Risk and Prevalence of Developmental Delay in Young Children With Congenital Heart Disease

WHAT'S KNOWN ON THIS SUBJECT: Children with congenital heart disease demonstrate a high prevalence of low-severity developmental problems in the areas of language, motor skills, attention, and executive function. Systematic evaluation has been recommended to promote early detection of problems and ensure appropriate intervention.

WHAT THIS STUDY ADDS: This study presents results of longitudinal testing in early childhood. Developmental delays were common. Feeding difficulty and medical and genetic comorbidities increased risk for delays. Exposure to risk and prevalence of delay change over time; therefore, repeated evaluations are warranted.

abstract

BACKGROUND AND OBJECTIVE: Children with congenital heart disease (CHD) are at risk for developmental delay (DD). Changes in cognitive, language, and motor skills in early childhood have not been described. We report the results of a structured approach using longitudinal testing to identify problems and ensure early intervention in accordance with published guidelines.

METHODS: Bayley Scales of Infant Development, Third Edition, were used to assess cognitive, language, and motor skills in 99 children with CHD. Subjects were evaluated 3 to 6 times in the first 3 years of life. DD was defined as scores >1 SD below the population mean.

RESULTS: Cardiac anatomy was single ventricle (1V) in 34 subjects and 2 ventricles (2V) in 65. Medical comorbidities were present in 21% and genetic syndromes in 19%. Most subjects (75%) had DD in ≥ 1 area at ≥ 1 assessments. Subjects with 1V anatomy had equivalent outcomes to those with 2V. Cognitive and language scores declined in subjects with genetic syndromes but were stable and within the average range for subjects with 1V and 2V. Motor scores improved for subjects with 1V and 2V but remained low for those with genetic syndromes. In addition to age, need for supplemental tube feeding, longer cardiopulmonary bypass time, and shorter time since last hospitalization were significant predictors of developmental outcomes.

CONCLUSIONS: DDs in young children with CHD are both common and dynamic. Providers should encourage longitudinal surveillance for children with CHD because exposure to risk and prevalence of DD change over time. *Pediatrics* 2014;133:e570–e577

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KEY WORDS

congenital heart disease and defects, developmental follow-up, developmental outcomes, assessment and surveillance, child development

ABBREVIATIONS

1V—single ventricle

2V—2 ventricles

BSID-III—Bayley Scales of Infant Development, Third Edition

CHD—congenital heart disease

CHW—Children's Hospital of Wisconsin

CPB—cardiopulmonary bypass

DD—developmental delay

HHCDC—Herma Heart Center Developmental Follow-up Clinic

SES—socioeconomic status

Dr Mussatto conceptualized and designed the study, supervised data collection, prepared data for analysis, led interpretation of results, and prepared the manuscript; Dr Hoffmann oversaw the statistical analyses and reviewed and revised the manuscript; Dr Hoffman contributed to study design and interpretation of results and reviewed and revised the manuscript; Dr Tweddell contributed to interpretation of results and reviewed and revised the manuscript; Dr Bear completed the developmental evaluations of the subjects enrolled, oversaw subject recruitment and informed consent, and reviewed and revised the manuscript; Dr Cao carried out the statistical analysis and contributed to interpretation of results; Dr Brosig contributed to study design and interpretation of results and reviewed and revised the manuscript; and all authors approved the final manuscript as submitted.

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Children with congenital heart disease (CHD) are at risk for developmental delays (DDs).^{1–4} A characteristic pattern of a high prevalence of low-severity or combined disabilities in the areas of visual motor integration, language, motor skills, attention, executive function, and behavior has been described in multiple research studies.^{5–7} Although many studies have reported outcomes near 1 year of age, no previous studies have obtained serial measures by using a consistent developmental assessment tool in young children throughout the first 3 years of life. Longitudinal research is needed to understand the emergence of DD over time in order to improve developmental outcomes in children with CHD.

