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Risk Factors for Anemia in Preschool Children in Sub-Saharan Africa

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1. Introduction

Iron is a mineral that is found in nature and foods. It is involved in many physiological functions in the body, and poor iron intake can lead to iron deficiency and later to anemia. Iron deficiency anemia (IDA) is the most prevalent nutritional disorder in the world despite iron being the fourth most common element on earth. Anemia is amongst the most important contributing factors to the global burden of disease. According to a recent WHO report on the global prevalence of anemia, one in four people is affected by anemia worldwide (McLean et al., 2009; WHO, 2008), with pregnant women and preschool-age children at the greatest risk. Two thirds of preschool-age children are affected in developing regions of Africa and South East-Asia, and about 40% of the world's anaemic preschool-age children reside in South-East Asia (McLean et al., 2009; WHO, 2008). Of the 293.1 million children who suffer from anemia worldwide, 83 million (28%) are in sub-Saharan Africa, representing 67% of the total population of children of this age group in the continent.

Adverse health consequences of anemia in preschool children include altered cognitive function, impaired motor development and growth, poor school performance, poor immune function and susceptibility to infections, decreased in responsiveness and activity, increased in body tension and fatigue. Even before clinical symptoms are visible, iron deficiency that leads to anemia is detrimental to children and may condemn one third of the world population to live permanently below their full mental and physical potential. Indeed, the impact of iron deficiency anemia on psychomotor development and cognitive function in children under the age of two years may be irreversible despite adequate therapy (Lozoff et al., 2000). Horton & Ross (2003) estimated the median productivity lost due to iron deficiency anemia alone to be about US$2.32 per capita or 4.05% of gross domestic product (GDP). The authors estimated an additional US$14.46 per capita lost in cognitive function, for a total annual loss (cognitive & productive) of about $50 billion in GDP worldwide from iron deficiency anemia. Due to its detrimental effects among children, effective interventions

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to improve iron status and reduce the burden of anemia will likely promote health and development.

Anemia is preventable, yet it remains the most widespread nutritional deficiency in the world. Countries, which realized significant progresses in the control of the problem have identified contextual risk factors and implement context relevant programs. In sub-Saharan African, conditions which increase the risk for anemia in children are complex and multidimensional. A first step for evidence-based interventions and policies towards the control and elimination of iron deficiency anemia is a better understanding of these risk factors. The current chapter discusses the determinants of iron deficiency anemia in sub-Saharan Africa children.

2. Definition and conceptual framework

In the literature, the terms anemia, iron deficiency, and iron-deficiency anemia are often used interchangeably, but are not equivalent. Anemia is defined as a significant reduction in hemoglobin concentration, hematocrit, or the number of circulating red blood cells at a level below that is considered normal for age, sex, physiological state, and altitude, without considering the cause of the deficiency (Nestel et al., 2002). Iron deficiency anemia is a condition in which there is anemia due to lack of available iron to support normal red cell production. It is the third and last stage of iron deficiency which starts with depletion of iron stores as reflected by a reduced serum ferritin concentration. The second stage is iron deficient erythropoiesis, characterized by decreased serum iron, transferrin saturation and serum ferritin concentration but with a normal hemoglobin concentration. Because anemia can arise from nutritional factors and from non-nutritional ones, several terms are used to classify anemia, including nutritional anemia, anemia of infection, anemia of chronic diseases, pernicious anemia. For the purpose of this chapter, we focus on the first three that are the most common in developing countries, have modifiable risk factors and can be prevented through appropriate behavioral tailored intervention.

Several factors contribute concurrently in childhood anemia, but their relationships to the onset of anemia are not identical. Therefore, from an epidemiological perspective, it is important to distinguish between the different factors. A causal factor is linked to the onset of a disease or the condition and precedes the disease. A risk factor is an element linked to a person (biologic or hereditary), a behaviour, lifestyle or environment that increases the likelihood of developing the condition and has been found correlated with the condition in epidemiological studies (Last, 2004). When an intervention targeting a factor can reduce the likelihood of the condition developing, the factor is considered a modifiable risk factor. A factor susceptible to increase the onset of a pathological condition is a determining factor or determinant. For example the major causal factors of iron deficiency that lead to anemia are low dietary iron intake, inadequate iron absorption, chronic blood loss, and increased iron demand. However, there are several other factors (non causal relationship) that contribute to anemia including among others sociocultural factors, poverty, maternal factors, chronic conditions secondary to AIDS, tuberculosis and genetic factors such as sickle cell and thalassemia. There are several levels of stratification of anemia risk factors for children including structural and environmental level factors, community level factors, household level factors and individual health and nutrition related factors. Figure 1 summarizes the

multi-level risk factors of anemia in children in developing countries. There is an anthropological perspective that can be seen as a transverse risk factor.

