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Heart Failure in Children: A Review of Pathophysiology, Diagnosis, and Treatment

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Abstract

Heart failure in children is a clinical syndrome whose presentation and etiology, unlike in adult patients, vary with age and therefore require an age-specific diagnostic and therapeutic approach. The purpose of this article is to provide a general overview of the pathophysiology, diagnosis, and treatment of heart failure in the pediatric age group. Pediatric heart failure is highly variable depending on the patient's age and the most frequent etiology within each age group; however, in general and regardless of age, the main etiologies are congenital heart disease, cardiomyopathies, arrhythmias, and extracardiac causes. Diagnosis requires a thorough clinical evaluation and complementary studies, with echocardiography being the essential tool, although other imaging studies such as magnetic resonance imaging or cardiac catheterization may be required. Treatment depends on the etiology: for some congenital heart defects, corrective repair resolves the heart failure; however, before repair, or in cases without a corrective option, management is based on medical therapy (diuretics, ACE inhibitors or ARNi, beta-blockers, mineralocorticoid receptor antagonists, and SGLT2 inhibitors) or on advanced therapies (ventricular assist devices or heart transplantation). Early and timely identification of heart failure is essential to improve patient prognosis.

Keywords

Heart failure; Pediatrics; Cardiomyopathy; Congenital heart disease; Treatment.

Abbreviations

HF: Heart Failure; CHD: Congenital Heart Disease; ACEi: Angiotensin-Converting Enzyme inhibitor; ARNi: Angiotensin Receptor–Neprilysin inhibitor; MRA: Mineralocorticoid Receptor Antagonist; SGLT2i: Sodium-Glucose Cotransporter-2 inhibitor; NYHA: New York Heart Association; NT-proBNP: N-terminal pro-B-type Natriuretic Peptide; ANP: Atrial Natriuretic Peptide; BNP: B-type Natriuretic Peptide; RAAS: Renin-Angiotensin-Aldosterone System; TAPSE: Tricuspid Annular Plane Systolic Excursion; ALCAPA: Anomalous Left Coronary Artery from the Pulmonary Artery; VAD: Ventricular Assist Device; MRI: Magnetic Resonance Imaging; RR: Respiratory Rate; CI: Cardiac Index; PCWP: Pulmonary Capillary Wedge Pressure.

Introduction

Heart failure (HF) is the inability of the heart to meet the body's metabolic demands. Multiple definitions exist for this condition, in which the heart fails to maintain adequate blood flow to the systemic or pulmonary circulation, or to accommodate venous return at an adequate filling pressure [1]. HF is a condition in which there is diffuse structural damage to the myofibrils or an excessive hemodynamic overload, leading to a reduction in the contractile force of the heart and an increase in ventricular volumes, with or without a decrease in the ejection fraction [2]. It can be defined as a clinically and pathophysiologically progressive syndrome caused by cardiovascular and non-cardiovascular alterations that result in characteristic signs and symptoms—including edema, respiratory difficulty, failure to thrive, and exercise intolerance—accompanied by circulatory, molecular, and neurohormonal alterations [3,4]. Unlike the adult patient, in whom the main cause is myofibrillar injury, in the pediatric population volume overload from shunts and pressure overload from outflow-tract obstructions represent the main etiologies. Other etiologies, such as cardiac rhythm disturbances and intrinsic myocardial disease, may also occur, although less frequently. Moreover, each pediatric age group presents particular etiologies **(Table 1).**

Age group	Fetal	Newborn	Infant	School-age to adolescent
Main etiologies	Fetal anemia Viral infections Fetal cardiac rhythm disturbances	Asphyxia Myocarditis Cardiac rhythm disturbances Congenital heart disease (significant valvular regurgitation) Metabolic disorders (inborn errors of metabolism) Sepsis Anemia Polycythemia	Congenital heart disease with significant shunt ALCAPA Metabolic and endocrine disorders Myocarditis Kawasaki disease	Acquired conditions Untreated congenital heart disease Operated congenital heart disease with residual defects Endocarditis

Table 1: Main etiologies of heart failure according to pediatric age group.

Congenital heart disease is the most frequent congenital malformation, occurring in 1 of every 100 live newborns; owing to its high prevalence, it is the most frequent cause of HF in the pediatric age group, regardless of age. Cardiomyopathies—less frequent in childhood but important contributors to the

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etiology of HF in this group, as in adults—occur in approximately 3 to 40 per million children, depending on the type of cardiomyopathy and the age group, with dilated cardiomyopathy being the most frequent [3,5]. It is estimated that in the United States approximately 10,000 children are hospitalized each year for heart failure, and that in patients with congenital heart disease the rate of HF ranges between 5% and 40%. Unfortunately, clear statistics on the frequency of this condition are not available in Mexico.

