Congestive Heart Failure: Diagnosis, Pathophysiology, Therapy, and Implications for Respiratory Care

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Congestive heart failure (CHF) is a common clinical disorder that results in pulmonary vascular congestion and reduced cardiac output. CHF should be considered in the differential diagnosis of any adult patient who presents with dyspnea and/or respiratory failure. The diagnosis of heart failure is often determined by a careful history and physical examination and characteristic chest-radiograph findings. The measurement of serum brain natriuretic peptide and echocardiography have substantially improved the accuracy of diagnosis. Therapy for CHF is directed at restoring normal cardiopulmonary physiology and reducing the hyperadrenergic state. The cornerstone of treatment is a combination of an angiotensin-converting-enzyme inhibitor and slow titration of a β blocker. Patients with CHF are prone to pulmonary complications, including obstructive sleep apnea, pulmonary edema, and pleural effusions. Continuous positive airway pressure and noninvasive positive-pressure ventilation benefit patients in CHF exacerbations. *Key words: heart failure, diastolic dysfunction, systolic dysfunction, obstructive sleep apnea, Cheyne-Stokes respiration, respiratory failure, noninvasive ventilation.* [Respir Care 2006;51(4):403–412. © 2006 Daedalus Enterprises]

Introduction

Congestive heart failure (CHF) is a complex clinical syndrome that can result from any functional or structural cardiac disorder that impairs the ventricle's ability to fill with or eject blood. Since there is no definitive diagnostic test for heart failure, it remains a clinical diagnosis that is largely based on a careful history and physical examination and supported by ancillary tests such as chest radiograph, electrocardiogram, and echocardiography. Heart failure is a common disease, affecting approximately 5 million people in the United States, and it occurs predominately in the elderly, with almost 80% of cases occurring in patients over the age of 65.[1] The magnitude of the problem cannot be precisely assessed, because reliable population-based data on the prevalence, incidence, and prognosis are lacking. Nevertheless, several studies have found that CHF is associated with a 2-year mortality rate of approximately 45–50%, which approaches that of many malignancies.[2] Moreover, from a societal perspective, car-

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ing for patients with CHF accounts for 2–3% of the federal health-care budget. The estimated direct and indirect cost of CHF in the United States in 2005 was $27.9 billion.[1]

There are 2 mechanisms of reduced cardiac output and heart failure: systolic dysfunction and diastolic dysfunction. The most common causes of systolic dysfunction (defined by a left-ventricular ejection fraction of < 50%) are ischemic heart disease, idiopathic dilated cardiomyopathy, hypertension, and valvular heart disease. Diastolic dysfunction (defined as dysfunction of left-ventricular filling with preserved systolic function) may occur in up to 40–50% of patients with heart failure, it is more prevalent in women, and it increases in frequency with each decade of life. Diastolic dysfunction can occur in many of the same conditions that lead to systolic dysfunction. The most common causes are hypertension, ischemic heart disease, hypertrophic cardiomyopathy, and restrictive cardiomyopathy. Many patients who have symptoms suggestive of heart failure (shortness of breath, peripheral edema, paroxysmal nocturnal dyspnea) but also have preserved left-ventricular function may not have diastolic dysfunction; instead, their symptoms are caused by other etiologies, such as lung disease, obesity, or occult coronary ischemia.[3] This article will review the pathophysiology, diagnosis, and treatment of CHF, with specific discussion of the pulmonary manifestations and their treatment, including noninvasive positive-pressure ventilation (NPPV) strategies.

Pathophysiology of Congestive Heart Failure

The syndrome of CHF arises as a consequence of an abnormality in cardiac structure, function, rhythm, or conduction. In developed countries, ventricular dysfunction accounts for the majority of cases and results mainly from myocardial infarction (systolic dysfunction), hypertension (diastolic and systolic dysfunction), or in many cases both. Degenerative valve disease, idiopathic cardiomyopathy, and alcoholic cardiomyopathy are also major causes of heart failure. Heart failure often occurs in elderly patients who have multiple comorbid conditions (eg, angina, hypertension, diabetes, and chronic lung disease). Some common comorbidities such as renal dysfunction are multifactorial (decreased perfusion or volume depletion from overdiuresis), whereas others (eg, anemia, depression, disorders of breathing, and cachexia) are poorly understood.[4]

CHF indicates not only an inability of the heart to maintain adequate oxygen delivery; it is also a systemic response attempting to compensate for the inadequacy. The determinants of cardiac output include heart rate and stroke volume (Fig. 1). The stroke volume is further determined by the preload (the volume that enters the left ventricle), contractility, and afterload (the impedance of the flow from the left ventricle). These variables are important in under-
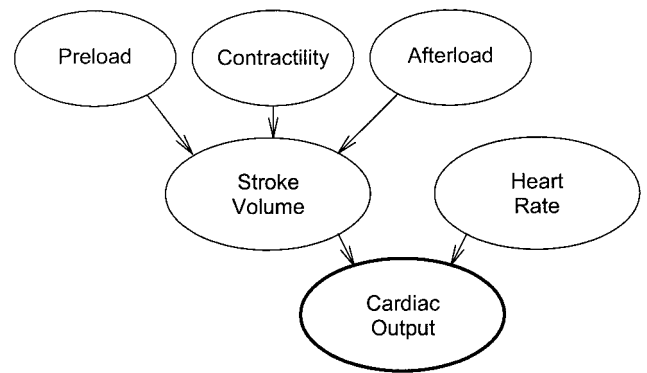

Fig. 1. Determinants of cardiac output.

standing the pathophysiologic consequences of heart failure and the potential treatments. Furthermore, an appreciation of cardiopulmonary interactions is important in our understanding of heart failure. In the simplest terms, the heart can be viewed as a dynamic pump. It is not only dependent on its inherent properties, but also on what is pumped in and what it must pump against. The preload characterizes the volume that the pump is given to send forward, the contractility characterizes the pump, and the afterload determines what the heart must work against.

