

Review

Neurocognition in Adult Congenital Heart Disease: How to Monitor and Prevent Progressive Decline

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ABSTRACT

Children born with congenital heart disease (CHD) are now living to adulthood in unprecedented numbers and many will eventually live to become senior citizens. As care goals shift from surviving to thriving, a new focus on quality of life has emerged. Neurocognition and the ability to participate fully in society, form meaningful relationships, and collaborate effectively with the health care system are important considerations. As adults with CHD age, research regarding their cognitive function becomes prescient. The focus is now shifting from defining neurocognitive deficits in children with CHD to preventing neurocognitive decline in adults living with CHD. In this review, we describe the possible etiologies and predictors of neurocognitive

RÉSUMÉ

Un nombre sans précédent d'enfants nés avec une cardiopathie congénitale atteignent maintenant l'âge adulte, et bon nombre deviendront des personnes âgées. Alors que les objectifs thérapeutiques passent de la survie à une vie épanouie, la qualité de vie suscite un nouvel intérêt. La fonction neurocognitive et la capacité de participer pleinement à la société, d'établir des relations significatives et de collaborer efficacement avec le système de soins de santé constituent d'importantes considérations. Au fur et à mesure que les adultes atteints de cardiopathie congénitale vieillissent, il devient important de mener des recherches sur leur fonction cognitive. L'intérêt passe maintenant de la définition des déficits neurocognitifs chez les enfants

Before contemporary surgical techniques, an infant with moderate or complex congenital heart disease (CHD) had a less than 50% chance of surviving to their first birthday.¹ Now, more than 90% survive to adulthood.² This has created a stark demographic shift and there are now twice as many adults living with complex CHD as there are children.³ Death from CHD has shifted from childhood to adulthood and the life expectancy

of CHD patients is now approaching that of individuals without CHD.² This changing disease course necessitates specialized care for adults with CHD and inquiry into the synergy between CHD and acquired comorbidities.⁴

There has been considerable investigation into the developmental deficits of children with CHD.⁵ Neurological insults begin in the womb, children often have their first open cardiac surgery within days of birth, and postoperative hypoxia and/or seizures compound neurological injury.⁵⁻⁹ Pediatric studies have shown that children with repaired cyanotic CHD, as a group, have lower IQs than their peers, more behavioural problems, and deficits in executive function.^{10,11}

In contrast, relatively minimal research has been conducted into the neurocognitive function of adults with CHD.¹² Existing research, mostly data collected on young adults up to their mid-30s, has identified increased prevalence of deficits

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decline in adults with CHD. We performed a comprehensive literature review to identify all of the current data available on neurocognitive function in adults with CHD. We summarize the available evidence by describing common deficits in this patient population and the potential effects of these deficits on adult functioning, health care decision-making, and long-term relationships with care providers. We review potential modifiable etiologies for progressive neurocognitive decline and suggest strategies for surveillance and prevention of the potential decline. We conclude that the current information available regarding the aging brain of adults with CHD and the effect of neurocognitive decline on morbidity and mortality is woefully insufficient. This review, therefore, provides a roadmap for future research endeavours to study neurocognition in older adults with CHD.

in executive function such as problem-solving and planning strategies.¹³ Processing speed, working memory, and attention were also found to be affected.¹⁴ Adults with CHD have higher rates of anxiety and depression than contemporaries in addition to risk of medical-related post-traumatic stress disorder (PTSD) symptoms.^{15,16}

To our knowledge, no prospective research has been focused on the cognition of older adults with CHD but we know that the life course of adults with CHD includes multiple threats to neurocognitive function such as those described in Figure 1.¹⁷ In this narrative review, our goal is to outline the complex etiologies of neurocognitive deficits in adults with CHD, postulate how these deficits can affect everyday function, and provide recommendations for surveillance and prevention for health practitioners caring for these patients. We summarize the existing literature to contextualize our recommendations that highlight growing challenges in the care of aging adults with CHD.

