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Congestive Heart Failure in Infants and Children

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Introduction

Congestive heart failure (CHF) refers to a clinical state of systemic and pulmonary congestion resulting from inability of the heart to pump as much blood as required for the adequate metabolism of the body. The clinical picture of CHF results from a combination of "relatively low output" and compensatory responses to increase it. Excellent reviews on CHF in infants and children are available [1, 2]. This article provides core information on selected aspects of CHF.

Broadly, heart failure results either from an excessive volume or pressure overload on normal myocardium (left to right shunts, aortic stenosis), or from primary myocardial abnormality (myocarditis, cardiomyopathy). Arrhythmias, pericardial diseases and combination of various factors can also result in CHF. The resultant decrease in cardiac output triggers a host of physiological responses aimed at restoring perfusion of the vital organs [3]. Important among these are renal retention of fluid, renin-angiotensin mediated vasoconstriction and sympathetic overactivity. Excessive fluid retention increases the cardiac output by increasing the end diastolic volume (preload), but also results in symptoms of pulmonary and systemic congestion.

Vasoconstriction (increase in afterload) tends to maintain flow to vital organs, but it is disproportionately elevated in patients with CHF and increases myocardial work. Similarly, sympathetic over-activity results in increase in contractility, which also increases myocardial requirements. An understanding of the interplay of the four principal determinants of cardiac output – preload, afterload, contractility and heart rate is essential in optimising the therapy of CHF. It is clinically useful to consider CHF in different age groups separately.

CHF in Neonates and Infants

The diagnosis of CHF in older children is often straight forward, but it may be difficult at times, to diagnose CHF or to distinguish it from pulmonary disease or sepsis in the neonate. Feeding difficulties and excessive sweating are the usual presenting features. Tachycardia >150/min is common, and heart rates >180/min are abnormal even in the setting of respiratory distress and suggests CHF. Grading the severity of CHF in infants is difficult and is not standardized. In the past, the most sensitive and specific variables for the presence of CHF ($p<0.0001$) were, a history of less than 3.5 oz/feed, respiratory rate greater than 50/min, an abnormal respiratory pattern, diastolic filling sounds, and hepatomegaly. Moderate to severe CHF was considered to be present when patients took less than 3 oz/feed or greater than 40 min/feed, had an abnormal respiratory pattern with a resting respiratory rate greater than 60/min, and had a diastolic filling sound and moderate hepatomegaly. Severe CHF was

accompanied by a heart rate greater than 170/min, decreased perfusion, and severe hepatomegaly. Thus, the grading of the severity of CHF in infants should include an accurate description of these historical and clinical variables [4]. A fresh scoring system has recently been developed to assess the clinical status of the patients (Table 1) [5]. A higher score was found proportional to increased severity of symptoms. A precise description of feeding history, heart rate, respiratory rate and pattern, peripheral perfusion, presence of S_3 and the extent of hepatomegaly should perhaps also be considered in this evaluation.

Table 1

Heart failure scores for infants with congestive heart failure

Symptoms (score)	Frequent (2)	Ocasional (1)	None (0)
Breathing difficulty			
Interrupted feeds			
Vomiting			
Sweating			
Poor activity			
Irritability			
Oedema			

Maximum score=14

Heart rates above 220/min indicate supraventricular tachycardia as the cause. Tachypnoea with respiratory rate >60/min in a sleeping neonate is abnormal. On chest X-ray a cardiothoracic ratio of > 60% in the newborn and > 55% in older infants with CHF is the rule. However, an expiratory film could often be misinterpreted as showing cardiac enlargement.

Absence of cardiomegaly in a good inspiratory film (with diaphragm near the 10^{th} rib posteriorly) practically excludes CHF except due to a cause like obstructed total anomalous pulmonary venous connection (TAPVC). Hepatomegaly of > 3 cm below the costal margin is usually present, even in the primarily left sided lesions. Hepatic enlargement regresses quickly in response to therapy and is thus a useful indicator of treatment. A gallop rhythm is the most helpful sign in the diagnosis of CHF. Wheeze may occur with left ventricular failure and may be confused with bronchiolitis, but rales are uncommon and suggest associated pneumonia or a severe CHF. Cold extremity, low blood pressure, skin mottling are signs of impending shock. Pulsus alternans (alternate strong and weak contractions of a failing myocardium), or pulsus paradoxus (decrease in pulse volume and bloodpressure with inspiration) are frequently observed in infants with severe CHF. In chronic CHF, poor feeding, frequent chest infections and increased metabolic requirements lead to inadequate growth. The weight gain is more inadequate than the gain in height or head circumference.