The preload is often expressed as the end-diastolic pressure/volume of the left ventricle and is clinically assessed by measuring the right atrial pressure. However, the preload is not only dependent on intravascular volume; it is also influenced by any restriction to ventricular filling. Since the heart resides in the thoracic cavity, an increased positive pleural pressure (as seen with dynamic hyperinflation in chronic obstructive pulmonary disease or asthma) can reduce right-atrial pressure (which equals central venous pressure minus pleural pressure) and thus reduce ventricular filling. The cardiac pump is a muscle and will respond to the volume it is given with a determined output. If volume increases, so will the amount pumped out in a normal physiologic state, to a determined plateau; this relationship is described by the Frank-Starling law (Figs. 2 and 3).[5]

A concept that is often poorly understood is the diastolic function of the heart. Diastolic function is determined by 2 factors: the elasticity or distensibility of the left ventricle, which is a passive phenomenon, and the process of myocardial relaxation, which is an active process that requires metabolic energy.[6] Relaxation of the myocardium occurs in early diastole, and the "untwisting" of the left ventricle is an active process that produces a suction effect that augments left-ventricular filling. Loss of normal left-ventricular distensibility or relaxation by either structural changes (eg, left-ventricular hypertrophy) or functional changes (eg, ischemia) impairs ventricular filling (preload). The exercise intolerance seen with diastolic dysfunction largely results from the impairment of ventricular filling,
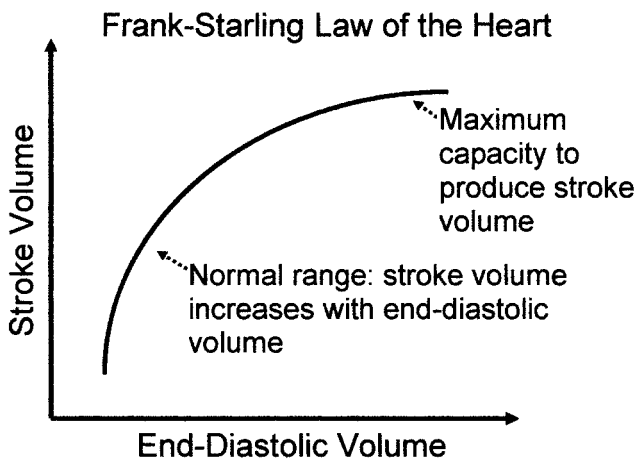
Frank-Starling Law of the Heart

Fig. 2. The Frank-Starling law of the heart states that as the ventricular volume increases and stretches the myocardial muscle fibers, the stroke volume increases, up to its maximum capacity. After that point, increasing volume increases pulmonary capillary pressure (and pulmonary congestion), without increasing the stroke volume or cardiac output. The mechanism is the length-force relationships of muscle contraction.

which elevates left-atrial pressure and pulmonary venous pressure and causes pulmonary congestion.[7] Additionally, inadequate cardiac output during exercise results in poor perfusion of skeletal muscles, especially the leg muscles and the accessory muscles of respiration.[8]

The second variable of stroke volume is cardiac contractility, which represents the muscular pumping of the heart and is commonly expressed as the ejection fraction. Based on autonomic input, the heart will respond to the same preload with different stroke volumes, depending on inherent characteristics of the heart. A heart with normal
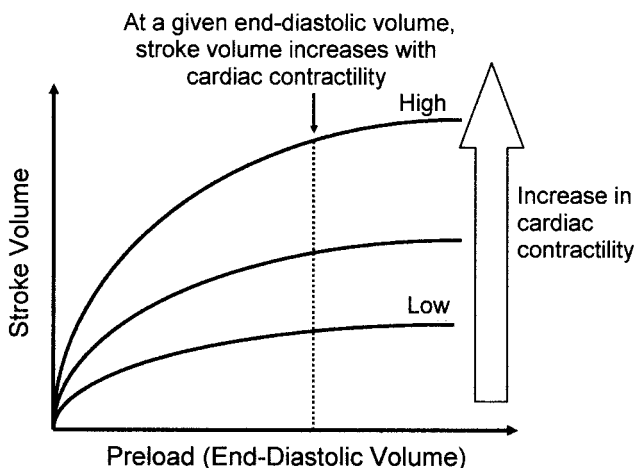

Fig. 3. This series of Frank-Starling curves demonstrates that at any given preload (end-diastolic volume), increases in contractility will increase stroke volume (volume of blood ejected from the ventricle with each beat).

systolic function will maintain an ejection fraction of over 50–55%. A previous myocardial infarction may result in nonfunctioning myocardium that will impair contractility. A recent concept is that ischemic myocardial tissue can be nonfunctioning (hibernating) but revitalized by surgical or medical therapy directed at ischemic heart disease.[9] Other depressants of myocardial systolic function include pharmacologic agents (calcium-channel blockers), hypoxemia, and severe acidosis.

The final determinant of stroke volume is afterload. In basic terms, afterload is the load that the pump has to work against, which is usually clinically estimated by the mean arterial pressure. The normal cardiac output is relatively insensitive to afterload up to 140 mm Hg. However, the afterload represents not only the vascular resistance but also the wall tension and intrathoracic pressure that the myocardium must work against. Together, these 3 variables are impaired in the patient with CHF.[5]

The failing heart in CHF can be best evaluated with the above variables considered together. If cardiac output falls, either the heart rate or stroke volume must change in order to maintain perfusion. If stroke volume cannot be maintained, then heart rate must increase to maintain cardiac output. However, the pathophysiology behind CHF includes not only a structural abnormality; it also includes the cardiovascular response to poor perfusion with the activation of the neurohumoral system.[10] Activation of the renin-angiotensin system attempts to increase preload by stimulating retention of salt and water, increasing vasoconstriction (and, thus, afterload), and augmenting cardiac contractility. Initially, this response will suffice, but prolonged activation results in loss of myocytes and maladaptive changes in the surviving myocytes and the extracellular matrix. The stressed myocardium undergoes remodeling and dilation in response to the insult.[11] This process also has detrimental effects on the functioning of the lungs, kidneys, muscles, blood vessels, and probably other organs. Remodeling also results in additional cardiac decompensation from complications, including mitral regurgitation from valvular annulus stretching, and cardiac arrhythmias from atrial remodeling.[10]