Pathophysiology

As with other organs, the heart continues to mature during the first years of life and undergoes structural changes that are decisive for the pathophysiology of HF. One of the most important features is that the neonate has fewer contractile elements and an immature conduction system. This results in a smaller contractile mass and, therefore, a cardiac output that is more dependent on heart rate than on stroke volume or preload. During the first years of life, particularly in infancy, the heart completes its maturation until it acquires the characteristics of the adult heart [5].

Pathophysiologically, HF can be classified into the following groups:

- **Volume overload:** mainly cardiac defects with a shunt, such as septal defects.
- **Pressure overload:** mainly obstructions of the outflow tract of one of the ventricles.
- **Cardiomyopathies:** most frequently dilated, although hypertrophic and restrictive cardiomyopathies and hyper trabeculated or non-compacted myocardium also occur.
- **Cardiac rhythm disturbances:** including supraventricular tachycardia or congenital atrioventricular block.
- **Systemic alterations:** such as sepsis, metabolic disturbances, or even the use of cardiotoxic drugs such as anthracyclines for cancer treatment.

There are multiple compensatory mechanisms in HF, which also participate in its clinical manifestations and, when perpetuated, produce deleterious effects on cardiac function; the most notable include:

- Production of natriuretic peptides in response to increased filling pressures (left atrial pressure and left ventricular end-diastolic pressure). Once cardiac function deteriorates, ventricular volume increases, and in response to dilation of the ventricular chambers, atrial and B-type natriuretic peptides (ANP and BNP) are produced. As their name indicates, these peptides increase renal sodium excretion and, therefore, free-water excretion, reducing volume overload. Their half-life is very short, so their effect is brief and they are rapidly broken down into the propeptide pro-BNP [6].
- An increased adrenergic response, which manifests clinically as the tachycardia characteristic of HF.
- Myocardial hypertrophy, which occurs mainly in response to increased ventricular afterload; according to Laplace's law, an increase in wall thickness decreases wall stress. However, this hypertrophy may ultimately reduce cardiac function, becoming more deleterious than beneficial.
- Activation of the renin-angiotensin-aldosterone system, which responds to renal hypoperfusion from low cardiac output: when the macula densa of the nephron senses reduced renal perfusion, it produces renin, which converts angiotensinogen into angiotensin I, which is then

converted by angiotensin-converting enzyme into angiotensin II, a potent vasoconstrictor. Activation of this system results in oliguria but an increase in actual blood volume and in peripheral edema, pulmonary edema, dyspnea, and cardiomegaly [7].

Diagnosis

The diagnosis of HF in the pediatric age group is a major challenge because of the variability of its etiology and clinical manifestations across age groups. For this reason, an adequate clinical history and a detailed physical examination are fundamental for reaching the diagnosis. On history and physical examination, findings that should raise suspicion of HF include feeding difficulties (dyspnea, pauses, or diaphoresis during feeds), the presence of a cardiac murmur, tachycardia or bradycardia, tachypnea, dyspnea, signs of respiratory distress (intercostal retractions, xiphoid retraction, expiratory grunting, nasal flaring), cyanosis or decreased oxygen saturation, alterations in the pulses of the four limbs, irritability, hepatomegaly, and failure to thrive.

Because of its association with congenital heart disease, the presence of some of these findings should raise suspicion of HF in a patient with a cardiac malformation. For example, a murmur in a pediatric patient should always raise suspicion of a congenital defect; cyanosis should prompt exclusion of a cyanotic congenital heart defect or, depending on the patient's age and course, an acyanotic defect that has progressed to Eisenmenger syndrome; and alterations in the peripheral pulses—particularly the absence or diminution of pulses in the lower limbs—should suggest aortic coarctation as a cause of left ventricular dysfunction from increased afterload and, consequently, HF.

The diagnostic workup should include a chest radiograph, which will show cardiomegaly and in some cases may suggest the etiologic diagnosis when the patient has congenital heart disease; an electrocardiogram, which may reveal conduction disturbances as the etiology of HF (atrioventricular block, ventricular or supraventricular tachycardia) or rhythm disturbances secondary to chamber dilation from HF; laboratory studies, particularly when systemic causes are suspected (complete blood count, blood chemistry with serum electrolytes, thyroid profile); cultures (when sepsis is suspected); NT-proBNP; cardiac enzymes; and echocardiography.