3. Anthropological perspective

Anthropologists believed that agrarian revolution that resulted in changes in dietary behaviours and outbreak of infectious diseases about 10,000 years ago has played an important role in the emergence and spread of iron deficiency and anemia (Denic & Agarwal, 2008; Wander et al., 2009). According to this theory, meat was the main source of energy prior to agrarian revolution. When humans turned from hunting to agriculture, the diet became deficient in bioavailable iron, thus increased the prevalence of iron deficiency and its subsequent anemia. Cultivating plant-based foods has increased calorie intakes, but reduced meat consumption. As a result, iron intake became insufficient to meet individual daily requirements. According to Mann (2007), daily total iron intake decreased from 87 mg in the Palaeolithic age to 15 mg in the twentieth century. In addition, increased consumption of plant-based foods has reduced the intake of absorbable iron because the amount of non-heme iron and inhibitors of iron absorption has increased in the diet, while the amount of heme iron has decreased.

With sedentarization and animal husbandry, carriers of infectious diseases were able to be transmitted from animals to humans leading to emerging or re-emerging human infectious diseases. Thereafter, poor environmental and hygienic conditions, crowding and lifestyle changes have resulted in proliferation and spread of these carriers (Denic & Agarwal, 2007). Several studies suggested that mild to moderate iron deficiency may protect against acute infection (Oppenheimer, 2001; Prentice, 2008; Sazawal et al., 2006). Thus some authors put forward the hypothesis of a potential metabolic adaptation during which the human body self-regulates its iron to a deficiency status, the « iron-deficient phenotype », to prevent the severity of infections when re-infection is a continuous process (Denic & Agarwal, 2007). According to these authors, the important advancement in developed countries to control anemia are more likely due to the successful eradication of infections rather than the quality of diet. In malaria endemic areas such as Africa, the iron deficiency phenotype survived better over time (Denic & Agarwal, 2007; Wander et al., 2009). Therefore, iron substitution therapy in some population groups such as iron supplementation in children with no functional iron deficiency may cause more harm than good (Sazawal et al., 2006; WHO/UNICEF, 2006).