In an effort to promote early detection of DD and appropriate intervention, the American Heart Association and the American Academy of Pediatrics issued a joint guideline statement in 2012.⁸ The guideline identified patients with CHD at high risk for DD and suggested systematic surveillance, screening, and evaluation throughout childhood to assess academic, behavioral, psychosocial, and adaptive functioning.⁸ Early detection of developmental problems will direct interventions that can prevent or reduce long-term problems known to have a profoundly negative impact on quality of life and ability to achieve optimum potential in adulthood.

The purpose of this study was to characterize changes in cognitive, language, and motor skills during the first 3 years of life in a sample of children with CHD undergoing longitudinal developmental evaluation in a clinical setting. We hypothesized that deficits in cognitive and language skills would become more apparent as expected skills become more complex with increasing age, and subjects with single-ventricle (1V) anatomy would have lower developmental scores than children with

2-ventricle (2V) anatomy. In addition, we evaluated the impact of previously identified risk factors, such as genetic and medical comorbidities, poor growth, feeding problems, and treatment-related factors, on outcomes.

METHODS

Patient Population

Subjects were recruited from the Herma Heart Center Developmental Follow-up Clinic (HHCDC) at Children's Hospital of Wisconsin (CHW). Children were eligible for inclusion if they had undergone a minimum of 3 evaluations in the follow-up clinic, and parents provided informed consent for inclusion in a research database approved by the institutional review board at CHW. No subjects were excluded based on race, language, or coexisting conditions.

Children were deemed to be at high risk for DD and eligible for the HHCDC⁹ if they had any cardiac surgery as a neonate, surgery using cardiopulmonary bypass (CPB) in the first year of life, a cardiac defect resulting in cyanosis or were otherwise at risk for delay due to comorbid conditions such as prematurity, genetic syndrome, or significant perioperative complications such as seizures or cardiac arrest (all subjects met high-risk criteria as defined by the American Heart Association and American Academy of Pediatrics guideline⁸).

Developmental Evaluation

HHCDC visits occurred approximately every 6 months beginning at 6 months of age. The multidisciplinary evaluations included solicitation of parental concerns related to development, medical history, physical examination, anthropometrics, and completion of the Bayley Scales of Infant Development, Third Edition (BSID-III).⁹ The BSID-III provides composite scores for cognitive, language, and motor skills with a normative population mean of 100 and SD of 15.

Recommendations for structured early intervention or therapy were made for all children where BSID-III scores were outside the average range (>1 SD below mean). Early intervention is a broad term that includes both individualized, systematic evaluation and interventions that may include general developmental support; physical, occupational, or speech therapy; or a combination of approaches. These interventions may be delivered in federally mandated programs or through private therapy.

Parents or guardians provided details of family structure, child care arrangements, feeding strategy, and information about early intervention services the child had received or was currently receiving. Socioeconomic status (SES) was calculated using the Hollingshead 4-factor index,¹⁰ taking both parents' education and occupation into account. Patient-related and treatment-related variables were abstracted from the medical record.

Statistical Analysis

Characteristics of the sample are presented as means with SD or medians with interquartile range for continuous data and frequencies for discrete data. Subjects were classified into 3 subgroups by diagnosis: 1V anatomy without genetic syndrome, 2V anatomy without genetic syndrome, and those with clinically diagnosed genetic syndromes. In addition to being treated as a numerical score, developmental outcomes at each assessment and within each domain (cognitive, language, and motor) were classified as "average" if they were within 1 SD of the mean or higher (scores >85), "at risk" if they were 1 to 2 SD below the mean (scores 70–84), and "delayed" if they were >2 SD below the mean (<70). The trajectory of development over time in each domain (cognitive, language, and motor), was modeled using a mixed model for the score with a random intercept and

random slope for each subject. Each outcome and subgroup was tested for departures from a linear model with a quadratic term orthogonal to the linear term. There was no evidence of a statistically significant curvilinear relationship between outcome scores and time. Age at each visit was based on calendar age and was not equal for all subjects. Sample means for each domain were estimated at 6-month intervals based on the model. Univariable regression was used to assess the impact of demographic and clinical variables on developmental outcomes for each subgroup. Coefficients were calculated to determine the change in composite score with each month of increasing age and whether this slope was significantly different from zero. Factors with the greatest univariate significance were included in a multivariable hierarchical regression model with elimination of variables when there was significant collinearity.