The time of onset of CHF holds the key to the aetiological diagnosis in this age group and is discussed subsequently, from a clinical standpoint, including CHF in the fetus.

a. CHF in the fetus

Disorders that are fatal in the immediate neonatal period are often well tolerated in the fetus due to the pattern of fetal blood flow (e.g. transposition of great vessels). Supraventricular tachycardia, severe bradycardia due to complete heart block, anaemia, severe tricuspid regurgitation due to Ebstein's anomaly of the tricuspid valve or mitral regurgitation from atrioventricular canal defect, myocarditis

etc. may cause CHF in the fetus. Most of these are recognised by fetal echocardiography. Severe CHF in the fetus produces hydrops fetalis with ascites, pleural and pericardial effusions and anasarca. Digoxin or sympathomimetics to the mother may be helpful in cases of fetal tachyarrhythmia or complete heart block [6] respectively.

b. CHF on first day of life

Most structural heart defects do not cause CHF within hours of birth. Instead, myocardial dysfunction secondary to asphyxia, hypoglycemia, hypocalcemia or sepsis are usually responsible for CHF on the first day. Tricuspid regurgitation secondary to hypoxia induced papillary muscle dysfunction or Ebstein's anomaly of the valve is also recognised. This improves as the pulmonary artery pressure falls over the next few days.

c. CHF in first week of life

Serious cardiac disorders which are potentially curable but carry a high mortality if untreated, often present with CHF in the first week of life. Accordingly, a sense of urgency should always accompany evaluation of the patient with CHF in the first week. The closure of the ductus arteriosus is often the precipitating event leading to catastrophic deterioration in a seemingly healthy neonate. It follows that prostaglandins E1, (now available in India) should be utilised in such babies. Regarding CHF in this age group a few points need to be emphasised.

i) Peripheral pulses and oxygen saturation (by a pulse oximeter) should be checked in both the upper and lower extremities. A lower saturation in the lower limbs means right to left ductal shunting and occurs due to pulmonary hypertension, coarctation of aorta or aortic arch interruption.

ii) An atrial or ventricular septal defect (ASD/VSD) does not lead to CHF in the first two weeks of life. Therefore, an additional cause must be sought (eg. coarctation of aorta or TAPVC).

iii) Premature infants have a poor myocardial reserve and a patent ductus arteriosus (PDA) may result in CHF in the first week in them.

iv) Adrenal insufficiency due to enzyme deficiencies or neonatal thyrotoxicosis could present with CHF in the first few days of life.

d. CHF beyond second week of life

The most common cause of CHF in infants is a ventricular septal defect that presents around 6–8 weeks of age. This is because the volume of the left to right shunt increases as the pulmonary resistance falls. Although a murmur of VSD is apparent by one week, the full blown picture of CHF occurs around 6–8 weeks. Other left to right shunts like PDA present similarly.

The fall in pulmonary vascular resistance is delayed in presence of hypoxic lung disease and at high altitude [7] and could somewhat alter the time course accordingly.

Medical management of CHF is perhaps most important in this age group, since the VSD may close on follow up. It is equally important to understand that spontaneous improvement in CHF could result from development of obstructive pulmonary arterial hypertension, even in early childhood [8].

Left coronary artery arising from the pulmonary artery (LCAPA), a rare disease in this age group merits separate mention, since it is curable and often missed. As the pulmonary artery pressure decreases in the neonatal period, these babies suffer from episodes of excessive crying with sweating (angina) and myocardial infarction. The electrocardiogram shows pathologic q waves or left ventricular hypertrophy. These infants are often misdiagnosed as having “dilated cardiomyopathy” [9].

CHF beyond Infancy

Onset of CHF beyond infancy is unusual in patients with congenital heart disease and suggests a complicating factor like valvular regurgitation, infective endocarditis, myocarditis, anaemia etc [10]. Continued volume or pressure load in a surgically palliated patient (e.g. after a Blalock Taussig shunt) may be responsible. Uncommonly, worsening of aortic or pulmonary stenosis may cause CHF in childhood [11]. Acquired diseases are common cause of CHF in children.

