population in SES and related indices. In a standard, normal distribution, approximately 16% (Tabachnick & Fidell, 1983) of all subjects fall at or below 1 standard deviation below the mean. Results showed that these children tended to perform at the low end of average or at deficient levels on neuropsychologic, achievement, and adaptive behavioral measures (see Table 3), and that the distributions of

almost all variables exhibited moderate to extreme positive skewness. Approximately half of the participants, who were administered the Woodcock-Johnson Skills Ouster subtests, Woodcock-Johnson Knowledge Ouster subtests, and the Kaufman Assessment Battery for Children (K-ABC) (Kaufman & Kaufman, 1983) Faces and Places subtest, scored below a standard score of 85. The distributions of a large majority of the neuropsychologic, adaptive, behavioral, and achievement test results had significantly more than 16% of subjects scoring at or below 1 standard deviation below the mean.

Peer relationships, behavior problems, and social adjustment have been shown to be important predictors of normal development in children. On the CBCL, few subjects were observed to score in the clinically significant range (t score > 70) on the various subscales, indicating the absence of particular social skills and social adjustment problems. In fact, these results suggest that the children had a tendency to exhibit internalized types of behavior problems, although these were some of the more impaired children who had elevations on the hyperactivity scale. On the Socialization Domain of the Vineland, the mean score of subjects was 86.6, and 48% of the subjects scored below a standard score of 85 on this domain-the least problematic of those assessed by the Vineland. The adaptive behavior scores of the majority (>60%) of subjects tended to be commensurate with the general intellectual/cognitive findings.

It was also predicted that length of time of cardiac arrest would correlate significantly and negatively with IQ, neuropsychologic functioning, neurologic outcome, academic achievement, hyperactivity levels, and adaptive behavior. The Stanford-Binet composite score $(r=-.47)$ and Vineland Adaptive Behavior composite score $(r=-.56)$ showed significant negative correlations with duration of CA. The number of internalizing behavior problems

TABLE 3
Descriptive Statistics for Neuropsychologic and Achievement Measures
for Children Surviving Cardiac Arrest (n = 25[a])

Variable	Mean[b]	sob	%<1 soc
Stanford-Binet Composite			
test score Verbal	87.0	17.4	66.7
Reasoning score	91.4	13.7	27.7
AbstractNisual Reasoning score	83.8	18.0	63.2
Quantitative Reasoning score	85.6	18.6	61.1
Short-Term Memory score	93.1	22.4	38.8
K-ABC			
Hand Movement subtest	85.0	18.6	68.8
Gestalt Closure subtest	95.7	17.7	33.3
Spatial Memory subtest	90.8	22.0	50.0
Faces and Places subtest	87.9	14.8	53.3
McCarthy			
Motor Battery	75.7	31.2	75.0
Verbal Memory I subtest	96.0	10.3	20.0
Right-Left Orientation subtest	78.8	20.6	62.0
Developmental Test of Visual-Motor Integration	82.7	19.9	64.3
Peabody Picture Vocabulary Test-Revised	80.9	15.5	72.2
Purdue Pegboard Test			
Left Hand	70.5	38.4	72.2
Right Hand	74.8	28.3	82.4
Woodcock-Johnson			
Knowledge Cluster subtests	89.5	17.2	50.0
Skills Cluster subtests	86.6	28.5	46.2
Vineland Adaptive Behavior Scales			
Communication Domain	87.2	20.8	59.1
Daily Living Skills Domain	83.0	18.3	56.5
Socialization Domain	86.6	16.4	47.8
Motor Skills Domain	78.9	18.3	60.0
Adapt1ve Behavior Composite	81.1	17.4	68.1

•some Ns are <25 due to limitations of certain tests at young ages. bNormative mean = 100 and SD = 15 for all variables. °% of subjects sconng at or below 1 SD below the normative mean.

(CBCL) correlated positively (r=0.36) with duration of CA.

In a post hoc analysis, the sample was divided, based on clinical experience, into two groups. Group 1 comprised subjects whose duration of CA was less than or equal to 15 minutes (n=17), and Group 2 comprised subjects whose duration of CA was greater than 15 minutes (n=8). The Vineland Adaptive Behavior composite score (z= -2.99; p<.003) and the Stanford-Binet composite score (z= -2.17; p< .03) were significantly different between these two groups of children. For the Vineland Adaptive Behavior composite score, Group 1 and 2 means were 87.0 and 67.5, respectively; for the Stanford-Binet composite score,

Group 1 and 2 means were 87.8 and 68.2, respectively.