RESULTS

Characteristics of the Patient Population

From January 2007 through December 2011, 99 subjects completed 3 to 6 longitudinal evaluations at a total of 395 HHCCDC visits. Median time interval between visits was 6.0 months (interquartile range 5.9–6.4), and age at evaluation ranged from 5.5 to 37.3 months. Children were referred for evaluation based on diagnostic and clinical history. We did not attempt to control when subjects entered or left the program. Age at visit is shown in Table 1. Parents of 9 children evaluated in the clinic declined participation in the research database (participation rate of 92%, 99/108).

Demographic characteristics of the 99 children with longitudinal follow-up are presented in Table 2. The sample was consistent with the population served by the Herma Heart Center at CHW; 61%

TABLE 1 Age at Visit

	3–8 mo	9–14 mo	15–20 mo	21–26 mo	27–32 mo	33–38 mo	Total
Visit 1	78	13	5	3	0	0	99
Visit 2	0	74	17	5	3	0	99
Visit 3	0	1	61	27	6	4	99
Visit 4	0	0	1	38	16	2	57
Visit 5	0	0	0	0	25	10	35
Visit 6	0	0	0	0	0	6	6
Total	78	88	84	73	50	22	395

of the subjects were white, and SES was middle class for the majority. In addition to CHD, 21 children had additional chronic medical conditions involving the following systems: neurologic or neuromuscular ($n = 8$), respiratory ($n = 4$), hearing ($n = 3$), gastrointestinal ($n = 1$), immunologic ($n = 1$), and multisystem ($n = 4$). Anatomy resulted in 1V in 34 subjects and 2V in 65. Nineteen children had a clinically diagnosed genetic syndrome or abnormality, including trisomy 21 ($n = 9$), 22q11 deletion ($n = 5$), Turner ($n = 2$), CHARGE syndrome (coloboma, congenital heart disease, choanal atresia, mental and growth retardation, genital anomalies, and ear malformations and hearing loss; $n = 1$), Pierre Robin ($n = 1$), and central core myopathy ($n = 1$). Ninety-five percent (18/19) of the children with genetic syndromes had 2V anatomy. One subject with Pierre Robin had 1V anatomy. We did not use universal genetic screening. Genetic consultations were obtained when there was clinical suspicion of an abnormality. All children with heterotaxy syndrome or conotruncal abnormalities such as tetralogy of Fallot or truncus arteriosus had a chromosomal analysis with microarray and a fluorescence in situ hybridization test.

Treatment characteristics, feeding strategy, and use of early intervention services are outlined in Table 3. Treatment characteristics were calculated as cumulative lifetime experience at time of visit. Need for supplemental tube feeding occurred in 33% of the subjects after their first hospitalization and persisted at 25% of follow-up visits. Growth failure, de-

TABLE 2 Demographic Characteristics

Demographics	<i>n</i> (%)
Gender	
Male	56 (57)
Female	43 (43)
Race	
White	61 (62)
Black	10 (10)
Hispanic	19 (19)
Other	9 (9)
SES	86 (missing for 13)
Low (<30)	27 (31)
Mid (30–55)	43 (50)
High (>55)	16 (19)
Prenatal diagnosis	61 (62)
Premature (GA <37 wk)	20 (20)
GA (mean $\pm$ SD)	38.1 $\pm$ 2.1
Birth weight <2.5 kg	16 (17)
Anatomy	
1V	34 (34)
2V	65 (66)
Other chronic conditions	
None	59 (60)
Other medical	21 (21)
Genetic syndrome	19 (19)

GA, gestational age.

fined as weight or height below fifth percentile at any visit, occurred in 55% (54/99). Poor growth was significantly more common in subjects with genetic syndromes, occurring in 100% of this group compared with 35% of subjects with 1V anatomy and 52% of those with 2V anatomy ($P < .05$).