Treatment of CHF

The treatment of CHF includes treatment of the cause, management of the precipitating events and control of the congested state.

a. Treatment of the cause

The curative therapy is directed towards the cause of CHF, wherever possible. Some of these have been alluded to in the preceding section.

b. Treatment of the precipitating events

Almost always, the worsening in clinical state of a patient with CHF can be traced to a precipitating event, the treatment of which leads to significant improvement. The checklist includes rheumatic activity, infective endocarditis, intercurrent infections, anaemia, electrolyte imbalances, arrhythmia, pulmonary embolism, drug interactions, drug toxicity or non-compliance and other system disturbances etc.

c. Treatment of congested state

This deals with the conventional medical management of CHF. The therapy is often resorted to before a definitive diagnosis is made, and is chronically used. It is aimed at reducing the pulmonary or systemic congestion (diuretics), reducing the disproportionately elevated afterload (vasodilators including ACE inhibitors), increasing contractility (inotropes) and other measures. The details of such therapy are widely discussed in standard texts. Few salient points about therapy are reproduced here.

Digoxin: Despite some controversy regarding the use of digoxin in patients with left to right shunts, it remains the mainstay of treatment of CHF in infants and children. Rapid digitalization (over 24 hours) should be resorted to in babies with severe CHF. A total dose of 30–40 micrograms/kg body weight orally (intravenous doses – 75% of the oral dose) would digitalise term infants and children. For most other circumstances, starting with an oral maintenance dose (8–10 micrograms/kg/day) with no loading dose is adequate. It is the physician's responsibility to ensure that the patient receives the correct dosages, simply because the mistakes in this regard can prove fatal. It is preferable to give the daily dose in two divided dosages. This is also easier to remember (eg. 0.4 ml BD oral for a 4 kg infant). Nausea and vomiting are commonest signs of toxicity but severe toxicity may be present without these. If the child regurgitates a dose, it may be prudent to give the next dose 12 hours later. Bradycardia and blocks are commoner in children than ectopy during toxicity. The individual tolerance varies, but the safety margin is not high. Digoxin should be avoided in patients with myocarditis. Few advise against using digoxin in prematures with CHF from patent ductus arteriosus [12].

Diuretics afford quick relief in pulmonary and systemic congestion. One mg/kg of frusemide is the agent of choice. For chronic use 1–4 mg/kg of frusemide or 20–40 mg/kg of chlorothiazide in divided dosages are used. It is important to monitor body weight, blood urea, serum electrolytes (at least twice weekly initially). Potassium supplementation is usually not required with <2 mg/kg of frusemide or equivalent doses of other diuretics. Secondary hyperaldosterinism does occur in infants with CHF and addition of spironolactone 1 mg/kg single dose to other diuretics conserves potassium. A daily supplementation of 1–1.5mEq/kg of potassium may be required if there is significant hypokalemia. Metabolic alkalosis, hypomagnesemia and hyponatremia are the other problems. Infants tolerate hyponatremia much better than adults. The treatment for hyponatremia is rarely required even when serum sodium is as low as 120 mEq/L. Reducing the dose of diuretics, restriction of free water intake and liberalising salt for a short period would restore the serum sodium except in patients with a very low cardiac output [13].

In refractory CHF, a combination of diuretics having different sites of action should be tried and intravenous rather than oral preparations should be used. Dopamine in a renal vasodilating dose of 2–3 micrograms/kg/min may be useful as a diuretic although scientific data is limited [14].

Vasodilators: The physiologic rationale of using vasodilators in CHF is now amply demonstrated. Several trials in adults have shown that ACE inhibitors prolong life in patients with CHF and improve quality of life [15]. These drugs are now more commonly used in paediatric practice. These are especially useful in the presence of hypertension, mitral or aortic regurgitation. In children with left to right shunts, ACE inhibitors have been found useful in patients with large shunts or in those with an elevated systemic vascular resistance. These drugs should not be used in patients with aortic or mitral stenosis.

ACE inhibitors can lead to severe hypotension in volume depleted patients hence diuretics may be reduced or eliminated initially. A test dose (one fourth of the usual dose) should be given first, as some patients react with exaggerated hypotension to the initial dose. Patients with pre-existing renal failure (serum creatinine >1.5mg/dl) should not receive ACE inhibitors. ACE inhibitors precipitate renal failure in bilateral renal arterial stenosis. Cough is common, angioedema rarely occurs. Optimal dosages are variable. Enalapril in a dose from 0.1 to 0.5 mg/kg/day has been used in children [16]. Captopril is used in a dosage of upto 6 mg/kg/day in divided doses.

