Anemia is a common comorbidity in patients with heart failure and is associated with worse long-term outcomes. Although the cause of anemia in heart failure is unclear, the weight of evidence suggests that renal dysfunction, along with neurohormonal and proinflammatory cytokine activation in heart failure, favors the development of anemia of chronic disease, with defective iron utilization, inappropriate erythropoietin production, and depressed bone marrow function. Similarly, the mechanisms by which anemia worsens heart failure outcomes are unknown but may be related to increased myocardial workload. If anemia is a mediator and not just a marker of poor outcomes, correcting anemia could become an important and novel therapeutic target to improve long-term outcomes in such patients. Indeed, several small-sized studies have shown the beneficial effects of empirically treating anemia in heart failure patients with recombinant erythropoietin and intravenous iron. However, the ideal threshold at which therapy should be initiated and the extent of correction considered safe and desirable in the individual patient with heart failure need to be known. These issues become more important because of increasing safety concerns that recombinant erythropoietin therapy for treating anemia may be associated with adverse cardiovascular outcomes in patients with chronic kidney disease and may worsen cancer in patients receiving chemotherapy to treat various types of cancer. Therefore, further prospectively designed studies are required to address some of these questions. Fortunately, 2 large mortality morbidity trials, TREAT (Trial to Reduce Cardiovascular Events with Aranesp Therapy) in patients with chronic kidney disease and RED-HF (Reduction of Events with Darbepoetin alfa in Heart Failure) in heart failure patients, are in progress and are likely to provide definitive answers. (J Am Coll Cardiol 2008;52:501–11) © 2008 by the American College of Cardiology Foundation

The annual mortality in patients with chronic heart failure (HF) who are randomized in clinical trials has shown a remarkable decrease to approximately 8% with the use of beta-blockers and renin-angiotensin-aldosterone antagonists (1). However, the mortality in clinical practice remains very high (2). One reason for this disparity is the exclusion of patients from clinical trials with comorbid conditions that contribute to high mortality. Anemia is one such comorbidity and a novel therapeutic target in HF. This review will summarize the magnitude of the problem of anemia in HF and examine the factors that are associated with the development of anemia and the mechanisms by which anemia may worsen HF. The risks and benefits of treating anemia with erythropoietin-stimulating agents (ESA), a subject of much recent debate, also will be discussed.

Prevalence of Anemia in HF

The World Health Organization defines anemia as hemoglobin (Hgb) <13.0 g/dl in men and <12.0 g/dl in women (3). Using this definition, Sarnak et al. (4) found 9% (men 5%; women 13%) of a normal population ages 45 to 64 years in the U.S. to have anemia. However, a more appropriate age-, gender-, and race-specific definition identified anemia in approximately 5% of the NHANES (National Health and Nutrition Examination Survey) population (5). The prevalence of anemia during HF varies depending on the definition and sample selection, as summarized in previous reviews (6–8). In clinical trials and large HF registries, the prevalence ranged from 15% to 61% and 14% to 70% among hospitalized patients. During the course of 1 year, new anemia developed in 9.6% of SOLVD (Studies Of Left Ventricular Dysfunction) patients (9), 16.9% of Val-HeFT (Valsartan Heart Failure Trial) patients (10), and 14.2% of COMET (Carvedilol Or Metoprolol European Trial) patients (11). The prevalence of anemia is similar in patients with impaired or preserved left ventricular (LV) function (12–15). In a large community study, 58% of HF patients had anemia of chronic disease, on the basis of International Classification of Diseases-9th Edition (285.9) code alone (16).
Anemia during HF has been associated with older age, diabetes, chronic kidney disease (CKD), greater New York Heart Association (NYHA) functional class, lower exercise capacity, worse health-related quality of life, greater edema, lower blood pressure, greater use of diuretics, and greater levels of neurohor-mones, proinflammatory cyto-kines, and C-reactive protein (CRP) (10,17–21). Importantly, Hgb has a weak inverse relation to ejection fraction (EF) (10,15), and an increase in Hgb over time is associated with a decrease, not an increase, in EF (10,22).