Another hypothesis predicted that the cumulative medical-problem risk score would show significant negative correlation with neuropsychologic and adaptive-functioning measures. The Stanford-Binet composite score $(r=-.54)$ and the Vineland Adaptive Behavior composite score $(r=-.31)$ were significantly correlated with a child's medical-problem risk score. In addition, there was a significant positive correlation between the medical-problem risk score and the hyperactivity scale on the Child Behavior Checklist.

A post hoc analysis used the cumulative medical-problem risk score as a

grouping variable. Low-risk children were considered to have cumulative medical-problem risk scores of <3.0, the high-risk children a cumulative medical-problem risk score > 3.0. The two groups of children scored significantly differently on the Stanford-Binet composite test (z= -2.80; p<.005): Group 1 and 2 means were 90.0 and 66.0, respectively. These groups of children also scored differently on the Vineland Adaptive Behavior composite test (z= -1.81; p<.07): Group 1 and Group 2 means were 85.8 and 68.8, respectively.

Discussion

This study is the first of its kind to quantitatively study the neuropsychologic, adaptive, and academic functioning outcomes of pediatric cardiac arrest survivors in a prospective study. In comparison to normative distributions, more children than expected who had survived a cardiac arrest showed deficits (score at or below 1 SD below the normative mean) on a wide range of IQ, neuropsychologic, achievement, and adaptive behavior measures. More children than expected (16%) performed at or below 1 SD below the normal mean on 37 of the 41 individual neuropsychologic, achievement, behavior, and adaptive behavior variables assessed. On 20 variables, more than half the children scored at or below 1 SD below the normative mean. These 20 variables fell into one of five general categories: IQ, VPM functioning, fine and gross motor control, achievement functioning, and adaptive behavior.

The problems detailed above closely parallel those exhibited by children with CHD. In view of the number of subjects with CHD included in the analyses, there is a possibility that the results of this study are partly due to the expected deficits of such subjects (O'Dougherty et al., 1985), irrespective of whether they had had an arrest.

Duration of CA did correlate significantly with a number of composite variables (Stanford-Binet composite score; the Vineland Adaptive Behavior composite score). In addition, the cumulative medical-problem risk score also correlated with these composite variates, among others. For this sample, medical problems represented by the cumulative medical-problem risk scores are more strongly related to the global measure of intellectual ability than they are to variables measuring more circumscribed cognitive abilities (i.e., verbal abilities), which suggests that these children may have heterogeneous and diffuse outcomes.

Summary

Assessments of children who have survived CA indicate that they have globally lowered IQ visual-perceptual-motor, achievement, adaptive, and fine and gross motor abilities. Sixteen of 23 subjects (65%) scored at or below a standard score of 85 on the IQ test. Eleven (48%) subjects fell in the mildly mentally retarded range (IQ between 50 and 70). These results are a strong indication that subjects in this sample have global intellectual/cognitive deficits. In addition, these results suggest that both length of CA and a cumulative medical-problem risk score can be useful in predicting the eventual intellectual, academic, and adaptive deficits of child CA survivors. Behavior problems are typically not observed, although a tendency to be hyperactive may be seen in subjects who are at highest risk. Clearly, children who have survived CA are at notable risk in their future development. Overall, a prudent course would be to evaluate child CA survivors psychologically after their CA or shortly before entering school. Because the standard neurologic exam may yield normal results, the child's pediatrician may not know to refer him or her for evaluation. Many of these children will require special education services, and a majority are at risk for academic struggles if they do not receive appropriate resources and support.

ABOUT THE AUTHORS

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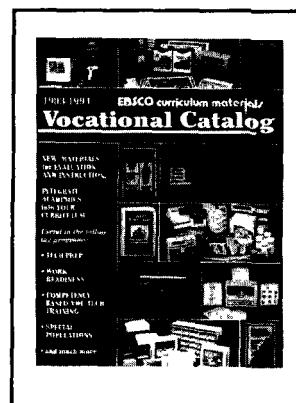
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