4. Dietary factors

The dietary risk factors for childhood anemia in developing countries include single or combined deficiency of micronutrients such as iron, folic acid, vitamin B6, vitamin B12, vitamin A and copper. Association has been found between anemia and deficiency of vitamin A, riboflavin, protein and other nutrients (Gamble et al., 2004, Semba & Bloem 2002; Thorandenya et al. 2006; Rock et al., 1988). Although nutritional factors are thought to be the most important contributing factors to childhood anemia, their exact contribution to the risk of anemia is not well established and may vary with the level of infection and the diet quality. Magalhaes & Clements (2011) estimated that about 37% of Anemia cases in preschool children in three West African countries namely; Burkina Faso, Ghana and Mali could be averted by treating nutrition related factors alone.
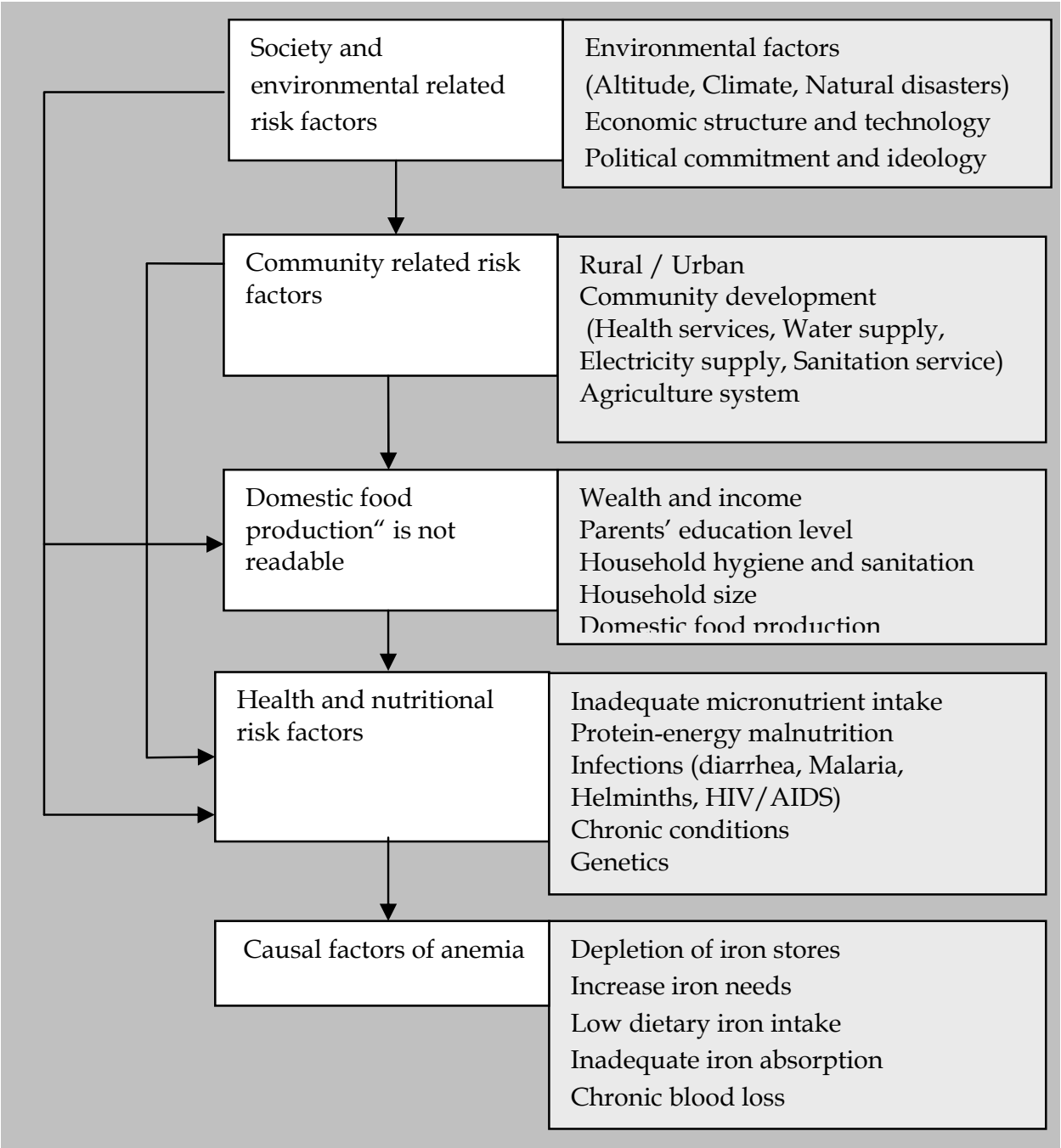
Fig. 1. Simplified conceptual framework for determinants of anemia among children (adapted from Ngnie-Teta et al, 2007).

4.1 Iron deficiency

The leading cause of anemia worldwide is iron deficiency due to inadequate intake or malabsorption of dietary iron. The adequacy of dietary iron depends on the intake and the bioavailability, which in turn are contingent to the nature of the food and the composition of the overall diet. In many developing countries, the amount of iron in the diet is usually enough to cover body needs, however because it is mainly provided by plant based food in the form of non-heme iron, its bioavailability is very low (Adish et al., 1998; Sanou et al., 2011; Zimmermann et al., 2005)

Iron is present in food in two forms: heme iron and non-heme iron. Heme is a component of hemoglobin and myoglobin and heme iron is mainly provided by animal tissues such as meat, poultry, fish and shellfish. Heme iron represents about 40% of animal tissue iron and is easily absorbed. However, it contributes to less than 15% of the total dietary iron, and may represent less than 1% in some countries where consumption of animal foods is very low (Monsen *et al.*, 1978). Most of the dietary iron is provided in the form of non-heme iron that is comprised of non-heme iron component of animal tissues, iron from eggs, milk and plant-based foods. The absorption rate of non-heme iron is very low and depends on iron status and combined effects of enhancers and inhibitors of iron absorption (Monsen et al., 1978). Enhancers of iron absorption include animal tissues (meat, poultry, and fish) and vitamin C and organic acids (Diaz *et al.* 2003; Reddy *et al.* 2000). Dietary factors that can reduce the absorption of iron (inhibitors) are phytates and some groups of polyphenols such as tannins (Reddy *et al.*, 2000; Sandberg et al., 1999), high intake of calcium and zinc (Lind *et al.*, 2003; Lynch, 2000), and cow's milk (Kibangou *et al.* 2005). Studies conducted in different regions of the world with high prevalence of anemia showed strong correlation between iron stores and absorbable iron intakes while there is no evidence of association between total iron intake, iron deficiency and anemia (Zimmermann *et al.*, 2005; Talata *et al.* 1998; Adish *et al.*, 1998).