**Potential Causes of Anemia During HF**

Hematinic abnormalities. Serum vitamin B12 and folic acid levels are low in only a minority of anemic patients with HF (23–25). Malabsorption and aspirin-induced gastrointestinal bleeding can cause iron deficiency. Detailed studies of iron homeostasis are not available. Lacking standard criteria (i.e., transferrin saturation, soluble transferrin receptor or ferritin levels), the reported prevalence of iron deficiency has varied from 5% to 21% (16,17,23,24,26). In a recent study, 43% of patients had either low serum iron (<8 μmol/l) or ferritin (<30 μg/l), but microcytic anemia was observed in only 6% patients (27). In contrast, Nanas et al. (28) found depleted iron stores in the bone marrow of 73% patients despite normal serum iron, ferritin, and erythropoietin. The mean corpuscular volume was at the lower limit of normal, suggesting that microcytic anemia was not present in all patients. These findings might be explained by diversion of iron from the bone marrow to the other reticuloendothelial stores, where it is not available for erythropoiesis even though serum iron and ferritin are normal or increased, a feature of anemia of chronic disease (29). Therefore, either absolute or relative iron deficiency may be more common than previously thought.

Renal dysfunction and impaired erythropoietin production. Erythropoietin is produced primarily in the kidney by specialized peritubular fibroblasts situated within the cortex and outer medulla (30). The primary stimulus for erythropoietin production is low PO$_2$ that activates hypoxia-inducible factor-1 in the peritubular fibroblasts, which induces transcription of the erythropoietin gene. The kidney is very susceptible to hypoxia despite the fact that it receives nearly 25% of the cardiac output and uses less than 10% of the oxygen delivered. To maintain the osmotic gradient generated by the loop of Henle, the arterial and venous blood vessels supplying it run countercurrent and in close contact, which leads to shunt diffusion of oxygen between the arterial and venous circulations, causing PO$_2$ to decrease across the renal parenchyma, reaching around 10 mm Hg at the tips of the cortical pyramids where the erythropoietin is produced (30). This area is very sensitive to small changes in the PO$_2$, resulting from an imbalance between oxygen supply and oxygen demand related to increased proximal tubular sodium reabsorption caused by low renal blood flow (RBF) and glomerular filtration rate.

During HF, RBF is decreased (31), and some renal dysfunction is common (7,32), but structural renal disease that could reduce erythropoietin production is infrequent. Therefore, reduced RBF should increase erythropoietin. Indeed, erythropoietin is increased, in proportion to the severity of HF, but is lower than expected for the degree of anemia, suggesting a blunted erythropoietin production (17,33,34). Studies of the complex relationship between RBF and erythropoietin secretion during HF have been inconsistent (25,35,36).

Anemia and the renin–angiotensin system. Angiotensin II decreases PO$_2$ by reducing RBF and increasing oxygen demand, thereby stimulating erythropoietin production. Angiotensin II also stimulates bone marrow erythroid progenitor cells (37). Angiotensin-converting enzyme inhibitors and angiotensin receptor blockers cause a modest reduction in Hgb (10,38) by decreasing erythropoietin (39) and by preventing the breakdown of the hematopoiesis inhibitor N-acetyl-seryl-asparyl-lysyl-proline (40).

Proinflammatory state, bone marrow dysfunction, and anemia of chronic diseases. Tumor necrosis factor-α, interleukin (IL)-6, and several other proinflammatory cyto-kines (17,41) and CRP are increased in HF (42) and inversely related to Hgb (18). Interleukin-6 and tumor necrosis factor-α inhibit erythropoietin production in the kidney by activating GATA-2 and nuclear factor-κB (43), which could explain the blunted erythropoietin response in HF. These cytokines also inhibit proliferation of bone marrow erythroid progenitor cells (44). Indeed, bone marrow in rats with HF show impaired erythropoiesis and have decreased number of erythropoietic progenitor cells (44). Thus, an activated proinflammatory state, an essential component of anemia of chronic disease (29), can contribute to the development of anemia by several mechanisms (Fig. 1).

In 148 patients with stable HF, a specific cause of anemia was identified in only 43% of cases (17). Iron deficiency was found in only 5% of patients. In the remaining 57%, proinflammatory cytokine activation, inadequate erythropoietin production, and/or defective iron utilization was found despite adequate iron stores,
suggesting anemia of chronic disease (29). Therefore, anemia of chronic disease could be the most frequent cause of anemia during HF. Hemodilution. Anemia might be due to hemodilution (25,46). Androne et al. (46) found that nearly one-half of the clinically euvoletic patients referred for cardiac transplant had hemodilution induced “pseudoanemia.” However, others have found that clinically euvoletic patients have normal plasma volume (47).