The respiratory care provider often becomes involved with the CHF patient as the elevated end-diastolic pressure leads to pulmonary edema and dyspnea. Patients' presentation can greatly differ, depending on the chronicity of the disease. For instance, most patients experience dyspnea when pulmonary-artery occlusion pressure exceeds 25 mm Hg. However, the patient with longstanding CHF can tolerate filling pressure up to 40 mm Hg.[12] The lung provides multiple mechanisms to avoid the consequences of pulmonary edema. Initially, as pressure increases, pulmonary capillaries are recruited and increase capacitance to deal with the added volume.[13] As pressure continues to increase, volume can be diverted from the alveoli to the

interstitium. At this point, by action of pressure gradients, fluid will form in the interlobular septae and the perihilar region. As noted above, chronic heart failure is associated with increased venous capacitance and lymphatic drainage of the lung. As a result, crackles are often absent, even in the setting of elevated pulmonary capillary pressure. Continued sodium retention preferentially results in peripheral edema and, ultimately, in the development of pleural effusions.[14] With acute decompensation, the pulmonary-capillary membrane may succumb to increased pressure, with shearing of the capillary and release of fluid, protein, and occasionally red blood cells into the alveoli.[15] The lungs' response will include cough, to expel the fluid in the alveoli. The long-term response to elevated pulmonary venous pressure includes interstitial fibrosis with thickening of the alveolar membrane.[12] Thus, severe, chronic heart failure can result in interstitial fibrosis and a restrictive lung disease.

Evaluation of the Patient With Congestive Heart Failure

The approach to the patient with suspected heart failure includes a history and physical examination, chest radiograph, and a series of diagnostic tests to assess both the acuity and severity. History alone is insufficient to make the diagnosis of heart failure, but often provides clues to the cause (myocardial infarction or uncontrolled hypertension), the precipitating event (noncompliance with diet or medications), and the severity. The symptoms of heart failure can be related to either the reduction of cardiac output (fatigue, weakness) or to excess fluid retention (dyspnea, orthopnea, and "cardiac wheezing"). With progression to right-heart failure there may be hepatic congestion (with right upper-quadrant discomfort), early satiety, anorexia, and discomfort with bending. Fluid retention also results in peripheral edema and occasionally in increasing abdominal girth secondary to ascites. Absence of dyspnea on exertion essentially rules out heart failure due to left-ventricular dysfunction.[16] Pulmonary congestion (with crackles and wheezing) is predominant in acute or subacute disease. Although commonly taught as an absolute finding in CHF, crackles are present in only 20% of patients with chronic CHF. In addition, lower-extremity edema presents in about 25% of patients younger than 70 years of age.[17]

The most reliable indicator of volume overload is the presence of elevated jugular venous pulsation (estimated by distention of the jugular veins with the patient sitting at 45°), which correlates with elevated pulmonary-artery occlusion pressure 80% of the time.[18] Ventricular enlargement can be estimated by precordial palpation, and an apical pulsation displaced laterally to the midclavicular line is usually indicative of left-ventricular enlargement. In
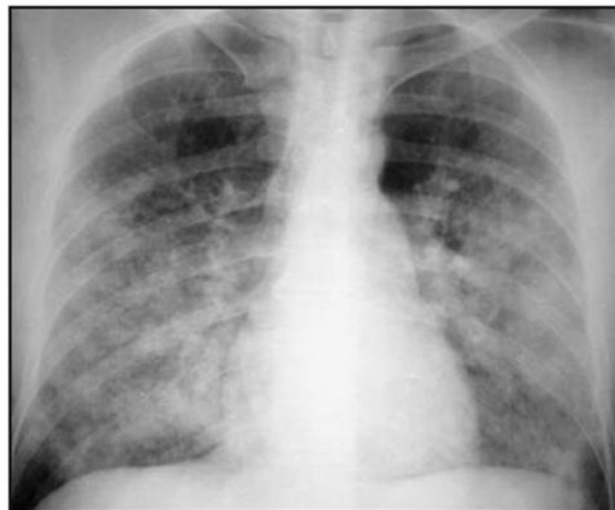

Fig. 4. This anteroposterior chest radiograph shows pulmonary vascular congestion, typical of acute congestive heart failure.

patients with dyspnea, a chest radiograph is a useful first test for differentiating patients with heart failure from patients with primary pulmonary disease (Fig. 4). Radiographic findings suggestive of heart failure include cardiomegaly (cardiac-to-thoracic ratio above 50%), cephalization of blood vessels, increased interstitial markings, and pleural effusions.[18]

A constellation of characteristic signs, symptoms, and radiographic findings, as described above, often lead to the diagnosis of CHF (Table 1). Patients with previous evidence of heart disease, diabetes mellitus, hypertension, or documented coronary-artery disease are at increased risk for CHF, and one should always consider CHF in the differential diagnosis of acute respiratory failure in these patients.[19] Until recently, beyond direct functional assessments of cardiac contractility, there were no laboratory tests to assist in the diagnosis of heart failure. Brain natriuretic peptide is one of a family of neurohormones that is produced by the ventricles in response to increased pressure and volume load. It works to counteract the effect of the renin-angiotensin system by providing vasodilation, natriuresis, diuresis, and decreased smooth-muscle proliferation. It has become a valuable tool to assist in determining the etiology, prognosis, and maintenance therapy for patients with CHF.[20] Plasma concentrations of brain natriuretic peptide are helpful in distinguishing dyspnea from cardiac causes (either left-ventricular dysfunction or cor pulmonale) versus from pulmonary causes (chronic obstructive pulmonary disease, asthma, or pneumonia). A cut-off value of > 100 pg/mL diagnoses heart failure with a sensitivity of over 90% and a predictive accuracy of 83%.[21] Reducing the cut-off point to 50 pg/mL increased the sensitivity to 97%, and a value below 50 pg/mL virtually rules out heart failure as a cause of dyspnea. Most

Table 1.   Modified Framingham Criteria for the Diagnosis of Chronic Heart Failure*

Major Criteria
Neck-vein distention
Orthopnea or paroxysmal nocturnal dyspnea
Crackles ($>$ 10 cm above base of lung)
Cardiomegaly on chest radiograph
S_3 gallop
Central venous pressure $>$ 12 mm Hg
Left ventricular dysfunction on echocardiogram
Weight loss $>$ 4.5 kg in response to CHF treatment
Acute pulmonary edema
Minor Criteria
Bilateral ankle edema
Night cough
Dyspnea on exertion
Hepatomegaly
Pleural effusion
Tachycardia ($>$ 120 beats/min)

*Diagnosis of chronic heart failure (CHF) requires two of the major criteria or one of the major plus two of the minor criteria.