Developmental Evaluation Outcomes

Developmental domains were significantly correlated with each other; cognitive and motor ($r = 0.73$), cognitive and language ($r = 0.72$), and motor and language ($r = 0.66$, all $P < .0001$). Most subjects (75%) had scores in the “at risk” or “delayed” range in ≥ 1 domain at ≥ 1 assessment. Significant delay

TABLE 3 Treatment Characteristics

Treatment Characteristic	N (%)	Mean	Median	SD	Interquartile range (25th–75th percentile)
Age at first visit, mo	99	8.5	7.2	3.6	(6.6–8.2)
Age at last visit, mo	99	27.6	29.4	5.7	(23–32)
Interval between visits, mo	296	6.4	6.0	1.4	(5.9–6.4)
Age at first open heart, d	87 ^a	79.8	19	126.8	(7–121)
Total no. of open heart operations	87 ^a	1.6	1	0.8	(1–2)
Length of hospitalization, d	98 ^b	66.9	43	74.2	(24–76)
CPB time, min	86 ^b	248.5	215	153.5	(145–308)
DHCA time, min	38	18	12	17.4	(7–20)
Days since last hospital discharge	98 ^b	488.9	528	294.3	(233–675)
Feeding at first discharge					
All by mouth	66/99 (67)				
Supplemental tube feeds	33/99 (33)				
Feeding at visit					
All by mouth	297/395 (75)				
Supplemental tube feeds	98/395 (25)				
Growth failure at any visit	54/99 (54)				
Ever in Birth to 3 (B–3)	73/99 (74)				
Currently in B–3 at visit	219/395 (55)				

DHCA, deep hypothermic circulatory arrest.

^a 12 subjects never had open heart surgery.^b Data on CPB time and hospitalization unavailable on 1 subject who had surgery at another center.

(cognitive, language, or motor score <70) occurred in 14/19 (74%) of children with known genetic syndrome, 11/33 (33%) of children with 1V anatomy, and 10/47 (21%) of children with 2V anatomy. Nineteen percent (8/42) of children who had cognitive, language, and motor scores in the average range at 1 year of age were later found to be at risk or delayed in ≥ 1 area. Parents reported that 74% (73/99) of the children had received or were actively receiving early intervention services from the state-based Birth to 3 programs or private therapy.

Effect of Diagnosis

The serial changes in cognitive, language, and motor scores by diagnostic subgroup are shown in Fig 1. Cognitive and language scores for subjects with 1V and 2V anatomy were in the low average range and varied little over time. Of note, the slope of cognitive and language scores was positive for subjects with 1V anatomy and negative for those with 2V anatomy, although neither was statistically significantly different from zero. Subjects with known genetic syndromes had declining cognitive scores

over time ($P < .01$). Subjects with 1V and 2V anatomy, without genetic syndrome, had normalizing motor scores that improved significantly over time ($P < .01$); however, those with genetic syndromes had unchanging low motor scores across all time points. In contrast to our hypothesis, subjects with 1V anatomy performed as well as, if not slightly better than, those with 2V anatomy in cognitive, language, and motor skills.

Risk Factor Analyses

Other factors that demonstrated a significant negative association with developmental outcomes in univariate analysis included supplemental tube feeding, the presence of other medical comorbidities, birth weight <2.5 kg, longer CPB time (every 200 minutes), >2 open heart procedures, longer hospital length of stay (every 30 days), and shorter time since last hospital discharge (every 100 days). Results for subjects with 1V and 2V anatomy without known genetic syndrome are shown in Table 4. Other factors considered, such as race or ethnicity, gender, prenatal diagnosis, prematurity, oxygen saturation at visit, or age at first open

heart operation, did not demonstrate significant associations with the developmental outcomes. Two variables were used as an indicator of SES, the Hollingshead 4-factor index¹⁰ and highest level of maternal education, and neither was found to be a significant predictor of any BSID-III scores.