4.2 Other micronutrient deficiencies associated with anemia

Other micronutrients are directly or indirectly involved in red blood cell metabolism. Vitamin B_6 (pyridoxal phosphate) for example is required for activation of Δ-aminolevulinic acid synthase that is necessary for heme synthesis. Vitamine B_9 (folate) and B_{12} (cobalamine) deficiencies result in immature erythrocyte leading to macrocytic anemia (Gropper *et al.*, 2005). Poor vitamin A status has been associated with Anemia (Gamble et al., 2004; Semba & Bloem 2002) and vitamin A supplementation has been shown to reduce the prevalence of Anemia (Semba *et al.*, 2001). Copper is an enzymatic cofactor of ceruloplasmin (ferroxydase) that is involved in iron mobilisation during the hemoglobin synthesis. Therefore, a deficiency of copper may contribute to iron deficiency anemia (Gropper *et al.*, 2005). It has been suggested that because of some similarities metabolic pathways of iron and zinc, high level zinc intake in the form of supplement may reduce the effectiveness of iron supplementation programmes aimed at reducing the burden anemia (Lind *et al.*, 2003).

4.3 Severe acute malnutrition

Acute malnutrition resulting from inadequate dietary intake of nutrients and/or from acute infection and disease may also lead to mild to moderate anemia. Several hypotheses have been put forward to explain the relationship between anemia and protein-energy malnutrition; 1) adaptation to lower tissue-metabolic requirements for oxygen transport, 2) the reduction of protein required for hematopoiesis and 3) the reduction of survival time of red blood cells and the maturation of the erythroblasts (MacDougall *et al.*, 1982). Some authors however consider that the anemia of PEM is the outcome of a complex haematological process in which iron and other micronutrient deficiencies interplay (Awasthi *et al.*, 2003).

5. Infections

Infections are the second most important cause of anemia after iron deficiency and contribute in some settings to up to 50% of the cases (Asobayire *et al.*, 2001; Stoltzfus *et al.*, 2000). Children are particularly affected by infection-related anemia because of their lower immune response

and their frequent exposure to poor sanitation and environmental conditions which favour the transmission and spread of parasites. Infections including malaria, hookworms, schistosomia, etc. are highly prevalent in developing countries and may negatively affect the nutritional status and growth of children. Studies conducted in many regions of Africa found positive associations between the presence and density of infection and chronic undernutrition, anemia and poor cognition (Brooker et al., 1999; Calis et al., 2008a; Friedman et al., 2005; Osazuwa et al. 2011; Sanou et al. 2008; Tolentino & Friedman, 2007). Regardless, the parasites or bacteria causing the anemia are different, all cases of anemia due to infection share some common pathways; 1) resulting iron deficiency through reduction of iron intake due to poor appetite and blood loss; 2) hemolysis i.e increased red blood cell destruction; 3) decreased red cells production and; 4) resulting inflammation. These mechanisms will be discussed later together with some pathways that are specific to each infection.

5.1 Malaria

The highest prevalence of childhood Anemia worldwide is found in malaria endemic regions. The WHO recent estimation of the global prevalence of anemia 1993-2005 suggested that between 31% and 90% of children in malaria-endemic areas of Africa suffer from anemia (WHO, 2008). Anemia is a common manifestation of the malaria infection and severe anemia can contribute to malaria mortality through hypoxia and cardiac failure (Memendez et al., 2000). Various *Plasmodium* species cause malaria, yet *P. falciparum* is the most critical for anemia in children. Contrary to iron deficiency anemia that develops slowly, *P. falciparum* causes severe and profound anemia within 48 hours of the onset of the fever. Other Plasmodium that can contribute to malaria include *P. vivax and P malariae*.

Table 1 shows the pathophysiology of malaria induced anemia. Philips and Pasvol (1992) summarized the pathophysiology of malarial anemia as follows, "anemia occurs when red cells are destroyed more rapidly than they can be replaced, or when red cell production falls below the minimal level required to maintain the steady state". Potential causes of increased red blood cell destruction include alteration of the red cell membrane rigidity and deformability, "loss of infected cells by rupture or phagocytosis, removal of uninfected cells due to antibody sensitization or other physico-chemical changes, and increased reticuloendothelial activity, particularly in organs such as the spleen" (Nuchsongsin et al., 2007; Park et al., 2008; Phillips & Pasvol, 1992). Factors leading to decreased red cell production include bone marrow hyploplasia and dyserythropoiesis. The severity of the malaria induced anemia is correlated with the density of the parasitaemia.