Table 2.   New York Heart Association Classification of Congestive Heart Failure*

Stage/Degree	Symptoms and Activity-Limitations
I - None	No symptoms from ordinary activities
II - Mild	Comfortable at rest or during mild exertion
III - Moderate	Symptomatic with any activity
IV - Severe	Symptomatic at rest. Confined to bed or chair

*http://www.americanheart.org

patients with heart failure have values of over 400 pg/mL, but caution is necessary because pulmonary emboli and other causes of cor pulmonale are associated with high values of brain natriuretic peptide.

Therapy for Congestive Heart Failure

Understanding the pathophysiology of heart failure allows one to achieve the goals of treatment, which are to relieve symptoms, avoid hospital admissions, and prolong life. Treatment for CHF consists of a combination of pharmacologic and nonpharmacologic therapies. Much literature and research has been published on medical management of CHF. The basic theories include termination of the renin-angiotensin system to prevent the long-term complications of the cascade. Treatment often focuses on a combination of afterload-reduction with angiotensin-converting-enzyme (ACE) inhibitors, reduction of catecholamine surges with β blockers, and preload-reduction with diuretics.[10,18] Each modality presents difficulties for certain characteristic patient types, and patients with diastolic dysfunction often develop dizziness or hypotension with overdiuresis. Although clinical trials have shown significantly lower mortality with multiple interventions, the overall death rate from heart failure continues to rise,[22] which reflects the avoidance of premature mortality from predisposing conditions (myocardial infarction and hypertension) that are only palliated, not cured, by advances in therapy.

ACE inhibitors reduce the production of angiotensin II and exert a biologic effect that improves symptoms, reduces hospitalizations, and prolongs survival.[23] ACE inhibitors are recommended for all patients with heart failure with reduced systolic function. The main adverse effects of ACE inhibitors are cough (up to 20%), symptomatic hypotension, and renal dysfunction.

β blockers protect the heart from the harmful effects of norepinephrine and epinephrine. β blockers, when started in low doses and slowly increased, further reduce mortality when added to an ACE inhibitor. Intolerance to β blockers is uncommon and is usually due to bradycardia or dizziness. β blockers may worsen pulmonary function in patients with obstructive lung disease, but most patients tolerate cardio-selective β blockers when carefully monitored. Consequently, the combination of an ACE inhibitor and a β blocker is now the cornerstone of treatment for heart failure.

Diuretics are essential in the relief of dyspnea and signs of sodium and water retention (peripheral edema or pleural effusion). They are best used in the minimum dose needed to maintain the "dry weight" in patients with symptomatic heart failure.

A nonpharmacologic method that has proven useful is the implantation of a biventricular pacing device to create ventricular synchronization, in the hope of improving cardiac output.[24] Additionally, implantable cardioverter defibrillators reduce the risk of death in patients who have moderate-to-severe symptomatic heart failure and a reduced ejection fraction despite maximum medical therapy.[25]

Clinical stratification of patients to determine the need for intervention in chronic CHF has been based on the New York Heart Association (NYHA) classification system, which separates patients based on the limitations they experience in performing certain activities (Table 2). An NYHA class I patient has almost no evidence of limitation in daily performance of activities, whereas an NYHA class IV patient experiences severe symptoms even at rest.[26] This system also provides a yardstick for comparing treatment modalities in clinical research. The remainder of this article will discuss specific respiratory interventions used in the management of patients with acute and chronic CHF.

Pulmonary Complications of Congestive Heart Failure

Often the consequences of chronic CHF are overlooked, because the focus is on acute pharmacologic interventions. In stable out-patients with chronic mild CHF, 40–50% have obstructive sleep apnea (OSA) and/or Cheyne-Stokes respiration/central sleep apnea (CSR/CSA).[27,28] Furthermore, CHF patients with CSR/CSA have higher mortality than same-stage CHF patients.[29] OSA creates multiple stresses to the cardiovascular system, further exacerbating the failing myocardium. Unlike patients who have primary OSA but do not have CHF, more than 50% of those who have both CHF and OSA are asymptomatic.[30] Apnea is characterized by a cessation of flow, measured at the nose or mouth, due to central or obstructive events, for $\geq$ 10 seconds. OSA is defined as more than 5 of these apnea events per hour.[31] The apneic events lead to an increased negative intrathoracic pressure, from the normal level up to -80 mm Hg.[32] This leads to decreased preload, increased afterload, and intraventricular septal shift to the left, with a cumulative effect of further decreasing cardiac output.[33]

Hypoxia is another consequence of obstructive events, with a responsive pulmonary vasoconstriction that usually is not sustained during the day; however, repeated episodes can lead to right-ventricular hypertrophy.[34] Furthermore, secondary to either hypoxia or the change in intrathoracic pressure, a sympathetic surge accompanies the apneic event, exacerbating the underlying cardiac dysfunction.[1] This often leads to the complications of secondary arterial hypertension.[35]

Multiple small trials on the physiologic effects of continuous positive airway pressure (CPAP) have shown improved hemodynamic variables. Takasaki et al were the first to demonstrate that CPAP decreases intrathoracic pressure, sympathetic surge stimulation, and blood-pressure variability.[36] Moreover, CPAP improves ejection fraction by 8–10%, with clinical symptom improvement. These improvements were reversed with the removal of CPAP after follow-up for 1 week.[37–39] CPAP also decreases mitral regurgitation fraction, heart rate, and afterload.[37]

CSR/CSA commonly presents as a direct complication of CHF. CSR represents the oscillation of P_{aCO_2} above and below the level that causes apnea. The mechanism is thought to be the stretch of J receptors in the lung, secondary to pulmonary edema, which leads to initial hyperventilation. An apneic period follows after CO_2 reaches a threshold level, only to be followed by a period of hyperventilation to compensate for the rising CO_2. This cycle then repeats itself.[40] In contrast to OSA, these apneas are secondary to increased ventilatory drive, as opposed to the effort in OSA to terminate the apnea.[41] Nonetheless, CSR/CSA has similar hemodynamic consequences, secondary to increased sympathetic stimulation from apnea, hypoxia, arousals, and CO_2 retention.[41]

