

## **Congestive Heart Failure: Diagnosis and Management**

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In simple terms, 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 detailed reviews on CHF in infants and children are available(1,2). This article is intended to provide core practical information on selected aspects of CHF.

Broadly, heart failure results either from an excessive volume or pressure load 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-angiotension mediated vasoconstriction and sympathetic over-activity. 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, after load, contractility and heart rate is essential in optimizing the therapy of CHF.

It is clinically useful to consider CHF in different age groups separately.

### **I. 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; heart rates >180/min are abnormal even in the setting of respiratory distress and are suggestive of CHF(4). Heart rates above 220/min indicate supra-ventricular tachycardia as the cause. Tachypnea 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

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good inspiratory film (with diaphragms near the 10th 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 blood pressure with inspiration) are frequently observed in infants with severe CHF. In chronic CHF poor feeding, frequent chest infection and increased metabolic requirements lead to inadequate growth. Weight gain is more inadequate than the gain in height or head circumference.

Grading the severity of CHF in infants is difficult and is not standardized. A precise description of feeding history, heart rate, respiratory rate and pattern, peripheral perfusion, presence of S<sub>3</sub> and the extent of hepatomegaly should be considered in this evaluation(5).

The time of onset of CHF holds the key to the etiological 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, anemia, 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 recognized 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(6) or complete heart block(7), 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 (*Table I*). Tricuspid regurgitation secondary to hypoxia induced papillary muscle dysfunction or Ebstein's anomaly of the valve is also recognized. 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. Prostaglandin E<sub>1</sub>, now available in India, should be utilized in such babies.

The causes and important features in this age group are listed in *Table II*. However, the following few aspects need emphasis: (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 arterial or ventricular septal defect (ASD/VSD) does not lead to CHF in the first two weeks of

**TABLE I- CHF on First Day of Life.**

Causes	Comments
Asphyxia	History of birth asphyxia, dominant neurologic findings, relative bradycardia, conservative treatment.
Hypoglycemia	Occurs in infants of diabetic mothers or because of liver glycogen depletion due to stress
Hypocalcaemia	Corrected Q-T on EKG <0.20 excludes significant hypocalcaemia.
Sepsis	Septic screen, CHF due to combination of factors.
Systemic arteriovenous fistula	Brisk carotids, weak femorals, bruit on skull, may cause cyanosis due to shunting across foramen ovale.
Neonatal myocarditis	History in the mother, associated hepatitis or encephalitis.
Anemia	Chronic anemia results in high output failure
Polycythemia	PCV >65%, associated pulmonary hypertension; partial exchange transfusion may be needed
SVT & complete heart block	HR <50/min or >220/min may cause CHF.
Tricuspid regurgitation (Ebstein's anomaly, papillary muscle dysfunction)	Tricuspid regurgitation improves as the pulmonary artery pressures decline, Ventilation, pulmonary vasodilators including PGE-1 may be required initially

life. There

**TABLE II-CHF in the First Week of Life**

Causes	Comments
<b>Structural abnormalities</b>	
Hypoplastic left heart syndrome	Unrewarding multiple surgeries presently, should be distinguished from severe aortic stenosis with small left ventricle Balloon dilatation or surgery.
Critical aortic stenosis and pulmonary stenosis	
Total anomalous pulmonary venous drainage (obstructed)	Chest X-ray shows pulmonary edema and normal size heart. Echo should be diagnostic. Contrast echo right to left shunt.
Coarctation of aorta	Femorals may be felt in presence of PDA. Prostaglandin helpful in stabilizing.
Interrupted aortic arch	Decreased saturation in lower limbs, misdiagnosed as persistent fetal circulation. Presentation early because of poor myocardial reserve, digoxin not helpful. Fluid restriction, indomethacin useful.
Patent ductus arteriosus (prematures)	As in Table I. (asphyxia now unlikely).
<b>Heart rate and muscle dysfunction</b>	
<b>Renal abnormalities</b>	
Renal failure	Abdominal ultrasound altered renal parameters
Systemic hypertension	
Endocrine abnormalities	
Hyperthyroidism	History in mother.
Adrenal insufficiency	Shock, hyponatremia, hypokalemia, virilization of female fetus.

fore, an additional cause must be sought (*e.g.*, 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; and (*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 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 (*Table III*). The fall in pulmonary vascular resistance is delayed in presence of hypoxic lung disease and at high altitude(8), 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(9).