Measurement of NT-proBNP is fundamental in the patient with HF, both diagnostically and prognostically. Values above 300 pg/mL of this biomarker are known to be associated with a higher risk of death or of requiring heart transplantation.

Echocardiography is the fundamental study for the diagnosis and evaluation of HF, as it demonstrates the state of cardiac function through parameters such as the left ventricular ejection fraction and shortening fraction; the right ventricular shortening fraction and the tricuspid annular plane systolic excursion (TAPSE); more advanced parameters of cardiac function such as strain; the size of the chambers; and, particularly in the pediatric patient, the structural evaluation to rule out congenital heart disease.

In complex congenital heart disease or some cardiomyopathies, advanced imaging studies such as magnetic resonance imaging, chest computed tomography, or cardiac catheterization may be necessary.

The patient's physical capacity allows HF to be classified into four clinical classes. In the adult patient, the New York Heart Association (NYHA) classification is used **(Table 2),** whereas in the pediatric patient the

Ross score (**Table 3)** and a more abbreviated form, the modified Ross classification **(Table 4),** are used [8].

Class	Meaning
I	No limitation of physical activity.
II	Slight limitation of physical activity.
III	Dyspnea with ordinary daily activities.
IV	Dyspnea at rest.

Table 2: New York Heart Association (NYHA) classification.

Variable	0	1	2
Ounces per feed	> 3.5	2.5–3.5	< 2.5
Feeding time	< 40 min	> 40 min	> 40 min
Respiratory rate (breaths/min)	< 50	50–60	> 60
Respiratory pattern	Normal	Abnormal	Abnormal
Peripheral perfusion	Normal	Impaired	Impaired
S3 / diastolic rumble	Absent	Present	—
Hepatic edge below costal margin	< 2 cm	2–3 cm	> 4 cm

Table 3: Ross score (0–2 points = no HF; 3–6 = mild; 7–9 = moderate; 10–12 = severe).

Class	Meaning
I	No limitation.
II	Mild tachypnea or diaphoresis with feeding or exertion.
III	Severe tachypnea or profuse diaphoresis with feeding or exertion, feeding pauses, poor weight gain.
IV	Tachypnea, respiratory distress, and diaphoresis at rest.

Table 4: Modified Ross classification.

The Forrester classification is also available, based on two hemodynamic parameters: the cardiac index and the pulmonary capillary wedge pressure. Patients with both parameters normal (cardiac index > 2.2 L/min/m² BSA and pulmonary capillary wedge pressure < 18 mmHg) do not have HF. When the cardiac index decreases (< 2.2 L/min/m² BSA) but the pulmonary capillary wedge pressure remains normal (< 18 mmHg), the patient has hypovolemia. If the cardiac index remains normal (> 2.2 L/min/m² BSA) but the pulmonary capillary wedge pressure increases (> 18 mmHg), the patient is in pulmonary edema; and if both parameters are affected (cardiac index < 2.2 L/min/m² BSA with pulmonary capillary wedge pressure > 18 mmHg), the patient is in cardiogenic shock [7].

Treatment

The goals of HF treatment include improving the patient's functional class and quality of life, reducing morbidity and mortality, correcting underlying problems, and thereby modifying the natural history of the disease.

To achieve these goals, treatment of HF in the pediatric patient must include, in addition to cardiovascular therapy, other aspects that are fundamental for children. One very important aspect is management by pediatric gastroenterology and nutrition, because pediatric patients with HF have failure to thrive; it is therefore very important to seek optimal caloric intake, often well above the requirements for age, weight, and height. When HF is due to a systemic condition, management of that condition is required as part of the treatment.

Pathophysiologically, the goals of HF treatment are to reduce afterload, reduce chronotropism, reduce volume overload, and improve contractility, thereby improving cardiac output and overall cardiac function.

It is important to distinguish between acute management for decompensated HF—generally based on intravenous inotropic agents and possibly ventilatory support or ventricular assist devices—and chronic management, which usually consists of oral drugs for long-term treatment.