Neurodevelopment Before Adulthood

For many infants born with complex CHD, neurological abnormalities precede birth. Dysmaturation associated with CHD might affect brain structure, microstructure, metabolism, and connectivity, and is associated with adverse neurodevelopmental outcomes in infants with CHD.¹⁸⁻²⁰

There are multiple mechanisms by which CHD might induce abnormal brain development. The relationship between neurological and cardiac dysmaturation might be linked because common genetic or epigenetic abnormalities can affect heart and brain during fetal development.^{5,21-23} Moreover, CHD is also associated with a high risk of spontaneous preterm birth and microcephaly.²⁴ This leads to adverse neurodevelopmental outcomes in addition to increased infant morbidity and mortality.^{25,26}

Brain injury might be present in up to 56% of infants with CHD, with white matter injuries (WMIs) and perioperative

atteints de cardiopathie congénitale à la prévention du déclin neurocognitif chez les adultes présentant une cardiopathie congénitale. Dans cette analyse, nous décrivons les étiologies et les facteurs de prédiction possibles du déclin neurocognitif chez les adultes atteints de cardiopathie congénitale. Nous avons effectué un examen approfondi de la littérature pour relever toutes les données actuelles sur la fonction neurocognitive chez les adultes présentant une cardiopathie congénitale. Nous avons résumé les données probantes existantes en décrivant les déficits fréquents chez cette population de patients et les effets possibles de ces déficits sur la fonction chez l'adulte, la prise de décision en soins de santé et le lien à long terme avec les dispensateurs de soins. Nous avons examiné les étiologies possibles modifiables du déclin progressif de la fonction neurocognitive et proposons des stratégies de surveillance et de prévention d'un déclin possible. Nous avons conclu que les données actuelles sur le cerveau vieillissant de l'adulte atteint de cardiopathie congénitale et les effets du déclin neurocognitif sur la morbidité et la mortalité sont nettement insuffisantes. Par conséquent, cette analyse fournit une voie à suivre pour des travaux de recherche futurs sur la fonction neurocognitive chez des adultes plus âgés atteints de cardiopathie congénitale.

ischemic strokes being the most commonly identified.^{8,19,27,28} Surgical factors have variably been associated with risk of injury, although the relative contribution is outweighed by patient-specific and preoperative factors including low birth weight, gestational age, socioeconomic status, and time to surgery.^{5,17,27-30} Longer times to surgery in neonates with hypoplastic left heart syndrome are predictive of postoperative WMI.²⁹ Hemodynamic studies have identified progressively declining tissue oxygenation and impaired cerebral blood flow response during the time between birth and first heart surgery.³¹ Postoperative factors including invasive circulatory support, critical care admission, and seizures have also been associated with the presence of brain injury, although the strength and directionality of these relations are not well characterized.⁵

Overall, pre- and postoperative WMI in infants with CHD are associated with adverse neurodevelopmental outcomes, including lower scores on cognitive testing at 2 and 6 years and higher rates of attentional problems.^{30,32,33} The extent and duration of preoperative cerebral oxygen desaturation has also been shown to predict degree of neurodevelopmental impairment.⁵

In addition to the structural abnormalities in the brains of many children with CHD, there are ongoing medical variables and social constructs that might exacerbate underlying deficits as the child ages. The average child with moderate to complex CHD undergoes between 1 and 5 cardiac interventions, either surgical or percutaneous, before reaching adulthood, and some endure more.¹⁵ Qualitative research has shown that frequent hospitalizations and recovery from cardiac surgery disrupt traditional education and make keeping up with peers academically difficult.³⁴ Embarrassment regarding surgical scars and physical deficits, such as an inability to participate in student athletics, can serve to further isolate young adults with CHD.^{34,35}

Studies have shown that children with CHD are at an increased risk of specific impairments such as

				
Fetal cyanosis and/or hypoxia Genetic Syndromes	Early Cardiac Surgery Post-operative complications (stroke, seizure, etc.)	Frequent hospitalizations Learning Difficulties	Psychiatric conditions (anxiety, depression, PTSD) Arrhythmia, Cardioembolic stroke	Acquired comorbidities Effects of Aging on the Brain