Risk factors for CSR/CSA in CHF patients include a body mass index > 35 kg/m^2 and age > 60 years.[42] The Framingham Heart Study discovered that, for reasons unknown, CSR/CSA is rarely found in women with CHF.[43] Similar to OSA patients, those with CSR/CSA rarely present with excessive daytime sleepiness.[28] Interestingly, there is a subgroup of patients who start the sleep period with OSA, which progresses to CSR/CSA late in the sleep period. This could represent a failing heart with increasing pulmonary pressure and edema leading to the activation of the oscillatory cycle of breathing and CSR/CSA.[41]

The treatment of both OSA and CSR/CSA has been reviewed in multiple trials that attempted to elucidate long-term effects. Until recently, the majority of trials concerning the use of CPAP for sleep-disordered breathing and CHF have been short in length (approximately 3 months) and with few patients. The majority of studies have focused on physiologic end points, as described above, and few studies have looked at clinical responses.

The Epworth Sleepiness Scale is often used as a clinical qualitative assessment of the amount of sleepiness a person experiences, and has been validated by multiple studies,[44] which showed improved physiologic outcomes, such as cardiac function and sympathetic stimulation. However, those improvements did not translate to a clinical change in blood pressure, NYHA classification, or maximum exercise capacity. A recent randomized controlled trial by Mansfield et al[45] attempted to show clinical benefit from CPAP in CHF, comparing variables such as changes in Epworth Sleepiness Scale, blood pressure, maximum oxygen consumption ($\dot{V}_{O_2max}$), and change in NYHA classification. Only a minimal change in Epworth Sleepiness Scale was found to be clinically important.[45] Nevertheless, the authors did note a significant change in quality-of-life assessments. Studies of CPAP intervention in patients with OSA and CHF are difficult because of ethical considerations. A large comparative trial with nontreatment of patients who have known OSA/CHF, or the use of sham CPAP, is ethically complex.[46]

In contrast to OSA, CSR/CSA and CHF has been more extensively studied, showing a clearer association as a consequence of the disease. Furthermore, there have been limited data to support the treatment of CSR/CSA in patients with CHF. This allows randomizing patients to treatment and nontreatment groups without ethical dilemmas. The respiratory drive consists of a balance of the control of peripheral and central chemoreceptors to changes in P_{CO_2}, P_{O_2}, and blood pH.[47]

Javaheri found that patients with CSR/CSA and CHF have an increased response to changes in CO_2, which translates to an overshoot in hyperventilation in patients who experience apnea events.[48] This accelerated respiratory

drive leads to a fall below the apneic threshold, which creates a cessation of breathing, a rise in CO_2, and repetition of the cycle.

Nocturnal oxygen therapy is effective in patients who have CSR/CSA and CHF. Hanly et al, in a one-night study, discovered that nocturnal oxygen improved oxygenation and sleep architecture and decreased sleep-disordered breathing.[49] Javaheri et al found that nasally administered oxygen, titrated up from 2 L/min to 4 L/min (based on desaturation below 90%) decreased the incidence of CSA.[50] Nocturnal oxygen decreases the incidence of sympathetic stimulation, which is a major determinant of poor prognosis in CHF.[51,52] Multiple mechanisms have been hypothesized to explain the effect of oxygen on CSR/CSA. Administration of oxygen increases P_{CO_2} by decreasing tidal volume and is hypothesized to increase ventilation-perfusion mismatch.[53,54] This rise in CO_2 allows a wider variation between the daytime CO_2 and apneic threshold, which decreases sleep-disordered breathing.

As with OSA, the use of CPAP for CSR/CSA has multiple physiologic effects. The majority of clinical trials have been limited to small groups of patients and short duration, and with varied results. However, a recent large randomized controlled trial (the CANPAP trial), which included 258 patients followed over a mean of 2 years, provided the first long-term-follow-up data. The patients were predominantly older, white, and male, and had ischemic cardiomyopathy and an average ejection fraction of 24%. Two thirds of the patients were in NYHA class II, and the rest were in NYHA class III or IV. Consistent with previous trials, early analysis showed an improvement in the occurrence of central apnea, increases in mean oxygen saturation, improved ejection fraction, and suppression of plasma catecholamine levels. However, the primary outcomes (death and cardiac transplantation) did not differ between the 2 groups with the use of CPAP. Furthermore, no difference was observed in morbidity measured by quality-of-life assessment and hospitalization.[55] These outcomes may reflect the difficulty in changing outcomes for patients who have a poor prognosis with CHF at this stage. Only one prior study reported a mortality benefit with the use of CPAP, and greater use of β blockers in the treatment group may have accounted for the difference.[56] By decreasing sympathetic surge, CPAP may have provided a nonpharmacologic benefit that vanished with the increased use of β blockade in the CANPAP trial. It remains speculative whether patients who have CSR/CSA and are intolerant of β blockers should be treated with CPAP.

Sleep-disordered breathing occurs in approximately half of patients who have chronic CHF, and the physiologic consequences are detrimental to the struggling cardiovascular system. The respiratory therapist (RT) becomes involved in providing means of support for patients who have both OSA and CSR/CSA. Positive-pressure ventilation improves physiologic variables in both groups, but no trials in OSA have shown a mortality benefit, and its use in CSR/CSA has not been proven beneficial.[55]

Patients with chronic CHF have decreased lung volume, decreased compliance, increased airway-closing pressure, increased work of breathing, and greater oxygen consumption.[57] These pathological effects lead to the progression and worsening of an already stressed system. Diffusion capacity is also altered by CHF, but the extent of the change in diffusion capacity depends on the timing of the disease. Acute CHF usually presents with an increased diffusion capacity secondary to intra-alveolar red blood cells, which increase the uptake of carbon monoxide. In contrast, patients with chronic CHF present with decreased diffusion capacity and a restrictive lung defect, which is probably from chronic interstitial edema and the resulting interstitial fibrosis.[58] Furthermore, this change in pulmonary mechanics is not reversed in patients who undergo cardiac transplantation.[59] Pulmonary rehabilitation improves quality of life and exercise capacity in patients with chronic heart failure.