Compensatory mechanisms and pathophysiological consequences of anemia. Nonhemodynamic responses to anemia include increase in erythropoiesis to enhance oxygen carrying capacity, and increase in RBC 2,3-diphosphoglycerate that shifts the hemoglobin-oxygen dissociation curve to the right and improves oxygen delivery to the tissues (48). Because erythropoiesis is defective in HF, hemodynamic responses may predominate. In chronic severe anemia, low Hgb reduces systemic vascular resistance (SVR) (49) as the result of decreases in blood viscosity and enhanced nitric oxide-mediated vasodilation (50,51). Low SVR reduces blood pressure (BP) and causes baroreceptor-mediated neurohormonal activation (49), identical to that seen in low output HF (31,52). The increased sympathetic and renin-angiotensin activity decreases RBF and glomerular filtration rate, resulting in salt and water retention by the kidneys and expansion of the extracellular and plasma volumes. The combined effect of volume expansion and vasodilation increases the cardiac output (49), which may help to increase oxygen transport (53). Correction of anemia in patients with normal LV function causes a rapid and complete regression of the syndrome of high output HF (49,51). Although these hemodynamic and neurohormonal responses were observed in patients with severe anemia, it is unclear whether these mechanisms are also operative in HF patients with less severe anemia. However, similar changes have also been reported in CKD patients with mild-to-moderate anemia. McMahon et al. (22) found that in patients with CKD,
when Hgb was increased progressively from 8.5 to 10 to 14 g/dl with epoetin, the cardiac output (7.0 to 6.6 to 5.2 l/min) and the LV fractional shortening (36% to 33% to 29%) decreased significantly. Therefore, these data suggest that correction of anemia is unlikely to improve LV function. The possible sequence of events in the pathogenesis of HF in anemia is shown in Figure 2.

Implications of Anemia and Lower Hemoglobin on Outcomes

Anemia and low Hgb have consistently been shown to be independently associated with increased risk of mortality and hospitalizations for HF in acute and chronic HF with LV dysfunction. The data are summarized in recent reviews (6–8). Anemia increased the relative risk of death in these studies by 20% to 50%. A similar relationship has also been shown in patients with preserved LV function (13–15,54). New-onset anemia and a decrease in Hgb over time are also associated with increased mortality (9,10).

The association of Hgb with mortality is not linear, and most of the increased risk occurs at low Hgb concentrations (10,11,55). In Val-HeFT, the risk of death were nearly identical in the 2 upper Hgb quartiles, 13.7 to <14.7 g/dl and >14.7 g/dl, whereas increased risk was found in the lower 2 Hgb quartiles (<12.8 g/dl) and (12.8 to <13.7 g/dl) (10). Some studies have reported a “J”-shaped relationship between Hgb and mortality in the normal population (56), patients with coronary artery disease (57), acute coronary syndromes (58), and HF (54,55). The lowest mortality risk was observed in the Hgb range of 13 to 16 g/dl and the risk increased with Hgb concentrations below or above this range. Thus, the concern that excessive increases in hemoglobin may be associated with increased mortality.

Why Is Anemia Associated With Poor Outcomes?

The increased myocardial workload due to hemodynamic and neurohormonal alterations observed in chronic anemia (49) could cause adverse LV remodeling. LV hypertrophy and dilation are observed in animal models of severe anemia (59,60), and they may contribute to poor outcomes. Whereas LV hypertrophy is consistently found in anemic patients with CKD, it is unclear whether it is related to anemia or hypertension (61). Although there are no data directly linking LV hypertrophy and anemia in HF, a 1-g/dl increase in Hgb over the course of 24 weeks was associated with a 4.1-g/m² decrease in LV mass in the RENAISSANCE (Randomized Etanercept North American Strategy to Study Antagonism of Cytokines) trial (19). However, treatment of anemia with ESA does not reverse LV hypertrophy in CKD (61). Hemoglobin may be inversely related to EF (10,15,22), and whereas anemia is related to brain natriuretic peptide (BNP), a marker of LV dysfunction, anemia remains an independent predictor of adverse outcomes in the presence of BNP and EF, suggesting that these variables
may have their effect through different mechanisms (10). Taken together, these findings suggest that changes in LV structure and function might not entirely explain the pathogenesis of worse outcomes in anemia.

Chronic kidney disease is a common comorbidity in HF patients with anemia (7,20), and both anemia and renal dysfunction remain independent predictors of outcomes in multivariate models (10,15,20). The relative risk of death at 2 years was increased by a factor of 1.6 in anemic patients with heart failure who also had CKD in a large Medicare database (62). In addition, anemia is often associated with poor nutritional status, low albumin (10,15), and cardiac cachexia (63), all of which could worsen outcomes. Finally, anemic patients have worse neurohormonal and proinflammatory cytokine profile that may also contribute to worse outcomes (18,41,49). Thus, although anemia may be related to a worse prognosis through multiple mechanisms, it is not clear whether anemia is a mediator or just a marker of poor outcomes.