The multivariable hierarchical regression model included factors with the greatest univariate significance in addition to age at visit. Results for the subjects with 1V and 2V anatomy are shown in Table 5. After age at visit, feeding strategy at the time of the visit was entered as the first predictor variable because it had the strongest relationship with all outcomes. Subjects taking full oral feeding were compared with those who needed any supplemental tube feeding. Hospital length of stay was highly collinear with need for supplemental tube feeding. When both were entered into the multivariable model, need for tube feeding was the dominant factor for all outcomes, so length of stay was not included in the models.

For subjects with 1V anatomy, the ability to take full oral feedings at the time of their visit was strongly associated with cognitive, language, and motor outcomes; subjects taking full oral feedings had scores that were 10 to 21 points higher than those of subjects who needed supplemental tube feeding. Older age at visit was significantly associated with improved motor scores. For subjects with 2V anatomy, full oral feeding at time of visit remained the dominant factor; cognitive, language, and motor scores were 8 to 13 points higher in subjects taking oral feeds. Cognitive scores decreased by -0.7 points ($P < .05$) for each month of age for subjects with 2V anatomy. Language scores decreased by ~ 9 points for every additional 200 minutes of CPB time the subject experienced. Days since last hospitalization demonstrated an independent effect on cognitive and

FIGURE 1
Developmental trajectories by domain and diagnostic subgroup. Horizontal lines are shown at the population mean of 100 and 1 SD below the mean at 85.

motor scores. For every 100 days since the subject's last hospitalization, cognitive and motor scores increased by ~ 2 points. For the subjects with genetic syndromes, age at visit was a predictor of cognitive scores (-0.54 per month, $P < .01$) and approached significance for language scores (-0.36 per month, $P = .054$). Supplemental tube feeding (-10.8 , $P < .001$) and days since last hospitalization (-1.7 , $P < .05$) were significantly associated with motor skills.

DISCUSSION

Our research identified a high prevalence of DD in this cohort of children with CHD whose developmental progress was evaluated multiple times over the first 3 years of life. Serial assessment allowed us to model the longitudinal developmental trajectory in cognitive, language, and motor skills. Scores were considered at risk or delayed in ≥ 1 area in 75% of the group. However, many of the delays were subtle and may not have been detected without formal evaluation. Also of note, there were delays that emerged over time, emphasizing the importance of longitudinal evaluation and revealing that development is not static in children with CHD. This is in contrast to healthy children, who typically have stable development over time and of whom only 16% would be expected to have any DD. Health care providers caring for children with CHD should anticipate these problems and encourage developmental follow-up.

Developmental outcomes varied by age, diagnostic subgroup, and the domain assessed. Both patient- and treatment-related risk factors were considered. The most significant factor associated with developmental progress in all domains was the ability to achieve full oral feeding without the need for supplemental tube feeding. Feeding is one of the most important tasks for an infant and developing toddler and has

been associated with later developmental outcomes.^{11,12} Successful oral feeding despite complex CHD may be an early sign of neurologic integrity. Ab-

normal brain development has been described in infants with CHD before any surgical intervention,^{13,14} including a higher-than-expected incidence of

open opercula,^{1,15} a part of the brain associated with taste, oral motor coordination, and language.¹⁶ In this cohort, it is not clear whether the inability to achieve oral feeding was an indicator of neurocognitive deficit or injury or whether alteration of the normal feeding experience put development at risk. Neuroimaging was not included in this study, so the incidence of congenital or acquired brain abnormalities is unknown. Strategies to improve feeding skills, such as speech and feeding therapy or a multidisciplinary feeding clinic, should be recommended for all children who need supplemental tube feeding.

Beyond feeding, the presence of additional medical or genetic comorbidities and poor growth were the most significant risk factors for poorer outcomes. Longer duration of CPB and shorter time since last hospitalization were also significant risk factors for poorer outcomes in patients with 2V anatomy in multivariable analysis. This indicates that the whole child and his or her experience should be considered in evaluating risk. It is not possible to quantify risk for delay based on cardiac diagnosis alone.