Figure 1. Exposure to neurocognitive insults throughout the lifespan of the adult with congenital heart disease. PTSD, post-traumatic stress disorder.

neurodevelopmental delays, deficits and disabilities in intelligence, academic achievement, language, visual construction and perceptual skills, attention, executive function, fine motor skills, and gross motor skills.^{36,37} They are also more likely to display problematic behaviour and psychosocial maladjustment.^{36,37} Modern educational models focus on inclusion of students with learning difficulties with modification on the basis of their specific needs. Despite a theoretical focus on inclusivity, the needs of students with learning disabilities are often inadequately recognized and supported in public education models.³⁸ This can lead to students with CHD falling even further behind peers because teachers and parents might fail to recognize their unique educational needs.

Neurocognition During Transition of Care

Transition of care from pediatric to adult life might be a relatively quiescent time in terms of the medical complications of CHD because the focus in this turbulent phase shifts toward psychosocial functioning.³⁹ Teenage years pose a number of challenges for youth as they become adults and move from a pediatric to adult paradigm of care. For CHD patients, this turbulent time can exacerbate underlying neurodevelopmental dysfunction. There is evidence that, as a group, adolescents and young adults with CHD achieve lower overall educational attainment than their peers and the reasons are multifactorial.⁴⁰ Learning difficulties present a challenge in large postsecondary institutions and patients have stated that physical limitations have factored into their choice of education (ie, avoiding large campuses).³⁴ It might be postulated that lower educational attainment might sometimes stem from the belief that advanced education is futile because of a limited life expectancy, although it should be noted that patients with even severe forms of CHD often overestimate their life expectancy as being only slightly reduced compared with average.⁴¹

Lower educational attainment eventually results in higher unemployment. Men with CHD are twice as likely to be

unemployed as those without CHD and women with CHD are more likely to be engaged in part-time work.⁴² As a result of less education and subsequent difficulty obtaining full-time employment, adults with CHD tend to have lower incomes than average.⁴³ Although many patients with CHD overcome health obstacles and excel academically and professionally, care providers should be aware of the significant challenges they face.

There is also evidence that some teenagers with CHD have difficulty with interpersonal relationships and subsequently make risky decisions, possibly because of deficits in executive functions. One study has shown that fewer adolescents and young adults with CHD were sexually active compared with healthy peers, although 72% of adolescents who were sexually active were engaging in risky sexual behaviours (multiple partners in the past 3 months, no birth control, substance abuse mixed with sexual encounters).⁴⁴ Many young adults with CHD smoke and use illicit substances despite knowing that it could negatively affect long-term cardiovascular health.⁴⁵ There is also evidence that under-recognized depression and anxiety in young adults with CHD is associated with substance abuse.⁴⁶

Thus, overall, even after surviving an early childhood plagued by cardiac surgery and medical interventions, adolescents with CHD continue to face unique neurocognitive challenges because of ongoing medical and social factors.

Neurocognitive Functioning in Adults With CHD: What We Know So Far

The most important developmental changes to the brain cease in the mid- to late 20s.⁴⁷ Therefore, as patients become adults, the focus should move away from abnormal neurodevelopment to potential neurocognitive decline.¹⁷

A literature search in Medline and PubMed was conducted by 2 authors (M.K. and P.E.). We included studies with any neurocognitive outcomes reported in adults (average age, older than 18 years) with CHD. The references of relevant studies were then manually searched for additional studies that might