**Treatment Options**

Because anemia is strongly associated with poor clinical status and high mortality, it is logical to consider whether correcting anemia can improve outcomes. Only a few options are available to increase Hgb. Although blood transfusion can be used as an acute therapy, transfusions are associated with many risks and provide only temporary benefit (64). The correction of hematocrit abnormalities might help; however, most patients are thought to have anemia of chronic disease, where stimulating erythropoiesis with ESAs is a rational strategy. Several small studies in HF have tested the effects of increasing Hgb with ESAs. Three studies investigated epoetin alfa, 1 study used epoetin beta, and 3 examined darbepoetin alfa (Table 1).

Silverberg et al. (65) were the first to report the effect of epoetin alfa and intravenous (IV) iron in 26 patients with anemia and HF. An increase in Hgb was associated with improvements in NYHA functional class and LV ejection fraction and decreases in diuretic dose and hospitalizations. A year later, the same authors reported the result of another study (66) in 32 patients with anemia and HF, randomized to usual care (n = 16) or epoetin alfa and IV iron sucrose (n = 16) that confirmed the findings of the previous study. Although they are difficult to interpret because of the small number of patients studied and the uncontrolled open-label design, these pioneering studies lead to a great interest in the treatment of anemia during HF.

Mancini et al. (67) conducted a patient-blind randomized study in 26 HF patients with anemia and erythropoietin <100 μU/mL. Patients were randomized 2:1 to epoetin alfa plus oral iron and folate, to increased hematocrit (Hct) to >45% or to placebo. After 3 months, Hgb, peak VO2, and 6-min walk distance (6MWD) increased, and Minnesota Living with Heart Failure Questionnaire (MLHFQ) scores improved in treated patients with no changes in the placebo group. Recently, Palazzuoli et al. (68) reported the effects of epoetin beta and oral iron on LV structure and function, pulmonary artery pressure, and BNP in 51 anemic HF patients with CKD (68). Patients were randomized to subcutaneous epoetin beta (n = 26) or saline (n = 25) for 1 year. After 12 months, Hgb increased; LV dimensions, volume, and mass decreased; and EF increased in the epoetin group with no change in the control group. The pulmonary artery pressure and BNP also decreased in the epoetin group.

A randomized, double-blind, placebo-controlled trial on 41 HF patients with anemia and a peak VO2 ≤16 ml/kg/min, assigned subjects to placebo (n = 22) or darbepoetin alfa (n = 19) for 26 weeks (69). Although the mean Hgb increased significantly in the darbepoetin group, the mean changes in peak VO2, exercise duration, Kansas City Cardiomyopathy Questionnaire and MLHFQ scores, BNP, and renal function were not different between treatment groups. A multicenter, double-blind placebo-controlled trial included 165 HF patients who were randomized to placebo (n = 55) or darbepoetin given every 2 weeks for 26 weeks at a weight-adjusted (n = 56) or fixed dose (n = 54) (70). The increase in Hgb in the combined darbepoetin groups was associated with improvement in Kansas City Cardiomyopathy Questionnaire total symptom score, but not in NYHA functional class, EF, MLHFQ score, 6MWD, or Patient’s Global Assessment score. There were 6 deaths in the 110 darbepoetin and none in the 55 placebo group. Other adverse events were similar between groups. STAMINA-HeFT (Study of Anemia in Heart Failure-Heart Failure Trial) is the third and largest study in the darbepoetin program (71). In this multicenter, randomized double-blind placebo controlled study, 319 HF patients were randomized to darbepoetin and iron to maintain the Hgb at 14.0 ± 1.0 g/dl (n = 162) or placebo (n = 157) every 2 weeks for a year. At week 27, despite a significant increase in Hgb, the primary end point of change from baseline in treadmill exercise time was not improved, nor was there any improvement in NYHA functional class or MLHFQ score compared with placebo.

A prespecified pooled analysis of the aforementioned 2 trials showed that compared with placebo, treatment with darbepoetin was associated with a trend to lower composite end point of all-cause mortality or first HF-related hospitalization with hazard ratio (95% confidence interval) of 0.67 (0.44 to 1.03), p = 0.06, all-cause mortality 0.76 (0.39 to 1.48), p = 0.42, and hospitalization for HF 0.66 (0.40 to 1.07), p = 0.09 (72). The incidence of other adverse events including development of hypertension and myocardial infarction were similar in the 2 groups.