Left coronary artery arising from the pulmonary artery, 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".

**TABLE III-CHF Presenting Beyond 2 Weeks of Life**

Causes	Comments
<i>Structural lesions</i>	
Ventricle septal defect	Echocardiography diagnostic. Early surgery if medical management inadequate to control CHF or evidence of PAH.
Single ventricle	Irreversible pulmonary artery hypertension may occur by 2 years of age.
Patent ductus arteriosus	
Aortopulmonary window	
Truncus arteriosus	
ASD	Rarely result in CHF in early infancy, suspect additional lesion like mitral stenosis or a missed coarctation.
Unobstructed TAPVC	
Obstructive lesions	As in <i>Table II</i>
Left coronary artery from pulmonary artery (L-CAPA)	Rare, angina in infants, q waves in anterolateral leads or LVH. Misdiagnosed as dilated cardiomyopathy.
Hypertrophic cardiomyopathy	Noonan's syndrome or other familial variety. Prognosis poorer in infancy. Beta blockers or calcium channel blockers may be useful.
Dilated cardiomyopathy	Rule out obstructive lesion, L-CAPA, metabolic myopathy
Pompe's disease	Large complexes on EKG, short PR interval.
Myocarditis	Viral prodrome, poorer outcome in infancy, steroids not useful.
Pulmonary abnormalities	Usually obvious lung diseases, consider upper airway obstruction, broncho-pulmonary dysplasia, in appropriate settings.

## II. CHF BEYOND INFANCY

New onset of CHF beyond infancy is unusual in patients with congenital heart disease and suggests a complicating factor like valvular regurgitation, infective endocarditis, myocarditis, anemia, etc. 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. Acquired diseases are the common causes of CHF in children. Some important aspects regarding the common acquired disorders are listed in *Table IV*.

### 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 aspects 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, anemia, electrolyte imbalances, arrhythmia, pulmonary embolism, drug interactions, drug toxicity or non-compliance and other system disturbances.

**TABLE IV**-*Acquired Causes of CHF in Children*

Causes	Comments
Acute rheumatic fever	Valvulitis and not myocarditis important for CHF(10). Patients must receive steroids.
Chronic rheumatic heart disease	Consider balloon dilatation for mitral stenosis (11) and surgery for all cases of mitral regurgitation and CHF.
Infective endocarditis	Consider early surgery in patients with uncontrolled CHF even during active infection(12).
Takayasu's arteritis	Common in India, anti-tubercular drugs and steroids helpful during early phase (not proved). Balloon dilatation of aorta or renal arteries beneficial (13).
Myocarditis	Usually viral, may progress to dilated cardiomyopathy. Steroids, immunosuppression not found useful, but should be individualized (14).
Dilated Cardiomyopathy	Medical management variably successful. 30% mortality after one year (15). Transplant in children is limited by coronary artery disease in graft.
Tachyarrhythmias	Can cause "cardiomyopathy" like picture. Radio frequency ablation of arrhythmia may reverse myocardial dysfunction(16).
Primary pulmonary hypertension	Rare, difficult to treat, High dose nifedipine risky but sometime beneficial(17). Nitric oxide may be useful. (Not available in India).

#### 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 after load (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 the 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 h) should be resorted to in babies with severe CHF. A total dose of 30-40 microgrammes/Kg body weight orally (intravenous doses = 75% of the oral dose) would digitalize term infants and children. For most other circumstances, starting with an oral maintenance dose (8-10 microgrammes/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 (*e.g.*, 0.4 ml BD 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 experts advise against using digoxin in prematures with CHF from patent ductus(l).