The angiotensin II receptor antagonist Irbesartan has been found to have beneficial effects in patients with heart failure and an open-label study was conducted to characterize the pharmacokinetics and antihypertensive response to Irbesartan in children (1–12 years) and adolescents (13–16 years) with hypertension. Irbesartan was well tolerated and may be a treatment option for paediatric hypertensive patients [17]. However, there is no report of its use in CHF in the paediatric age group.

Nitroglycerin: Intravenous nitroglycerin is safe and very effective therapy for pulmonary edema [18]. It is predominantly a venodilator and also a weak arterial dilator. The blood pressure needs to be monitored frequently. The addition of an ionotrope such as dobutamine may be required if the child develops hypotension (systolic BP < 90 mmHg). With careful noninvasive monitoring, nitroglycerin may be administered with a micro drip set, although the use of an infusion pump is preferable. Dosages are titrated from 0.5 to 1.0 micrograms/kg/min.

Sodium nitroprusside: A potent arterial dilator, sodium nitroprusside requires careful monitoring of intraarterial pressure. It is rapid acting and severe hypotension may occur within minutes. Careful titration is required. The dosage ranges from 0.5 to 10 micrograms/kg/min. The infusion fluid needs to be protected from sunlight. Renal failure enhances its toxicity. It is most useful for treatment or acute left ventricular failure in presence of hypertension and for acute mitral or aortic regurgitation.

Nifedipine: This calcium channel blocker causes peripheral vasodilation and is useful in patients with coarctation of aorta or pulmonary arterial hypertension. The advantages are a rapid onset action, safety and sublingual administration. It can be used in infants also in a dose of 0.1–0.3 mg/kg/dose sublingual 6 hourly.

Hydralazine is an infrequently used vasodilator for the treatment of CHF now. Chronic use results in tachyphylaxis. It is a predominantly arterial dilator. The dosage is 1–7 mg/kg/day in divided doses.

Inotropes other than digoxin are used for short term support of circulation or to tide over the crisis. Their long term use is not associated with improved long term survival. Dopamine is currently the most widely used inotrope for acute support in paediatric practice. It has the advantages of peripheral vasoconstriction and raising blood pressure at moderate to high doses (6–10 micrograms/kg/min). At higher doses (20 micrograms/kg/min), intense vasoconstriction raises blood pressure but is counter productive as it increases myocardial work. Dopamine also increases pulmonary vascular resistance and causes tachycardia. Both these factors may be detrimental to some patients (eg with mitral stenosis). For hypotension in the preterm neonate dopamine is particularly effective at low dosages [19]. Dobutamine is a synthetic sympathomimetic agent and causes increase in contractility with relatively less tachycardia or rise in blood pressure. It is compatible with dopamine in the same

infusion and often a combination of dopamine and dobutamine is used to provide inotropic support. A dose as low as 0.5 micrograms/kg/min may be effective in some children [20]. The individual variations however, are wide and dosages of 5–20 micrograms/kg/min are generally used.

Epinephrine, nor-epinephrine and isoprenaline are potent, naturally occurring sympathomimetics used during postoperative low output only. Isoprenaline, a beta stimulant is a pulmonary and systemic vasodilator and causes tachycardia. Rarely, nor-epinephrine has been found effective in septic shock unresponsive to other treatment [21].

Amrinone

This phosphodiesterase inhibitor inotropic agent has pulmonary vasodilating properties also. A loading dose of 3 mg/kg over one hour followed by 5–10 micrograms/kg/min is used in children, mainly in post operative or refractory failure [22]. Thrombocytopenia and hepatic dysfunction limit its use. It should not be mixed in dextrose containing solutions or with frusemide.

Miscellaneous

Beta blockers: Paradoxically, some patients with dialated cardiomyopathy may respond to beta-blockers [23]. The rationale perhaps relates to down grading of beta receptors due to chronic catacholamine stimulation. The therapy is best undertaken in hospital as careful monitoring is required. Carvedilol, a nonselective beta blocker with alfa-1 blocking and anti-oxidative properties has proven to be beneficial in a majority of adult patients with congestive heart failure. Although the experience from adult patients may be extrapolated to older children, symptomatic infants remain a subset for whom dosage, safety and efficacy need to be established. It has been recently reported that carvedilol is well tolerated in infants with dilated cardiomyopathy and there is significant improvement in their functional status. Optimal timing of starting therapy, dosage and long-term effects need to be investigated with multiinstitutional trials. A recent multi-centre study has suggested carvedilol as an adjunct to standard therapy for pediatric heart failure. It improves symptoms and left ventricular function. Side effects are common but well tolerated. Further prospective study is required to determine the effect of carvedilol on survival and to clearly define its role in pediatric heart failure therapy [24]

L carnitine: Some forms of metabolic myopathy respond to replacement with carnitine in a dosage of 50 to 100 mg/kg/day in divided doses. Its role in other cardiomyopathies is not proved [25].