In summary, analysis of all the published ESA trials in HF reveal that the early small-sized, single center studies that lacked a placebo-controlled arm showed a remarkable improvement in clinical status and LV function when ESA was used to treat anemia. However, the 3 more recent double-blind, placebo-controlled, randomized trials with darbepoetin showed less impressive results. Erythropoietin-stimulating agents were generally well tolerated in the HF.
Table 1: Summary of All Published Studies That Have Tested the Effects of Erythropoietin-Stimulating Agents in Anemic Patients With HF

<table>
<thead>
<tr>
<th>Author, Year (Ref. #)</th>
<th>Study Design</th>
<th>Inclusion Criteria</th>
<th>Patients (n)</th>
<th>Follow-Up Duration (months)</th>
<th>Baseline Hgb (g/dl)</th>
<th>Target Hgb (g/dl)</th>
<th>Achieved Hgb (g/dl)</th>
<th>Agents and Dose Used</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silverberg et al., 2000 (65)</td>
<td>Single-center, uncontrolled, open-label</td>
<td>EF &lt; 35, Hgb &lt; 12 g/dl</td>
<td>26</td>
<td>7.2 ± 5.5</td>
<td>10.2</td>
<td>12.0</td>
<td>12.1</td>
<td>S/C epoetin alfa (mean 5,277 IU/week) + IV iron sucrose (mean 185 mg/month)</td>
<td>↓ NYHA functional class (3.7 ± 0.5 to 2.7 ± 0.7, p &lt; 0.05), ↓ LVEF (28 ± 5% to 35 ± 8%, p &lt; 0.001) Decrease in diuretic dose Decrease in hospitalizations</td>
</tr>
<tr>
<td>Silverberg et al., 2001 (66)</td>
<td>Single-center, randomized, no placebo, open-label</td>
<td>NYHA functional class III/IV, EF &lt; 40%, Hgb 10–11.5 g/dl</td>
<td>16 usual care, 16 EPO</td>
<td>8.2 ± 2.6</td>
<td>10.3</td>
<td>12.5</td>
<td>12.9</td>
<td>S/C epoetin alfa (4,000 IU 1–3× week) IV iron sucrose (200 mg/2× weeks)</td>
<td>↓ NYHA functional class, ↑ LVEF + 5.5% Decrease in diuretic dose Decrease in hospitalizations</td>
</tr>
<tr>
<td>Mancini et al., 2003 (67)</td>
<td>Single-center, single-blind, randomized, placebo-controlled</td>
<td>NYHA functional class II/IV, Hct &lt; 35%, 9 control, 17 EPO</td>
<td>3.0</td>
<td>11.0 ± 0.6</td>
<td>Hct &gt; 45%</td>
<td>14.3 ± 1.2</td>
<td>S/C epoetin alfa 15,000 to 30,000 IU/week + oral iron 325 mg and folate 1 mg OD</td>
<td>↑ Peak VO2 11.0 ± 0.8 to 12.7 ± 2.8 ml/kg/min Improvement in MLHFQ</td>
<td></td>
</tr>
<tr>
<td>Palazzuoli et al., 2003 (68)</td>
<td>Single-center, single-blind, randomized, placebo-controlled</td>
<td>NYHA functional class III/IV, EF &lt; 40%, Hgb 9.0–12.0 g/dl, serum creatinine 1.5–3.0 mg/dl</td>
<td>25 control, 26 beta EPO</td>
<td>12</td>
<td>10.4 ± 0.6</td>
<td>NA</td>
<td>12.4 ± 0.8</td>
<td>S/C epoetin beta 6,000 IU/2× week + oral iron 300 mg for 1 year</td>
<td>↑ LVEF, ↓ LV volumes, mass ↓ PAP and BNP No change in serum creatinine</td>
</tr>
<tr>
<td>Ponikowski et al., 2007 (69)</td>
<td>Multicenter, randomized, double-blind, placebo-controlled</td>
<td>Hgb 9.0–12.0 g/dl, peak VO2 &lt; 16 ml/kg/min</td>
<td>22 placebo, 19 darbepoetin</td>
<td>27 weeks</td>
<td>11.8 ± 0.2</td>
<td>13.0–15.0</td>
<td>13.9 ± 0.4</td>
<td>Darbepoetin alfa, 0.75 µg/kg Q2W + 200–300 oral iron if serum ferritin &lt; 800 ng/ml</td>
<td>Mean change in peak VO2 (45 ml/min, p = 0.27) or (0.5 ml/kg/min, p = 0.40) Ex duration 108 s (p = 0.08), ↑ PGA (79% vs. 41%, p = 0.01) No change in KCQ/MLHFQ</td>
</tr>
<tr>
<td>van Veldhuisen et al., 2007 (70)</td>
<td>Multicenter, randomized, double-blind, placebo-controlled</td>
<td>Hgb &gt; 9.0 and &lt; 12.5 g/dl, NYHA functional class II/III CHF, LVEF &lt; 40%</td>
<td>55 placebo, 56 darbepoetin (weight based), and 54 darbepoetin (fixed dose)</td>
<td>27 weeks</td>
<td>11.5</td>
<td>14 ± 1.0</td>
<td>13.3</td>
<td>Darbepoetin weight adjusted 0.75 µg/kg vs. fixed dose 50 µg vs. placebo Q2W + oral iron (200 mg OD if serum ferritin &lt; 800 ng/ml)</td>
<td>Rate of rise Hgb 1.87 vs. 1.64 g/dl in weight-based vs. fixed dose (p = 0.07), improvement in KCQ (p &lt; 0.03), no significant improvement in 6MWD (p = 0.074), patients global assessment (p = 0.057), NYHA functional class, LVEF, or MLHFQ score</td>
</tr>
<tr>
<td>Ghali et al., 2008 (STAMINA-HeFT) (71)</td>
<td>Multicenter, randomized, double-blind, placebo-controlled</td>
<td>Hgb &gt; 9.0 and &lt; 12.5 g/dl, NYHA functional class II/III CHF, LVEF &lt; 40%</td>
<td>157 placebo, 162 darbepoetin</td>
<td>27 weeks for efficacy 55 weeks for safety</td>
<td>11.4</td>
<td>14 ± 1.0</td>
<td>13.4 at 27 weeks, 13.4 at 53 weeks</td>
<td>Darbepoetin dose 0.75 µg/kg Q2W vs. placebo + oral iron (200 mg OD if serum ferritin &lt; 800 ng/ml)</td>
<td>No significant difference in exercise duration, NYHA functional class or quality of life scores at 27 weeks but trend to a decrease in the combined end point of death and hospitalization for HF</td>
</tr>
<tr>
<td>van Veldhuisen and McMurray 2007 (72)</td>
<td>Combined safety analysis</td>
<td>Hgb &gt; 9.0 and &lt; 12.5 g/dl, NYHA functional class II/III CHF, LVEF &lt; 40%</td>
<td>209 placebo, 266 darbepoetin</td>
<td>55 weeks</td>
<td>11.4 ± 0.8</td>
<td>14 ± 1.0</td>
<td>13.4</td>
<td>Darbepoetin dose 0.75 µg/kg or 50 µg vs. placebo Q2W + oral iron (200 mg OD if serum ferritin &lt; 800 ng/ml)</td>
<td>Trend to a decrease in the combined endpoint of death and hospitalization for HF (hazard ratio) and 95% confidence interval for darbepoetin vs. placebo 0.67 (0.44 to 1.03), p = 0.06</td>
</tr>
</tbody>
</table>