Exacerbations of Heart Failure: Use of CPAP and NPPV

Acute pulmonary edema with respiratory distress is a common presentation to the hospital. The RT often becomes involved in NPPV, to prevent the need for intubation. The rationale for using CPAP and NPPV in acute pulmonary edema is that positive pressure may limit the decrease in functional residual capacity, improve respiratory mechanics and oxygenation, and decrease left-ventricular preload and afterload. Theoretically, NPPV could improve hypercarbia, with a greater decrease in work of breathing.[60] The patients who will most benefit from NPPV are probably those presenting to the emergency room and who have a narrow time-window for intervention. The skill of the RT is critical in improving synchrony between the patient and the NPPV device.

Pang et al performed the first meta-analysis concerning the use of positive-pressure airway support. They found a lower rate of intubation and a trend toward lower mortality with CPAP.[61] Later studies, however, failed to show a clear mortality benefit.[62–64] One of the early randomized controlled trials, by Mehta et al, raised the concern that NPPV might increase the rate of myocardial infarction, compared to CPAP.[65] However, the randomization of patients differed with the NPPV patients, such that there was a difference in the number of patients with chest pain (71% vs 31%), and several patients in the NPPV group had evidence of evolving myocardial infarct at the time of randomization. NPPV (at 15/5 cm H_2O) more rapidly improved dyspnea, arterial blood gases, and vital signs than did CPAP (at 10 cm H_2O).

Recently, a large randomized multicenter controlled trial ($n = 130$) by Nava et al compared NPPV to conventional therapy (oxygen and pharmacologic intervention) in an emergency-department setting.[66] Using a portable ventilator (PV102, Breas Medical, Mölnlycke, Sweden) and full face mask, a standardized protocol titrated the inspiratory pressure to the maximum tolerated, and expiratory pressure to a rise in oxygen saturation (initial settings 10/5 cm H_2O, average final settings 14.5/6.1 cm H_2O). Compared to standard medical treatment, NPPV significantly improved the respiratory rate, dyspnea score, and ratio of P_{aO_2} to fraction of inspired oxygen; however, there was no significant reduction in hospital mortality or need for intubation. In a subgroup analysis of hypercapnic patients, NPPV improved P_{aCO_2} significantly faster than did medical therapy, and significantly reduced the intubation rate. Adverse events, including myocardial infarction, were evenly distributed between the groups.

The RT must be aware of and communicate the common contraindications for CPAP and NPPV in the acute setting, including inability to cooperate, inability to protect the airway, inability to clear secretions, high risk for aspiration, and cardiovascular instability. Moreover, clinically the most critical factor is setting an end point for the determination of the need for invasive ventilation, thereby preventing an extended NPPV trial that could have cardiovascular consequences.

Summary

Chronic heart failure is a complex cardiac condition that encompasses several etiologies and comorbidities. It arises in the differential diagnosis in all adult patients who present with dyspnea and/or respiratory failure. Definitive diagnosis is established by a careful history and physical examination and supportive laboratory data. A chest radiograph is useful in excluding a pulmonary etiology (eg, pneumonia); however, a spiral computed-tomography angiogram may be required if the diagnosis of pulmonary emboli is entertained. The availability of measuring serum brain natriuretic peptide and bedside echocardiography has aided in our diagnostic precision. Therapy is primarily directed toward normalizing the underlying physiologic changes with ACE inhibitors and slow titration of β blockers. Diuretics are useful in reducing pulmonary vascular congestion, which may reduce or resolve dyspnea. Excessive therapy often reduces cardiac output or causes symptomatic hypotension, which occurs most commonly in patients with diastolic dysfunction. Treatment of the underlying etiology (silent ischemia or poorly controlled hypertension) may halt or slow the progression of the disease. Treatment of comorbidities (eg, underlying pulmonary disease, cigarette abuse, or diabetes) is essential in optimizing patient outcome and improving quality of life.

REFERENCES

1. Nadar S, Prasad N, Taylor RS, Lip GY. Positive pressure ventilation in the management of acute and chronic cardiac failure: a systematic review and meta-analysis. Int J Cardiol 2005;99(2):171–185.
2. Khand A, Gemmel I, Clark AL, Cleland JG. Is the prognosis of heart failure improving? J Am Coll Cardiol 2000;36(7):2284–2286.
3. Caruana L, Petrie MC, Davie AP, McMurray JJ. Do patients with suspected heart failure and preserved left ventricular systolic function suffer from "diastolic heart failure" or from misdiagnosis? A prospective descriptive study. BMJ 2000;321(7255):215–218.
4. McMurray JJ, Pfeffer MA. Heart failure. Lancet 2005;365(9474): 1877–1889.
5. Brausnwald E. Disorders of the heart: normal and abnormal myocardial function. In: Fauci AS, editor. Harrison's principles of internal medicine, 14th ed. New York: McGraw-Hill; 1998: 1278–1286.
6. Aurigemma GP, Gaasch WH. Clinical practice: diastolic heart failure. N Engl J Med 2004;351(11):1097–1105.
7. Kitzman DW. Exercise intolerance. Prog Cardiovasc Dis 2005;47(6): 367–379.
8. Mancini DM. Pulmonary factors limiting exercise capacity in patients with heart failure. Prog Cardiovasc Dis 1995;37(6):347–370.
9. Choudhury L, Gheorghiade M, Bonow RO. Coronary artery disease in patients with heart failure and preserved systolic function. Am J Cardiol 2002;89(6):719–722.
10. Jessup M, Brozena S. Heart failure. N Engl J Med 2003;348(20): 2007–2018.
11. Eichhorn EJ, Bristow MR. Medical therapy can improve the biological properties of the chronically failing heart: a new era in the treatment of heart failure. Circulation 1996;94(9):2285–2296.
12. Gehlbach BK, Geppert E. The pulmonary manifestations of left heart failure. Chest 2004;125(2):669–682.
13. West JB, Dollery CT, Naimark A. Distribution of blood flow in isolated lung: relation to vascular and alveolar pressures. J Appl Physiol 1964;19:713–724.
14. Malik A, Vogel SM, Minshall RD, et al. Pulmonary circulation and regulation of fluid balance. In: Murray JF, Nadel JA, Mason RJ, et al, editors. Textbook of respiratory medicine. Philadelphia: Saunders; 2000:19–54.
15. Tsukimoto K, Mathieu-Costello O, Prediletto R, Elliott AR, West JB. Ultrastructural appearances of pulmonary capillaries at high transmural pressures. J Appl Physiol 1991;71(2):573–582.
16. Davie AP, Francis CM, Caruana L, Sutherland GR, McMurray JJ. Assessing diagnosis in heart failure: which features are any use? QJM 1997;90(5):335–339.
17. Stevenson LW, Perloff JK. The limited reliability of physical signs for estimating hemodynamics in chronic heart failure. JAMA 1989; 261(6):884–888.
18. Nohria A, Lewis E, Stevenson LW. Medical management of advanced heart failure. JAMA 2002;287(5):628–640.
19. He J, Ogden LG, Bazzano LA, Vupputuri S, Loria C, Whelton PK. Risk factors for congestive heart failure in US men and women: NHANES I epidemiologic follow-up study. Arch Intern Med 2001; 161(7):996–1002.
20. de Denus S, Pharand C, Williamson DR. Brain natriuretic peptide in the management of heart failure: the versatile neurohormone. Chest 2004;125(2):652–668.
21. Maisel A. B-type natriuretic peptide measurements in diagnosing congestive heart failure in the dyspneic emergency department patient. Rev Cardiovasc Med 2002;3 Suppl 4:S10–S17.