Table 1. Studies of neurocognition in adults with CHD

Reference and Country of Recruitment	Study description			Results	
	Age of participants, years	Participants with CHD, n	CHD diagnoses	Neurocognitive outcome	Noteworthy findings
Utens et al. ⁴⁸ (1998) The Netherlands	19-25	166	All lesions (simple to complex)	Patients with cyanotic CHD had the lowest IQ scores of the cohort; although still within the normal range	CHD patients self-reported more “obsessive” or “strange” thoughts than average
Daliento et al. ¹³ (2005) Italy	25 ± 4	54	ToF	Normal IQ; lower academic achievement; deficits in executive function, problem solving, and planning strategies	Particular deficit was detected on a test that requires spatial planning and organizational strategies
Eide et al. ⁴⁹ (2006) Norway	20-32	166	All congenital heart defects	IQ was significantly lower in men with CHD than in age-matched controls; higher risk of being qualified as being disabled	All participants were male (recruited and assessed during draft for mandatory military participation)
Tyagi et al. ¹² (2014) United Kingdom	18-76	310	All lesions (simple to complex)	Memory was largely unaffected; patients with CHD showed deficits in executive function, divided attention, verbal fluency, and fine motor function; approximately one-quarter had deficits in general IQ	Patients with TGA had significantly worse cognitive function scores than those with simple CHD
Brewster et al. ⁵⁰ (2015) United States of America	17.82 ± 2	22	Severe CHD	Patients with CHD showed reduced white matter integrity on brain MRI and deficits in auditory attention and verbal memory compared with healthy controls	Patients with known neurological deficits (previous stroke, genetic syndromes) were excluded, which created a bias toward the null hypothesis
Chiavarino et al. ⁵¹ (2015) Italy	29 ± 12	16	PV disease, ToF, TGA	CHD patients performed worse than healthy controls on the ability to understand another’s mental states (ie, were more likely to have “theory of mind” deficits)	Patients with known neurological deficits (previous stroke, genetic syndromes, low IQ) were excluded, which created a bias toward the null hypothesis
Klouda et al. ¹⁴ (2017) United States of America	18-49	48	Moderate or severe CHD	Patients with severe CHD were twice as likely as the normative sample to have impairment in > 1 cognitive domain; lower psychomotor speed, processing speed, complex attention, and reaction time scores	Patients with known neurological deficits (previous stroke, genetic syndromes) were excluded, which created a bias toward the null hypothesis
Ilardi et al. ⁵² (2017) United States of America	17-56	48	All lesions (simple to complex)	Deficits in working memory and visuospatial construction (executive functioning); no significant difference was detected on the basis of severity of CHD	CHD patients had an increased likelihood of being unemployed or were receiving disability benefits, which was associated with greater executive dysfunction
Pike et al. ⁵³ (2017) United States of America	18 ± 2	80	CHD that required surgery via CP bypass	Two-thirds of patients with ACHD had impairment on the MoCA, a validated cognitive screening measure; specific deficits noted in attention and delayed recall; lower scores on the WRAML (ie, memory battery)	

Brunmeier et al. ⁵⁴ (2018) United States of America	30 ± 10	337	All lesions (simple to complex)	One-third of patients self-reported neurocognitive deficits on a screening questionnaire; those with a greater number of surgeries and more complex CHD were more likely to report cognitive concerns. Reduced performance in attention, visual-spatial skills, executive function, and memory	No objective comparison with formal neurocognitive testing was made. Very few patients (17%) who self-reported deficits followed-up on the opportunity to coordinate formal testing. Significant deficits in “episodic memory” were identified (long-term memory of previous experiences with context)
Kasmi et al. ⁵⁵ (2018) France	23 ± 3	67	TGA post-ASO		

ACHD, adult congenital heart disease; ASO, arterial switch operation; CHD, congenital heart disease; CP, cardiopulmonary; MoCA, Montreal Cognitive Assessment; MRI, magnetic resonance imaging; PV, pulmonary valve; TGA, transposition of the great arteries; ToF, tetralogy of Fallot; WRAML, wide range assessment of memory and learning.

meet our inclusion criteria. Meta-analysis was not conducted because of the heterogeneity of the data and the variable neurocognitive outcomes reported between studies. Table 1 shows a summary of the current literature on neurocognitive outcomes in adults with CHD. We found 11 studies published between 1998 and 2018 that met our inclusion criteria. In these studies, the age range of included participants was mostly between 18 and 30 years with only 4 studies extending observations beyond the age of 40 years.