CHF = congestive heart failure; EF = ejection fraction; EPO = epoetin; Hct = hematocrit; HF = heart failure; Hgb = hemoglobin; IV = intravenous; KCQ = Kansas City Cardiomyopathy Questionnaire; LV = left ventricular; MLHFQ = Minnesota Living with Heart Failure Questionnaire; NYHA = New York Heart Association; OD = once daily; PAP = systolic pulmonary artery pressure; PGA = Patient’s Global Assessment; Q2W = every 2 weeks; S/C = subcutaneous; 6MWD = 6-min walk distance.
patients with no significant increase in cardiovascular or other complications reported in the CKD and cancer population (73).

Are There Risks of Increasing Hemoglobin With ESA Therapy?

The second National Kidney Foundation Kidney Disease Outcomes Quality Initiative anemia guidelines recommended use of erythropoietin in CKD patients to a target Hgb of 11 to 13 g/dl to avoid blood transfusions and improve quality of life (74). In the 1990s, several trials were conducted to assess whether complete normalization of Hgb would produce additional benefits. The NHCT (Normal Hematocrit Cardiac Trial) study randomized 1,223 CKD hemodialysis patients to receive epoetin alfa to achieve a Hct of 45% versus 30% (75). The study was terminated early because of a trend to increased risk of the composite of death or nonfatal MI and greater incidence of vascular access thrombosis in the normal Hct group (39% vs. 29%, p = 0.001). More recently, 2 publications—CREATE (Cardiovascular Risk Reduction by Early Anemia Treatment with Epoetin Beta) (76) and CHOIR (Correction of Hemoglobin and Outcomes in Renal Insufficiency) (77)—have raised real concerns about the cardiovascular safety of greater Hgb with the use of ESAs in CKD patients. In CREATE, 603 patients (Hgb 11.6 ± 0.6 g/dl) were randomized to epoetin beta to normalize Hgb (13.0 to 15.0 g/dl) or use of epoetin only if Hgb decreased to <10.5 g/dl. There was a trend to increased mortality relative risk of 34% (p = 0.14) with the greater Hgb. In CHOIR, researchers randomized 1,432 patients (Hgb 10.1 ± 0.9 g/dl) to receive epoetin to achieve an Hgb of 13.5 or 11.3 g/dl. The trial was stopped early for presumed futility but showed a 34% (p = 0.03) increase in the composite of death, myocardial infarction, hospitalization for HF, and stroke in the high Hgb group.