Motor deficits were the most common in early assessments; cognitive and language deficits became more prevalent with time. The gap between typically developing children and children with delays or disabilities becomes apparent in different domains at different ages. Developmental testing is more sensitive in older children because the

TABLE 4 Variables Significantly Associated With Bayley Scores by Univariate Analysis

	1V Without Genetic Syndrome (<i>n</i> = 33)			2V Without Genetic Syndrome (<i>n</i> = 47)		
	Cognitive	Language	Motor	Cognitive	Language	Motor
Linear age trajectory (per month)	0.15	0.15	0.74***	−0.25	−0.23	0.44**
Intercept	95.0	90.4	77.4	104.2	99.1	86.2
Baseline variables						
Race or ethnicity (other than Caucasian); ref: Caucasian	−3.9	7.0	−1.6	−3.1	−0.6	−6.4
SES (ref: >55)						
30–55	−5.8	−14.0	−17.2	−1.9	−4.9	−6.9
<30	4.5	2.0	−2.9	5.5	−4.2	−0.04
Gender of child (female); ref: male	−2.9	3.6	−4.4	−2.4	5.6	−6.5
Feeding at first discharge (supplemental tube feeding); ref: all by mouth	−15.3**	−19.0**	−23.8***	−5.5	−13.7*	−18.0**
Premature ≤37 wk (yes); ref: no	5.5	9.2	1.0	0.42	−4.3	−5.3
Age at first open surgery (per day)	0.03	0.03	0.04*	−0.009	−0.02	−0.05
CHD + other medical condition; ref: CHD only	−7.7	−5.2	−1.5	−14.0**	−13.3**	−11.2*
Growth failure (yes); ref: no	−8.1	0.19	−19.2**	−6.7	−7.4	−7.6
Weight at birth category (<2.5 kg); ref: ≥2.5 kg	−8.5	−6.7	−12.1	−1.5	−7.1	−9.1
Dynamic variables						
Feeding at visit (supplemental tube feeding); ref: all by mouth	−10.6**	−14.8***	−20.8***	−11.5**	−8.6*	−15.4***
Cyanotic at visit (SaO ₂ <90%); ref: Yes	−1.9	1.6	−2.8	0.74	−0.27	−1.1
Total open procedures; ref: ≥2 open						
0 open	10.5	9.8	18.7*	12.8**	10.9*	14.7**
1 open	15.5**	11.1*	10.5	6.5	5.4	4.0
CPB time (per 200 min)	−8.7**	−6.5**	−7.1**	−4.4	−9.0**	−6.3
Days since last hospital discharge (per 100 d)	−0.06	−4.5	0.8	2.1**	0.9	2.4**
Cumulative LOS (per 30 d)	−2.3**	−1.8**	−2.0**	−7.2***	−6.4***	−8.2***
Current height percentile; CDC	0.10	0.22**	0.09	0.08	0.10*	0.11*

CDC, Centers for Disease Control and Prevention; LOS, length of stay; SaO₂, arterial oxygen saturation.

* *P* < .05.

** *P* < .01.

*** *P* < .001.

TABLE 5 Multivariable Predictors of Bayley Scale Scores

Predictor	1V Without Genetic Syndrome, Estimate ± SE			2V Without Genetic Syndrome, Estimate ± SE		
	Cognitive	Language	Motor	Cognitive	Language	Motor
Age at visit (per month)	0.1 ± 0.1	0.1 ± 0.1	0.7 ± 0.1***	−0.7 ± 0.2**	−0.1 ± 0.1	−0.1 ± 0.2
Oral feeding (at visit)	10.6 ± 3.7**	14.8 ± 3.4***	20.8 ± 3.6***	9.9 ± 3.0**	8.3 ± 3.4*	13.4 ± 3.5***
CPB time (per 200 min)	NA	NA	NA	NA	−9.4 ± 3.0**	NA
Days since last hospitalization (per 100 d)	NA	NA	NA	1.7 ± 0.7*	NA	2.0 ± 0.7**

NA, variable not included because of collinearity in multivariable model.