When administered a screening questionnaire, many adults with CHD (34%) reported difficulty in areas of math, memory, and attention.⁵⁴ Formal neuropsychological testing has shown a higher prevalence of executive dysfunction (eg, problem-solving, planning), lower scores on cognitive screening, poorer memory performance, slower psychomotor or processing speeds, and weaker attention.^{12,14,51,50,53} Research has also indicated an elevated risk of multimodal defects (ie, neurocognitive deficits in multiple cognitive domains).¹² Initial research indicates that risk factors for neurocognitive compromise include cyanotic disease, structural complexity of CHD, and a higher number of surgeries.^{12,54} Results of studies that investigated overall intellectual functioning in those with CHD have been mixed with some studies showing lower IQ scores than individuals without CHD although scores were typically in the normal range. As well, the results of studies that investigated memory performance have also been mixed.

Most studies have indicated that attention and executive functions are the most commonly affected areas of cognitive performance. Good executive function or “higher order” cognitive abilities can assist in educational attainment, job performance, ability to interact with the health care system, instrumental activities of daily living (eg, problem-solving, financial management, etc), quality of life, and the ability to form meaningful interpersonal relationships.^{12,56-58} Executive dysfunction can also make it challenging for patients to adhere to medical recommendations.

Although most adults with CHD live fulfilling and independent lives, psychosocial studies in adulthood have shown that adults with CHD have lower educational attainment, higher rates of unemployment, are less likely to be in romantic relationships, and experience higher rates of sexual dysfunction.⁵⁹ However, little research is available to evaluate the neurocognitive underpinnings of these outcomes. In addition, adults with CHD are often at a higher risk of mood disorders that can be associated with cognitive difficulties, especially attention, memory, and executive functioning.¹⁵

Several syndromes associated with congenital heart defects, such as 22q11.2 microdeletion and Williams syndrome, are also associated with a variety of psychiatric disorders. Even in the absence of syndromic disease, there is abundant evidence that adults with CHD have a higher rate of anxiety and depression including generalized anxiety, health/heart-related anxiety, depressed mood, and difficulty coping with a medical condition.^{15,46,60,61} This can lead to poor transition from pediatric to adult care, nonadherence to medical advice, and denial of illness effects.¹⁵ Preliminary studies have indicated that psychotherapy is a feasible and valuable treatment for managing these difficulties.⁶¹

Contemporary research has also explored PTSD in adults with CHD.¹⁶ Qualitative assessment of childhood experience has revealed that many adults with CHD have easy recall of

traumatic events in childhood and acknowledge that these traumatic recollections still influence adult behaviours.³⁴ Another study reported that 11%-21% of CHD patients self-report PTSD symptoms but less than 5% have a formal diagnosis and fewer than 5% have a formal diagnosis and fewer than half of the patients were receiving any mental health care.¹⁶ The interplay between psychiatric disorders, underlying neurocognitive deficits, and long-term functioning of adults with CHD warrants further study.

Neurocognitive Function in Older Adults: What Is Yet to Discover

Despite awareness that many adults with CHD will now achieve a normal life expectancy, little research has been conducted on neurocognition in older adults with CHD. Current assessments of cognitive function, as outlined in Table 1, include primarily adults younger than 30 years and no studies have focused on seniors.

Although the cognitive function of seniors living with CHD has not been well studied, a study in Denmark has shown that the risk of all-cause dementia was increased by 60% in individuals with CHD, and the risk for developing early-onset (younger than 65 years) was more than double.⁶² Other medical factors such as severe or univentricular CHD and CHD with cyanotic potential were also associated with increased risk of dementia.⁶² Registry data, which estimated the Canadian prevalence of CHD in seniors to be 3.8/1000, suggests that dementia is a primary predictor of mortality in adults with CHD.⁶³ These findings lend credence to the hypothesis that cumulative brain injury across the lifespan might predispose to neurocognitive decline in the adult CHD population.