There are significant limitations with these trials, particularly CHOIR, regarding imbalance of cardiovascular disease at baseline, issues of dropout, and the use of high doses of erythropoietin (78). Nevertheles, a meta-analysis of 9 randomized trials, including the 3 mentioned previously, that compared different target Hgb concentrations (73), found an increase in all-cause mortality relatively by 17% (p = 0.03), arteriovenous access thrombosis by 34% (p = 0.0001) and poorly controlled BP by 27% (p = 0.004) in the high Hgb group. Therefore, until definitive data are available from well-conducted trials, clinicians should refrain from complete correction of anemia.

Researchers for the TREAT (Trial to Reduce Cardiovascular Events with Aranesp Therapy) study, a 4,000-patient, multicenter, double-blind, placebo-controlled trial in patients with CKD and type 2 diabetes mellitus, have completed enrollment (79). Subjects are randomized to either darbepoetin to a target Hgb of 13 g/dl or placebo and darbepoetin for Hgb <9 g/dl until Hgb is >9 g/dl. The primary end point is the time to mortality and nonfatal cardiovascular events. The accumulated safety database in TREAT already exceeds all previous ESA trials, and the Data Safety Monitoring Board has not recommended any change in its conduct (80). The results of TREAT are likely to provide definitive information regarding the role of ESAs in the management of patients with anemia and CKD.

Meanwhile, on the basis of all the safety data from ESA therapy, the Food and Drug Administration updated the “black box warning” in the prescribing information for all ESAs in November 2007 and revised the dosing recommendations for anemic patients with CKD to maintain Hgb within 10 to 12 g/dl to avoid use of blood transfusion, and removed the previous quality of life claim (81).

Mechanisms of the Observed Adverse Effects in CKD Patients

The greater risk of developing poorly controlled BP in CKD patients randomized to achieve higher Hgb with ESAs (73) could have contributed to worse cardiovascular events. Increase in BP at higher Hgb is explained on increased viscosity and reduced nitric oxide availability (49,51). Other possible mechanisms include increase in vascular cytosolic calcium (82), and endothelin-1 and tissue-specific renin-angiotensin activity (83,84) associated with erythropoietin use. Greater viscosity and erythropoietin associated anti-fibrinolytic activity may increase thrombotic risk (85).

Correcting anemia in HF is a tradeoff between the favorable effects of improving oxygen delivery and unfavorable effects of increasing viscosity and SVR on the BP, cardiac output and LV function. An increase in Hgb is associated with reduction in EF and an increase in BP (22,49,51). Hence, correction of anemia is unlikely to have a beneficial effect on LV function or hemodynamics. However, the small uncontrolled trials reported an increase in EF, and no increase in BP or thrombotic events were observed in any trial (65–68). Whether the potential benefit of correcting anemia are outweighed by harm can only be resolved with prospective, double-blind, placebo-controlled randomized controlled trials. Darbepoetin alfa is currently being tested in the RED-HF (Reduction of Events with Darbepoetin alfa in Heart Failure) trial, a large-scale, phase III morbidity and mortality trial (72). The results of this trial are likely to provide important information on the safety and efficacy of ESAs in patients with anemia and HF.

Nonerythropoietic Effects of ESA

Erythropoietin receptors are also present on the neurons, cardiomyocytes, and endothelial cells (86). Several studies have confirmed that ESAs decrease experimental infarct size, reduce hypoxic injury, prevent myocyte apoptosis, and mobilize endothelial progenitor cells, independent of increases in Hgb (87–89). It is therefore possible that the beneficial effects of ESA are related to their nonhemopoietic effects and not to an increase in Hgb. These findings have
lead to the design of 2 phase II studies, one in the U.S. (90) and another in Europe (91), to examine the effect of an ESA on LV structure and function in post-myocardial infarction patients.

Recently, a second receptor for erythropoietin that mediates tissue protection has been identified consisting of the common β receptor subunits, also known as CD 131, that is not within the erythropoietin receptor-binding domain and is present in the myocardium (92). Modification of erythropoietin by carbamylation of all its lysines to homocitrulline carbamylated erythropoietin caused the compound to completely lack erythropoietic activity but retain tissue protection (93). Carbamylated erythropoietin has been shown to prevent ischemia/reperfusion related apoptosis after myocardial infarction in vivo and in isolated cardiomyocytes in vitro (94). These agents could potentially provide myocardial protection in HF without the undesirable effects of erythropoietin. At present, there are no clinical data in HF.