* *P* < .05.

** *P* < .01.

*** *P* < .001.

complexity of skills they are expected to perform increases with age. The cumulative impact of both biologic and environmental factors also becomes more apparent with time. It is not clear how well the developmental outcomes measured in young children will predict their abilities at later ages. In a cohort of subjects with hypoplastic left heart syndrome assessed at 12 months, 30 months, and 5 years of age, early outcomes were significantly associated with scores achieved at 5 years.¹⁷ In subjects with repaired transposition of the great arteries, developmental achievement at 1 year of age was only modestly associated with outcomes at 8 years.¹⁸

This study allowed direct comparison of similar-aged children with 1V anatomy to those with 2V anatomy. An unexpected finding was that subjects with 1V anatomy had stable cognitive and language scores in the low average range. Those with 2V had similar cognitive and language scores; however, there was evidence of a downward trend in scores over time. Although children with 1V and 2V CHD without genetic findings had stable developmental trajectories, scores were consistently in the low range of average, and mild delays were common. These subtle delays are typical of the CHD population and may represent the type of problems that are most amenable to improvement with early intervention.

In this sample, subjects with 1V anatomy performed better than expected and notably better than other recently published reports of outcomes at 14 months of age in similar subjects. In our cohort, 11% of subjects with 1V anatomy had motor scores >2 SD below the mean at ~ 1 year of age, compared with 28% in the Infant Single Ventricle Trial¹⁹ and 44% in the Single Ventricle Reconstruction Trial (both assessed with BSID-II Psychomotor Development Index at 14 months of age).²⁰ These encouraging results in subjects with 1V anatomy

may be associated with a programmatic approach that systematically monitors this population.^{21,22} This program also promotes a high level of parent engagement, and the importance of ongoing developmental support is stressed. In contrast, there is less opportunity to engage with parents of young children with 2V anatomy because reparative surgeries may occur later in life, and there may be less contact with clinicians. The need for developmental surveillance in this population may be both underappreciated by clinicians and underemphasized to parents. In addition, the high prevalence of clinically diagnosed genetic abnormalities in subjects with 2V anatomy implies that there may be other underlying genetic variation in this population that does not manifest as a specific syndrome but could influence development.

Children with known genetic syndromes demonstrated the greatest delays in all domains. This is consistent with previous findings in children with CHD in association with Down syndrome²³ and 22q11.2 deletion.²⁴ Greater use of genetic evaluation in the CHD population may be warranted, given the profound impact of a genetic diagnosis on all aspects of development. It is possible that genetic abnormalities were overlooked in this sample because universal genetic screening was not used.

Our study has some important limitations. First, the study relied on subjects who were being evaluated as part of clinical follow-up; therefore, subjects entered or left the program for reasons we did not attempt to control. Subjects with more problems may have been more likely to attend the HHCDC. We compared attendees with nonattendees and found that nonattendees lived farther away and had less complex operations. Formal genetic evaluations and neuroimaging were not available on all subjects, so some important abnormalities may have been overlooked. It was also impossible to

quantify the amount, quality, and impact of early intervention services that the children received during the testing period. Finally, it is too early to assume that these findings are generalizable to the population of children with CHD as a whole. Additional research is needed to determine whether similar patterns of development and the impact of risk factors are identifiable in a multicenter cohort.

CONCLUSIONS

DDs in children with CHD are common and should be expected. Both subjects with 1V anatomy and those with 2V anatomy are at risk. The presence of feeding difficulty, poor growth, medical comorbidities, genetic abnormalities, and more complex treatment increases risk for DD. These data confirm that longitudinal surveillance throughout childhood and into adulthood is necessary for children with CHD because exposure to risk and prevalence of DD change over time. Systematic developmental screening and surveillance can identify subtle emerging problems and facilitate access to early intervention services to prevent or reduce long-term problems. Primary and specialty care providers for children with CHD should anticipate these problems and encourage developmental follow-up. Additional research is needed to evaluate the long-term impact of routine developmental follow-up and early intervention in this population.

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