The underlying pathophysiology of adults with CHD provides fertile ground for neurocognitive decline.¹⁷ Risk factors can include atrial arrhythmias, subsequent stroke, and heart failure in addition to other acquired comorbidities.^{64,65} Conditions such as hypertension, diabetes, heart failure, and coronary artery disease increase the risk of neurocognitive compromise as individuals with CHD age.¹⁷ Heart failure is a common comorbidity in adults with CHD and there is clear evidence that heart failure leads to brain hypoperfusion and contributes to cognitive decline.⁶⁶ Heart failure has been associated with progressive deficits in attention, language, executive function, and visuospatial episodic memory, possibly because of a lowered rate of cerebral blood flow and loss of grey matter.⁶⁷ Heart failure has been identified as the leading cause of premature death in adults with CHD.⁶⁸ As well, atrial fibrillation is a common complication of CHD and can double the risk of developing dementia in affected individuals.⁶⁹

In addition, the prevalence of coronary artery disease and stroke in adults with CHD is on the rise and guideline-based antiplatelet use in this population is suboptimal.⁷⁰ Although coronary artery disease in the CHD population might result from traditional vascular risk factors, an increase in cardioembolic stroke compared with the general population might result from underlying structural defects.⁷¹ An increased risk of atherosclerotic disease is associated with an increased risk of vascular dementia and Alzheimer's disease.⁷² Despite the lack of prospective research, it is reasonable to postulate that, as adults with CHD age, they might have

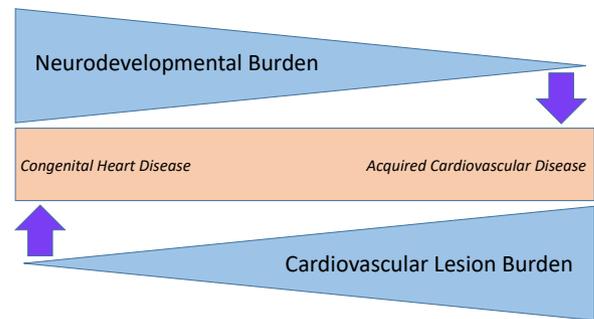


Figure 2. Interplay between neurodevelopment and cognitive decline in adults with congenital heart disease. CV, cardiovascular. Modified from Marelli et al.¹⁷ with permission from the American Heart Association.

accelerated or premature neurocognitive decline. Figure 2, adopted from Marelli et al., illustrates the concept of adding insult to injury, which predisposes CHD patients to cognitive decline as they age.

The evidence for a unifying hypothesis linking cognitive decline and comorbidity in adults with CHD emerging from large population registries underscores the need for prospective mechanistic research with cerebral imaging. This research would evaluate the hypothesis that cumulative brain injury across the lifespan results in neurocognitive decline in the adult CHD population.^{62,63}

Assessing the Risk Profile for Neurocognitive Decline

Each adult with CHD has a personal nonmodifiable risk profile for cognitive decline and dementia including age, ethnicity, and genetics.⁷³ Well-known modifiable risk factors include poor diet, physical and mental inactivity, smoking, head trauma, and alcohol. Various studies have shown that a reduction in these modifiable risk factors can decrease the likelihood of neurocognitive decline.⁷⁴

Interestingly, at least one-third of all Alzheimer disease is related to 7 modifiable risk factors: depression, diabetes, hypertension, obesity, physical inactivity, smoking, and educational attainment.⁷⁴ Although rigorous analysis of cognitive deficits in older adults with CHD has not been performed, assessment of these well known modifiable risk factors for dementia has been undertaken and are summarized in Table 2. There is clear evidence that individuals with CHD have higher rates of depression than age-matched peers.¹⁵ Also, studies of cardiovascular risk factors in patients with CHD have shown a higher rate of diabetes than in the general population.⁷⁵ Proposed mechanisms of abnormal glucose metabolism in CHD patients include suppression of insulin because of high levels of circulating norepinephrine, excessive clearance of insulin in the lung in those with left to right shunting, and hypoxia of the liver and/or pancreas in those with cyanotic disease or congestive heart failure.⁷⁶

In addition to diabetes, the rate of hypertension in adults with CHD is higher than that observed in the general population.⁷⁵ One population especially prone to hypertension is those with a history of coarctation, either repaired or unrepaired. A European study focused specifically on patients with

Table 2. Traditional risk factors for cognitive decline in adults with CHD

Risk factor for dementia	Prevalence in adult CHD patients compared with age-matched controls
Depression	↑
Impaired glucose tolerance or diabetes	↑
Hypertension	↑
Obesity	↑
Physical inactivity	← →
Smoking	↓
Low educational attainment	↑

↑, higher prevalence; ↓, lower prevalence; ← →, equal prevalence; CHD, congenital heart disease.

repaired coarctation showed that many had gaps in care longer than 2 years and that, upon first visit to an adult CHD specialist, more than half (55%) had untreated hypertension requiring initiation of medication.⁷⁷ We can, therefore, postulate that untreated hypertension in adults with CHD is a quality measure that could be aggressively targeted to reduce the rate of ongoing cognitive decline in this population.