### *Diuretics*

These afford quick relief in pulmonary and systemic congestion. One mg/kg of furosemide is the agent of choice. For chronic use 1-4 mg/kg of furosemide 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 furosemide 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 1-1.5 mEq/kg of potassium may be required if there is significant hypokalemia. Metabolic alkalosis, hypo-magnesemia and hyponatremia are the other problems. Infants tolerate hyponatremia much better than adults. The treatment for hyponatremia is rarely required with serum sodium levels even as low as 120 mEq/l. Reducing the dose of diuretics, restriction of free water intake and liberalizing salt for a short period would restore the serum sodium except in patients with a very low cardiac output.

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 microgrammes/kg/min may be useful as a diuretic although scientific data is limited(18). Newer and more efficacious diuretics like metaxim in the dose of 2.5-5 mg/day have also been used in refractory cases.

### *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(19). These drugs are now more commonly used in pediatric practice(20). 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 >1.5 mg/dl) should not receive ACE inhibitor. ACE inhibitors precipitate renal failure in bilateral renal arterial stenosis. *I* 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(21,22). Captopril is used in a dosage of upto 6 mg/kg/day in divided doses.

#### *Nitroglycerin*

Intravenous nitroglycerin is safe and very effective therapy for pulmonary edema(23). It is predominantly a venodilator and also a weak arterial dilator. The blood pressure needs to be monitored frequently. Addition of an inotrope like dobutamine may be required if hypotension develops (systolic BP <90 mm Hg). With careful non invasive monitoring, nitroglycerin may be administered with a micro dripset although infusion pump is preferable. Dosages are titrated from 0.5 to 1.0 microgrammes /kg/min.

#### *Sodium Nitroprusside*

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

#### *Nifedipine*

This calcium channel blocker causes peripheral vasodilatation 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.

Hydrallazine is 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, these 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 pediatric practice(24). It has the advantages of peripheral vasoconstriction and raising blood pressure at moderate to high doses (6-10 microgrammes/kg/min). At higher doses (20 microgrammes/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 (*e.g.*, with mitral stenosis). For hypotension in the preterm neonate, dopamine is particularly effective at low dosages(24).

*Dobutamine* is 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 recent study has shown that as low a dose as 0.5 microgrammes/kg/min may be effective in some children(25). The individual variations however, are wide and dosages of 5-20 microgrammes/kg/min are generally used.

*Epinephrine, nor-epinephrine and isoprenaline* are potent naturally occurring sympathomimetics used during post operative 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(26).

*Amrinone:* This phospho-diesterase inhibitor inotropic agent has pulmonary vasodilating properties also. A loading dose of 3 mg/kg over one hour followed by 5-10 microgrammes/kg/min is used in children, mainly in post operative or refractory failure(27). Thrombocytopenia and hepatic dysfunction limit its use. It should not be mixed in dextrose containing solutions or with furosemide.

#### *Miscellaneous*

*Beta-Blockers:* Paradoxically, some patients with dilated cardiomyopathy may respond to beta-blockers(28). The rationale perhaps relates to down grading of beta receptors due to chronic catecholamine

stimulation. The therapy is best undertaken in hospital as careful monitoring is required.

*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(29).

*Prostaglandin E1:* As described earlier, neonates with TGA, coarctation of aorta, aortic stenosis in failure or hypoplastic left heart syndrome, *etc.* improve remarkably with PGE. The therapy is initiated at 0.05 microgrammes/kg/min and may be raised up to 0.4 microgrammes/kg/min if an adequate response is not seen. The dose may be reduced subsequently. Apnea may occur during the infusion and ventilatory support should be available. Irritability, seizures, hypotension and hyperpyrexia are rare(30).

#### *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 edema. 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 hyper-alimentation may be required prior to corrective surgery.

#### *Oxygen*

It is not generally appreciated that oxygen may sometimes worsen the CHF(31) in patients with left to right shunts due to its pulmonary vasodilating and systemic vasoconstrictor effects. Similarly, it may constrict PDA in neonates and may be detrimental to patients with ductus dependent lesions. However, in patients with pulmonary edema and hypoxia, raising alveolar  $P_{O_2}$  by oxygen supplementation is required and regularly

used.

Finally, Talner(1) 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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