Prostaglandins E1: As described earlier, neonates with transposition of great arteries, coarctation of aorta, aortic stenosis in failure or hypoplastic left heart syndrome etc. improve remarkably with PGE. The therapy is initiated at 0.05 micrograms/kg/min and may be raised upto 0.4 micrograms/kg/min if an adequate response is not seen. The dose may be reduced subsequently. Apnoea may occur during the infusion and ventilatory support should be available. Irritability, seizures, hypotension and hyperpyrexia are rare [26].

Other options

Extracorporeal membrane oxygenation and ventricular assist devices:

Extracorporeal membrane oxygenation (ECMO) was initially developed for respiratory failure. Its use, however, has evolved into an excellent method of preoperative and postoperative support in the treatment of infants and children with acquired and congenital heart disease. Along with ECMO, the left ventricular assist device (LVAD) and the intraaortic balloon pump (IABP) have also found a place in the management of paediatric patients with heart failure. There is a 74% survival rate and the long-term outcome has been excellent in most cases [27].

A combination of external implantable pulsatile and continuous-flow external mechanical support now can be used to bridge paediatric patients with end stage cardiomyopathy to orthotropic heart transplantation. Such a combination has been found to complement each other to significantly extend the lives of a wide range of paediatric patients with severe cardiomyopathies and myocarditis [28, 29].

Biventricular pacing: Biventricular pacing therapy is an innovative therapy for improving cardiac output in adult patients with severe heart failure. However, recently this technique had been used in a six month young infant with tetralogy of Fallot and atresia of the left pulmonary artery in whom biventricular stimulation led to improved left ventricular function and successful weaning from extracorporeal circulation [30].

Cardiac transplantation: Paediatric heart transplantation has become an accepted method of treatment for certain paediatric heart diseases. Of the 25 orthotopic paediatric heart transplantations at the University of Minnesota Hospital and Clinics, the average age was 8.5 years with a range from 7 days to 18 years. 3 of the patients were younger than one year of age. The two year survival for patients with a minimum 24 months evaluation was 79% (15 of 19). Of 12 patients available for 5 year assessment, 75% (9 of 12) were alive and doing well at the time this article was written [31]. Paediatric heart transplantation can provide good intermediate and long-term survival for selected paediatric patients.

Cardiac transplantation has since become a standard therapeutic option for certain disorders in which poor cardiac output without other surgical options exists in the face of maximized medical therapy. The most common disorder requiring transplantation is dilated cardiomyopathy, although other forms of cardiomyopathy, (i.e. restrictive cardiomyopathy, arrhythmogenic right ventricular dysplasia/cardiomyopathy, and hypertrophic cardiomyopathy with poor ventricular function) may require transplantation as well [32].

General Measures

Nursing the infant with head end elevated, judicious use of sedation and temporarily denying oral intake to avoid aspiration in the distressed infant, are useful practices. Morphine in the dose of 0.05 mg/kg is cautiously used in infants with pulmonary oedema. More severe cases require mechanical ventilation.

Infants with CHF require 120–150 Kcal/kg/day of caloric intake and 2–3 mEq/kg/day of sodium. Enteral or parenteral hyperalimentation may be required prior to corrective surgery. It is not generally appreciated that oxygen may sometimes worsen the CHF in patients with left to right shunts due to its pulmonary vasodilating and systemic vasoconstrictor effects [33]. Similarly, it may constrict PDA in neonates and may be detrimental to patients with ductus arteriosus dependent lesions. However, in patients with pulmonary edema and hypoxia, raising alveolar PO_2 by oxygen supplementation is required and regularly used.

Finally, it is suggested that in dealing with parents, it is preferable to use words like “pulmonary congestion”, “liver congestion” rather than ‘heart failure”, since “heart failure”, is likely to be misunderstood by the parents and this may hamper useful interaction.

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