Another risk factor for dementia is obesity. The current North American epidemic of overweight and obesity among children and young adults, with a recently estimated prevalence of 31% and rising, has also afflicted the CHD population.⁷⁸ Assessment of children with CHD show that the rate of overweight and obesity mimics that of the general pediatric

population, although the long-term consequences for patients with CHD might be more severe.⁷⁹ An American study showed that the prevalence of metabolic syndrome, defined as obesity combined with additional cardiovascular risk factors, was significantly higher in adults with CHD than controls (odds ratio, 1.82).⁸⁰

Physical inactivity is another risk factor for cognitive decline that has been studied in CHD. Historically, many children with CHD were counselled to avoid physical activity in childhood and, although recommendations have changed in the current era, this counselling can have lifelong repercussions.³⁴ Some studies have shown that adults with CHD perform the recommended amount of physical activity, whereas others have shown that patients with CHD, especially women, perform less activity than age-matched peers.^{75,81,82}

One advantage for patients with CHD is that their rates of substance abuse, including smoking and alcohol, are similar or lower than age-matched peers.^{45,75} The final major risk factor for dementia is education and we previously outlined the reasons why CHD patients might have lower educational attainment than their peers.⁵⁹

In summary, although the rate of dementia and cognitive impairment has not been prospectively studied in older adults with CHD, Table 2 illustrates that patients with CHD are known to be at elevated risk of 5 of the 7 known risk factors for cognitive decline. This risk profile, in addition to neurological insults during childhood and early adulthood, combine to theoretically increase the risk of cognitive impairment and

Suggested Strategies for Early Detection (Surveillance) of Neurocognitive Decline in Adults with Congenital Heart Disease
When patients transition from pediatric to adult care, summaries of any neurocognitive assessments performed in childhood should be provided to adult providers as part of the transition documentation.
CHD providers should have an openness to discuss psychological distress and/or cognitive deficits with patients. Patients who manifest distress and/or deficits should be referred to appropriate resources (Psychology, Psychiatry, Memory Clinic, and/or Neuropsychiatry) for formal assessment and management without delay.
Patients with CHD over the age of 50 should undergo periodic screening for cognitive impairment with an established screening tool (ie. MoCA).
CHD providers should receive continuing education regarding the neurocognitive challenges faced by adults with CHD in order to increase their awareness of signs and symptoms for which to remain alert.
Suggested Strategies for Managing and Preventing Neurocognitive Decline in Adults with Congenital Heart Disease
CHD care providers should help patients create realistic educational goals based on individual strengths, deficits, and life expectancy so they can reach their optimal education and career attainment.
Physical activity and weight management (obesity prevention) should be encouraged at each CHD clinic visit.
Secondary cardiovascular risk factors (smoking, HTN, diabetes) should be aggressively managed in all patients with CHD to mitigate dementia risk.

Figure 3. Key recommendations for surveillance and prevention of neurocognitive decline in adults with congenital heart disease (CHD). HTN, hypertension; MoCA, Montreal Cognitive Assessment.

dementia in the CHD population. Although older adults with CHD have a baseline higher risk of neurocognitive decline than their age-matched counterparts, it is important to recognize that modifiable risk factors will also play a significant role in disease course. Neurocognitive decline should be considered preventable and modifiable risk factors should be managed aggressively.