Regarding acute treatment, the aim is rapid compensation of HF by modifying the determinants of cardiac output: preload, afterload, and inotropism. This group includes dopamine, which improves contractility and heart rate without affecting systemic vascular resistance—therefore without increasing afterload—at low doses, an effect that does occur at high doses greater than 10 mcg/kg/min [9]. Dobutamine increases contractility and decreases afterload through peripheral vasodilation; in newborns and infants, however, it may cause hypotension without truly improving contractility, owing to the characteristics of the newborn myocardium, which has fewer contractile elements than the adult heart, and it is therefore not the first-choice drug in HF [9]. In newborns it may be preferable to choose dopamine or adrenaline, because adrenaline increases contractility and produces peripheral vasoconstriction without causing hypotension. Noradrenaline is a potent peripheral vasoconstrictor that markedly increases afterload without any effect on contractility; it is therefore not indicated for HF, except in cases accompanied by hypotension, as in sepsis, in which it should be combined with an inotrope. Milrinone is an inotrope that inhibits phosphodiesterase III, increasing intracellular cyclic AMP and calcium and thereby producing greater contractility; an advantage is that it can be used in any age group, from newborns to adolescents, and it is widely used after cardiac surgery because of its inotropic effect and because it reduces pulmonary and peripheral vascular resistance, at doses of 0.3 to 0.8 mcg/kg/min [10]. Among intravenous inotropes, one of the newest is levosimendan, which sensitizes the cardiomyocyte to calcium and thereby improves myocardial contraction, at a dose of 0.1 mcg/kg/min. In adults, its residual effect over 1 to 3 weeks is well described, so a bolus is administered over 24–72 hours and then discontinued; in pediatric patients this effect is not yet clear, although the improvement in cardiac function it produces is quite evident. Among its adverse effects, one of the most relevant is hypotension [11].

Regarding oral treatment for the chronic management of HF, the primary objective is to control the compensatory mechanisms that, although they seek to restore homeostasis, ultimately prove counterproductive. From this premise arise the four pillars of HF management: beta-blockers;

angiotensin-converting enzyme inhibitors or, if there is no contraindication, preferably angiotensin receptor–neprilysin inhibitors (ARNi); mineralocorticoid receptor antagonists; and sodium-glucose cotransporter-2 inhibitors (SGLT2i).

The patient with HF has an increased adrenergic response, manifested as tachycardia, aimed at increasing cardiac output as heart rate rises; however, this response is counterproductive, limiting ventricular filling, increasing peripheral vascular resistance, and increasing myocardial oxygen consumption. To limit these deleterious effects, beta-blockers are administered; among the most used in pediatrics are propranolol, metoprolol, esmolol, and carvedilol. In very young patients, particularly newborns and infants, their use in HF is limited, because in this group cardiac output is heart-rate dependent, as noted above, and a marked reduction in heart rate could compromise cardiac output [12].

Another compensatory mechanism of HF that can be deleterious if perpetuated is activation of the renin-angiotensin-aldosterone system. Several pharmacologic strategies limit this mechanism, notably the angiotensin-converting enzyme inhibitors—particularly enalapril and captopril—which reduce afterload through their effect on peripheral vascular resistance and reduce filling pressures by increasing natriuresis and decreasing preload. For this same effect on the renin-angiotensin-aldosterone axis, a newer drug combines an angiotensin receptor antagonist (valsartan) and a neprilysin inhibitor (sacubitril), constituting the ARNi group. Valsartan, by blocking angiotensin receptors, reduces afterload by decreasing peripheral vascular resistance, and sacubitril, by inhibiting neprilysin, inhibits the metabolism of natriuretic peptides—another compensatory mechanism of HF—with a consequent increase in natriuresis and a reduction in filling pressures and preload. This drug has improved the prognosis of patients with HF by reducing morbidity and mortality, rapidly becoming one of the pillars of treatment for this condition [13].

Mineralocorticoid receptor antagonists are among the drugs that should be used routinely in the management of HF unless a contraindication exists; in this group, spironolactone is the most used. The main mechanism by which they improve HF is not really their diuretic effect—which is in fact modest—but rather that, by blocking the final pathway of the renin-angiotensin-aldosterone system, they reduce afterload; they have also been shown to have a direct effect on myocardial remodeling.

Finally, the fourth and most recently added pillar of HF management are the sodium-glucose cotransporter-2 inhibitors (SGLT2i). These reduce glucose reabsorption at the proximal convoluted tubule, with consequent urinary excretion of glucose and sodium, reducing preload and ventricular filling pressures; a direct effect on the myocardium has particularly been described, improving its metabolism, reducing fibrosis, and improving myocardial remodeling [14].

In addition to the pillars of HF management, adjuvant drugs are used in these patients. One of the historically most used medications, with great utility as an inotrope, is digoxin [2,3,7]. In the pediatric patient the dose is 5–7 mcg/kg/day, which limits the possibility of toxicity, one of its most feared adverse effects; a great advantage is its availability as an elixir, which facilitates administration in the pediatric population.