**Treatment of Anemia Using Iron Alone**

As discussed previously, either relative or absolute iron deficiency is frequently found in anemic HF patients. Iron is essential not only for erythropoiesis but also for several enzyme-linked bioenergetic processes in the skeletal muscle and in the Krebs cycle (95). Chronic iron deficiency may, by itself, reduce exercise capacity (96) and cause ultrastructural alterations in the cardiac myocytes (97). Therefore, IV iron alone may be beneficial in iron-deficient, anemic or non-anemic HF patients. Three studies have tested this hypothesis in patients with iron deficiency defined by transferrin saturation and ferritin levels. In an uncontrolled open-label study in 16 anemic (Hgb ≤12 g/dl) HF patients with iron deficiency in 44% of patients, IV iron sucrose was given for 12 to 17 days, and patients were followed for 92 ± 6 days (98). Iron treatment increased Hgb from 11.2 ± 0.7 g/dl to 12.6 ± 1.2 g/dl (p = 0.0007) and improved NYHA functional class, MLHFQ score, and 6MWD. The second study was a randomized, double-blind, placebo-controlled trial in 40 anemic HF patients (99). Control subjects (n = 20) received IV saline whereas the treatment group was given 200 mg of IV iron sucrose weekly for 5 weeks. After 6 months, Hgb increased by a mean of 1.4 g/dl (p < 0.01), and there was an improvement in creatinine clearance and MLHFQ score, decrease in CRP and N-terminal-proBNP, and increase in EF and 6MWD in the IV iron but not placebo group. The FERRIC-HF (Ferric iron sucrose in Heart Failure) (100) trial evaluated exercise capacity in iron-deficient anemic and nonanemic, HF patients with peak VO₂ ≥18 ml/kg/min. Eighteen anemic (Hgb <12.5 g/dl) and 17 nonanemic (Hgb 12.5 to 14.5 g/dl) patients were randomized to open-label, observer-blinded treatment with placebo or intravenous iron sucrose 200 mg/week for 4 weeks and then 200 mg/month for 3 months. Iron therapy increased serum ferritin and improved NYHA functional class but, unlike the previous 2 studies, Hgb did not increase. Peak VO₂ increased significantly in the anemic but not in the nonanemic group. Although these 3 small underpowered studies raise the possibility that iron therapy alone may have a role in anemic patients with HF, large randomized placebo-controlled trials are required to confirm these intriguing findings. One such trial, IRON-HF (Iron Supplementation in Heart Failure Patients With Anemia), is in progress (101).

It must be emphasized that iron therapy is not without risks and has been associated with the risk of developing bacteremia (102). Moreover, iron therapy in the setting of immune activation may promote highly toxic hydroxyl radicals that can cause tissue damage and endothelial dysfunction, and increase the risk of adverse cardiovascular outcomes (103).

**Implication for Clinicians**

None of the HF clinical practice guidelines from the U.S. or Europe currently discuss the assessment and management of anemia in HF. Given current evidence, the use of ESA and supplemental iron should only be considered in patients with concomitant CKD. The National Kidney Foundation KDOQI clinical practice guideline were updated in 2007 after publication of CREATE and CHOIR trials and recommend use of ESA to achieve a Hgb target in the range of only 11.0 to 12.0 g/dl (104). With the removal of the quality of life claim by the Food and Drug Administration, the only claim for the use of ESA is to improve exercise tolerance and functional ability of CKD patients (81). In HF patients, even these have not been convincingly shown to improve. Therefore, until long-term clinical outcomes data are available in HF patients with anemia, the use of ESA is not recommended in anemic patients with HF who do not have a CKD indication for its use.

**Conclusions**

Anemia is a common comorbidity in patients with HF and is associated with worse long-term outcomes. Although the cause of anemia in HF is unclear, the weight of evidence suggests that renal dysfunction and neurohormonal and proinflammatory cytokine activation in HF favor the development of anemia of chronic disease. Similarly, the mechanisms by which anemia worsens HF outcomes are unknown but may be related to increased myocardial workload. Although anemia is a rational therapeutic target to improve outcomes, there are as yet no convincing data regarding the efficacy and long-term safety of ESA. Further studies are required to understand the basis of the remarkable association of anemia with HF outcomes, to prospectively assess the potential benefit of correcting anemia, to evaluate the ideal threshold at which therapy should be initiated, and the extent of correction considered safe and desirable. Two large mortality morbidity trials, TREAT
CKD (79) and RED-HF (72) in HF, are in progress and may be able to provide answers to some of these questions.

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