Suggested Surveillance and Prevention Strategies

We have established that there are many reasons across the lifespan that adults with CHD are at elevated risk for cognitive decline and dementia compared with age-matched peers. The question then becomes one of prevention. Although few evidence-based recommendations can be made, it is reasonable to propose interventions that might be helpful in stemming the tide of cognitive decline in this specific population (Fig. 3). This approach requires an openness to discuss cognitive impairment and social functioning from the time of transition throughout the life span, amending the traditional cardiology appointment, which has a limited primary focus on physical symptomatology. It also demands a multidisciplinary care team to evaluate and provide services to patients of any age who struggle with academic, occupational, and/or psychosocial functioning.

Two specific strategies with the potential to ward off cognitive decline are physical activity promotion and weight management across the lifespan. Low cardiovascular fitness as a teenager has been linked to early-onset dementia.⁸³ This suggests that it is never too early to address traditional cardiovascular risk factors and aggressively manage them. It has been shown that individuals who perform either 20 minutes of vigorous activity 3 or more days per week, or 30 minutes of moderate activity 5 or more days per week, can help stave off cognitive decline.⁷⁴ Obesity in CHD patients should not be overlooked and dietary interventions, obesity management programs, and referral for bariatric surgery should be performed without delay as warranted.

Detection and management of acquired heart disease is also indicated. Atherosclerotic risk factors in adults with CHD are often suboptimally managed and, therefore, aggressive guideline-based pharmacologic management should be a priority for quality of care in CHD.^{77,84} In addition to traditional cardiovascular risk factors, patients with CHD are at high risk of developing interatrial tachyarrhythmias, which can predispose to stroke.⁸⁴ Screening and prompt management with anticoagulation of atrial arrhythmias might reduce the risk of cognitive decline. Atrial fibrillation studies in the general population have, indeed, shown that anticoagulation can be helpful to reduce risk of neurocognitive decline.^{73,85}

After aggressively managing dementia risk factors in adults with CHD, when should we begin to screen for cognitive decline? Traditionally, dementia affects geriatric patients older than the age of 65. Studies of presenile dementia have shown that vascular dementia is a greater contributor to dementia in the young than in an older population.⁸⁶ Because CHD patients are at high risk of vascular dementia, earlier introduction of cognitive screening might be warranted. For example, adults with CHD aged 50 years and older could undergo cognitive screening with a validated tool, such as the Montreal

Cognitive Assessment. Patients' beliefs and expectations regarding social and cognitive function and impairments can also be explored routinely at clinic appointments. In addition, patients with identified anxiety, depression, and substance abuse should be referred to appropriate mental health services because untreated concomitant psychiatric disorders can mimic cognitive deficits.

When it has been recognized that a CHD patient is struggling with cognitive impairment or decline, referral to appropriate services and resources should be made without delay. Management of neurocognitive decline depends on the deficits the person is experiencing and the symptoms they are expressing. Although there are numerous kinds of neurocognitive disorders, most require management of the symptoms that arise as the neurodegenerative disorder advances. All patients with early-onset dementia should be referred to a memory clinic where safety and decision-making capacity can be formally assessed.⁸⁷ Various medications (cholinesterase inhibitors, selective serotonin reuptake inhibitors, antipsychotics) might be helpful either with cognition or for behavioural symptoms such as agitation.⁸⁷ Intensive long-term education and support services for patients and caregivers should be offered.⁸⁷

Neurocognitive impairment and decline affect not only the patient, but also their family, friends, and caregivers. With increased vigilance, CHD health professionals can contribute to increased detection of cognitive dysfunction and referral to appropriate medical and community services. Prospective studies will help us learn more about cognitive functioning in adults with CHD across the lifespan and facilitate the development and evaluation of intervention strategies.

Conclusion

In this review, we summarized what is known about neurodevelopmental and neurocognitive challenges in individuals with CHD across the lifespan and outlined the potential risk factors for further decline as they reach unprecedented life expectancies. At this time, however, there exists minimal data regarding the aging brains of this population. Our review highlights this lack of evidence and can serve as a blueprint for future studies to fill in the current gap in knowledge. Strategies for prevention and surveillance to provide early identification of cognitive dysfunction and decline are clearly warranted.

Disclosures

The authors have no conflicts of interest to disclose.

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