Other adjuvant drugs are the diuretics, particularly the loop diuretics, which act on the Na/K/2Cl cotransporter at the loop of Henle—such as furosemide or bumetanide—increasing sodium and therefore water excretion; and the thiazide diuretics, which inhibit the Na/Cl cotransporter at the distal convoluted

tubule—such as hydrochlorothiazide—reducing sodium reabsorption at this level and increasing free-water excretion. Both reduce the preload and volume overload that characterize HF, with symptomatic improvement, but they do not have a direct effect on cardiac function like the drugs belonging to the four pillars of HF treatment.

When pharmacologic treatment fails to achieve its goals of improving quality of life and functional class—despite optimal doses of all available drugs—or when there is an acute decompensation of cardiac function that does not respond adequately to intravenous inotropic management, other strategies are necessary, such as ventricular assist devices or even consideration of heart transplantation [15].

Conclusions

Heart failure in the pediatric patient represents a challenge, both for its identification and for establishing an etiology and initiating optimal, timely treatment. Both the pediatrician and the pediatric cardiologist must be familiar with this condition in order to achieve early identification, establish the possible etiologies, and begin appropriate—and above all early—treatment to improve the prognosis and quality of life of these patients. Although many of the new drugs for the treatment of HF have not yet been tested or approved in the pediatric population, it is encouraging that new pharmacologic and device-based advances (ventricular assist devices) continue to be developed, which may eventually be applied in this population, significantly improving the prognosis and survival of these patients.

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Conflict of interest

The authors declare that they have no conflict of interest.

References

1. Shaddy R, et al. (2018) [Article title to be completed]. Pediatr Cardiol. 39: 415-436.
2. Guadalajara JF (2006) [Article title to be completed]. Arch Cardiol Mex.76(4): 431-447.
3. Calderón-Colmenero J, Patiño Bahena E, Rodríguez L (2013) Insuficiencia cardiaca en edad pediátrica. In: Attie F, Calderón-Colmenero J, Zabal C, Buendía A (Eds.), Cardiología Pediátrica. 2nd ed. Editorial Panamericana, Mexico City, Mexico, pp. 471-481.
4. Jayaprasad N (2016) Heart failure in children. Heart Views 17(3): 92-99.
5. Towbin JA, Lowe AM, Colan SD, Sleeper LA, Orav EJ, et al. (2006) Incidence, causes, and outcomes of dilated cardiomyopathy in children. JAMA. 296: 1867-1876.
6. Tan LH, Jefferies JL, Liang JF, Denfield SW, Dreyer WJ, et al. (2007) Concentrations of brain natriuretic peptide in the plasma predict outcomes of treatment of children with decompensated heart failure admitted to the intensive care unit. Cardiol Young. 17: 397-406.
7. Guadalajara Boo JF (2012) Cardiología. 7th ed. Méndez Editores, Coyoacán, Mexico City, Mexico.
8. Ross RD (2001) Grading the graders of congestive heart failure in children. J Pediatr. 138: 618-620.
9. García-Montes JA, Calderón-Colmenero J (2002) Farmacología cardiovascular. In: Quevedo A, Martínez Y, Duque JI, Mejía JO (Eds.), El niño en estado crítico. Corporación para Investigaciones Biológicas, Medellín, Colombia, pp. 229-238.
10. Hoffman T, Wernovsky G, Atz A, Kulik TJ, Nelson DP, et al. (2003) Efficacy and safety of milrinone in preventing low cardiac output syndrome in infants and children after corrective surgery for congenital heart disease. Circulation. 107: 996-1002.
11. Silvetti S, Silvani P, Azzolini L, Landoni G, Zangrillo A, et al. (2015) A systematic review on levosimendan in paediatric patients. Curr Vasc Pharmacol. 13(1): 128-133.

12. Shaddy RE, Boucek MM, Hsu DT, Boucek RJ, Canter CE, et al. (2007) Carvedilol for children and adolescents with heart failure: a randomized controlled trial. JAMA. 298: 1171-1179.
13. McMurray JJV, Packer M, Desai AS, Gong J, et al. (2014) Angiotensin-neprilysin inhibition versus enalapril in heart failure. N Engl J Med. 371(11): 993-1004.
14. McMurray JJV, Solomon SD, Inzucchi SE, Køber L, et al. (2019) Dapagliflozin in patients with heart failure and reduced ejection fraction. N Engl J Med. 381(21): 1995-2008.
15. McMurray JJV, Adamopoulos S, Anker SD, Auricchio A, Böhm M, et al. (2012) ESC guidelines for the diagnosis and treatment of acute and chronic heart failure 2012. Eur Heart J. 33: 1787-1847.