22. Konstam MA. Progress in heart failure management? Lessons from the real world. Circulation 2000;102(10):1076–1078.

23. The SOLVD Investigators. Effect of enalapril on mortality and the development of heart failure in asymptomatic patients with reduced left ventricular ejection fractions. N Engl J Med 1992;327(10):685–691. *Erratum in: N Engl J Med 1992;327(24):1768.*

24. Abraham WT, Fisher WG, Smith AL, Delurgio DB, Leon AR, Loh E, et al; MIRACLE Study Group; Multicenter InSync Randomized Clinical Evaluation. Cardiac resynchronization in chronic heart failure. N Engl J Med 2002;346(24):1845–1853.

25. Bardy GH, Lee KL, Mark DB, Poole JE, Packer DL, Boineau R, et al; Sudden Cardiac Death in Heart Failure Trial (SCD-HeFT) Investigators. Amiodarone or an implantable cardioverter-defibrillator for congestive heart failure. N Engl J Med 2005;352(3):225–237. *Erratum in: N Engl J Med 2005;352(20):2146.*

26. Grady KL, Dracup K, Kennedy G, Moser DK, Piano M, Stevenson LW, Young JB. Team management of patients with heart failure: a statement for healthcare professionals from The Cardiovascular Nursing Council of the American Heart Association. Circulation 2000; 102(19):2443–2456.

27. Blackshear JL, Kaplan J, Thompson RC, Safford RE, Atkinson EJ. Nocturnal dyspnea and atrial fibrillation predict Cheyne-Stokes respirations in patients with congestive heart failure. Arch Intern Med 1995;155(12):1297–1302.

28. Javaheri S, Parker TJ, Liming JD, Corbett WS, Nishiyama H, Wexler L, Roselle GA. Sleep apnea in 81 ambulatory male patients with stable heart failure: types and their prevalences, consequences, and presentations. Circulation 1998;97(21):2154–2159.

29. Hanly PJ, Zuberi-Khokhar NS. Increased mortality associated with Cheyne-Stokes respiration in patients with congestive heart failure. Am J Respir Crit Care Med 1996;153(1):272–276.

30. Young T, Palta M, Dempsey J, Skatrud J, Weber S, Badr S. The occurrence of sleep-disordered breathing among middle-aged adults. N Engl J Med 1993;328(17):1230–1235.

31. The Report of an American Academy of Sleep Medicine Task Force. Sleep-related breathing disorders in adults: recommendation for syndrome definition and measurement techniques in clinical research. Sleep 1999;22(5):667–689.

32. Virolainen J, Ventila M, Turto H, Kupari M. Influence of negative intrathoracic pressure on right atrial and systemic venous dynamics. Eur Heart J 1995;16(9):1293–1299.

33. Buda AJ, Pinsky MR, Ingels NB Jr, Daughters GT 2nd, Stinson EB, Alderman EL. Effect of intrathoracic pressure on left ventricular performance. N Engl J Med 1979;301(9):453–459.

34. Berman EJ, DiBenedetto RJ, Causey DE, Mims T, Conneff M, Goodman LS, Rollings RC. Right ventricular hypertrophy detected by echocardiography in patients with newly diagnosed obstructive sleep apnea. Chest 1991;100(2):347–350.

35. Somers VK, Dyken ME, Clary MP, Abboud FM. Sympathetic neural mechanisms in obstructive sleep apnea. J Clin Invest 1995;96(4):1897–1904.

36. Takasaki Y, Orr D, Popkin J, Rutherford R, Liu P, Bradley TD. Effect of nasal continuous positive airway pressure on sleep apnea in congestive heart failure. Am Rev Respir Dis 1989;140(6):1578–1584.

37. Granton JT, Naughton MT, Benard DC, Liu PP, Goldstein RS, Bradley TD. CPAP improves inspiratory muscle strength in patients with heart failure and central sleep apnea. Am J Respir Crit Care Med 1996;153(1):277–282.

38. Kaneko Y, Floras JS, Usui K, Plante J, Tkacova R, Kubo T, et al. Cardiovascular effects of continuous positive airway pressure in patients with heart failure and obstructive sleep apnea. N Engl J Med 2003;348(13):1233–1241.

39. Malone S, Liu PP, Holloway R, Rutherford R, Xie A, Bradley TD. Obstructive sleep apnoea in patients with dilated cardiomyopathy: effects of continuous positive airway pressure. Lancet 1991; 338(8781):1480–1484.

40. Roux F, D'Ambrosio C, Mohsenin V. Sleep-related breathing disorders and cardiovascular disease. Am J Med 2000;108(5):396–402.

41. Bradley TD, Floras JS. Sleep apnea and heart failure: Part II: central sleep apnea. Circulation 2003;107(13):1822–1826.

42. Sin DD, Fitzgerald F, Parker JD, Newton G, Floras JS, Bradley TD. Risk factors for central and obstructive sleep apnea in 450 men and women with congestive heart failure. Am J Respir Crit Care Med 1999;160(4):1101–1106.

43. Ho KK, Pinsky JL, Kannel WB, Levy D. The epidemiology of heart failure: the Framingham Study. J Am Coll Cardiol 1993;22(4 Suppl A):6A–13A.

44. Johns MW. Daytime sleepiness, snoring, and obstructive sleep apnea. The Epworth Sleepiness Scale. Chest 1993;103(1):30–36.

45. Mansfield DR, Gollogly NC, Kaye DM, Richardson M, Bergin P, Naughton MT. Controlled trial of continuous positive airway pressure in obstructive sleep apnea and heart failure. Am J Respir Crit Care Med 2004;169(3):361–366.

46. Leung RS, Tkacova R, Bradley TD. Obstructive sleep apnoea (letter). Lancet 1999;354(9185):1212–1213.

47. Kohnlein T, Welte T, Tan LB, Elliott MW. Central sleep apnoea syndrome in patients with chronic heart disease: a critical review of the current literature. Thorax 2002;57(6):547–554.

48. Javaheri S. A mechanism of central sleep apnea in patients with heart failure. N Engl J Med 1999;341(13):949–954.

49. Hanly PJ, Millar TW, Steljes DG, Baert R, Frais MA, Kryger MH. The effect of oxygen on respiration and sleep in patients with congestive heart-failure. Ann Intern Med 1989;111(10):777–782.

50. Javaheri S, Ahmed M, Parker TJ, Brown CR. Effects of nasal O_2 on sleep-related disordered breathing in ambulatory patients with stable heart failure. Sleep 1999;22(8):1101–1106.

51. Andreas S, Bingeli C, Mohacsi P, Luscher TF, Noll G. Nasal oxygen and muscle sympathetic nerve activity in heart failure. Chest 2003; 123(2):366–371.

52. Cohn JN, Levine TB, Olivari MT, Garberg V, Lura D, Francis GS, et al. Plasma norepinephrine as a guide to prognosis in patients with chronic congestive heart failure. N Engl J Med 1984;311(13):819–823.

53. Andreas S, Plock EH, Heindl S, Scholz KH. Nasal oxygen effects on arterial carbon dioxide pressure and heart rate in chronic heart failure. Am J Cardiol 1999;83(5):795–798.

54. Javaheri S. Pembrey's dream: the time has come for a long-term trial of nocturnal supplemental nasal oxygen to treat central sleep apnea in congestive heart failure. Chest 2003;123(2):322–325.

55. Bradley TD, Logan AG, Kimoff RJ, Series F, Morrison D, Ferguson K, et al; CANPAP Investigators. Continuous positive airway pressure for central sleep apnea and heart failure. N Engl J Med 2005; 353(19):2025–2033.

56. Sin DD, Logan AG, Fitzgerald FS, Liu PP, Bradley TD. Effects of continuous positive airway pressure on cardiovascular outcomes in heart failure patients with and without Cheyne-Stokes respiration. Circulation 2000;102(1):61–66.

57. Lenique F, Habis M, Lofaso F, Dubois-Rande JL, Harf A, Brochard L. Ventilatory and hemodynamic effects of continuous positive airway pressure in left heart failure. Am J Respir Crit Care Med 1997; 155(2):500–505.

58. Wright RS, Levine MS, Bellamy PE, Simmons MS, Batra P, Stevenson LW, et al. Ventilatory and diffusion abnormalities in potential heart transplant recipients. Chest 1990;98(4):816–820.

59. Mettauer B, Lampert E, Charloux A, Zhao QM, Epailly E, Oswald M, et al. Lung membrane diffusing capacity, heart failure, and heart transplantation. Am J Cardiol 1999;83(1):62–67.

60. Liesching T, Kwok H, Hill NS. Acute applications of noninvasive positive pressure ventilation. Chest 2003;124(2):699–713.

61. Pang D, Keenan SP, Cook DJ, Sibbald WJ. The effect of positive pressure airway support on mortality and the need for intubation in cardiogenic pulmonary edema: a systematic review. Chest 1998; 114(4):1185–1192.

62. Masip J, Betbese AJ, Paez J, Vecilla F, Canizares R, Padro J, et al. Non-invasive pressure support ventilation versus conventional oxygen therapy in acute cardiogenic pulmonary oedema: a randomised trial. Lancet 2000;356(9248):2126–2132.

63. Philip-Joet FF, Paganelli FF, Dutau HL, Saadjian AY. Hemodynamic effects of bilevel nasal positive airway pressure ventilation in patients with heart failure. Respiration 1999;66(2):136–143.

64. Takeda S, Takano T, Ogawa R. The effect of nasal continuous positive airway pressure on plasma endothelin-1 concentrations in patients with severe cardiogenic pulmonary edema. Anesth Analg 1997; 84(5):1091–1096.

65. Mehta S, Jay GD, Woolard RH, Hipona RA, Connolly EM, Cimini DM, et al. Randomized, prospective trial of bilevel versus continuous positive airway pressure in acute pulmonary edema. Crit Care Med 1997;25(4):620–628.

66. Nava S, Carbone G, DiBattista N, Bellone A, Baiardi P, Cosentini R,et al. Noninvasive ventilation in cardiogenic pulmonary edema: a multicenter randomized trial.Am J Respir Crit Care Med 2003; 168(12):1432–1437.
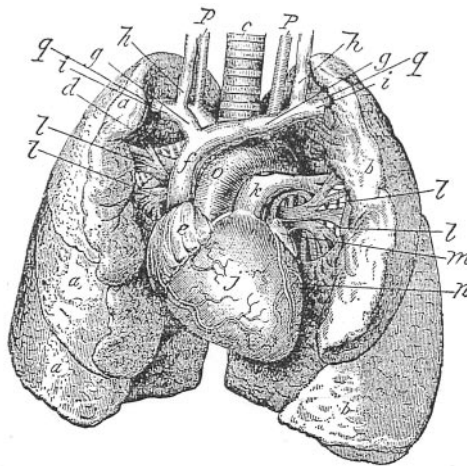
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