Although there is a consensus that clinical malaria causes severe anemia, there is limited evidence on the effect of asymptomatic malaria on severe anemia. While some authors reported that asymptomatic malaria does not significantly impact Haemoglobin level (Nkuo et al. 2002), some studies have demonstrated that asymptomatic malaria can cause homeostatic imbalance and lower Haemoglobin level in children (Kurtzhals et al. 1999); thus contributing to mild to moderate anemia (Price et al. 2001; Sowunmi et al., 2010; Umar et al. 2007). Imbalances of cytokines such as TNF-α, IL-6, IL-10 and IFN-γ resulting from malaria related-inflammation can induce changes in iron absorption and distribution, thus contributing to iron deficiency and subsequent iron deficiency anemia (Cercamondi et al., 2010; Shaw & Friedman, 2011). Bed net use is well documented as effective anemia prevention strategy (Korenromp et al., 2004, TerKuile, 2001). An exhaustive review of impact of malaria control on risk of anemia among children (Korenromp et al., 2004), estimates the protective effect of bed net on severe anemia to be 60%.

Mechanism	Comments
Increased erythrocyte destruction	
Non-immune mediated haemolysis	Rupture of parasitized red blood cells (PRBC) following invasion of RBC by malaria parasites
	Phagocytosis of parasitized (PRBC) and unparasitized red blood cells (NPRBC) due to proliferation and hyperactivity of macrophages in the reticuloendothelial system; thus shortening their life span
	Premature removal of NPRBC from the circulation due to reduce deformability and membrane binding of parasite components
	Increased clearance of parasitaemia due to splenic hypertrophy and hypersplenism (increased activity of the spleen that filters malaria infected RBC from the circulation)
Auto-immune haemolysis	Increased premature removal and clearance of unparasitized RBC due to immunoglobulin and complement activation leading to an extravascular haemolysis
	Hapten induced intravascular haemolysis due to the use of quinine that acts as a hapten combining with RBC protein to become antigenic
Decreased erythrocyte production	
Morphological abnormalities of the bone marrow	Aberrations of erythroblast morphology, macrophage hyperplasia, erythroid hypolasia and failure of reticulocyte release following a repeated attacks of malaria
Dyserythropoiesis	Morphological abnormalities of the eryhtroid series including multinuclearity of the normoblasts, intercytoplasmic bridging, karyorrhexis, incomplete and unequal mitotic nuclear divisions in some individuals with malaria
suppression of erythropoietin (EPO) synthesis	Suppression of EPO synthesis by inflammatory mediators such as TNF in some adults with malaria
Imbalances of cytokines (Inflammation induced anemia)	Bone marrow depression, dyserythropoeisis and erythrophagocytosis following low interleukine (IL-10 and IL-12) or excess of T helper cell type 1 (th1), cytokines THF-a et TNF-x, and nitric acid (NO)
Inflammation induced erythroid hypoplasia	Suppression of normal response to erythropoietin due to an autologous serum factor that may suppress the growth of early precursors of RBC including the burst-forming unit-erythron (BFU-E) and the colony-forming unit erythron (CFU-E).
Concomitant infections	Increased susceptibility to secondary infections due to reduced immune systems following malaria infection
Anti-malarial drugs	
Antifolate antimalarial	Megaloblastic anemia due to overdosing of pyremethamine and/or trimethoprim
	Quinine induced intravascular auto-immune haemolysis

Table 1. Pathophysiology mechanisms of malaria-related anemia (Memendez et al., 2000; Phillips & Pasvol, 1992).

Price et al. (2001) reported that treatment failure in uncomplicated malaria can lead to anemia. It has also been suggested that child undernutrition, particularly stunting modify the associations between malaria and anemia (Verhoef et al. 2002). Verhoef et al (2002) reported that stunting impairs host immunity, increases inflammation, and increases iron demand in developing erythroblasts, thus increasing the malaria-associated anemia.

5.2 Hookworms

Helminths are a group of intestinal nematodes that are recognized as a major public health problem in many developing countries. The effects on anemia are well documented for four species, namely trichomonas (*Trichuris trichiura)*, ankylostoma (*Necator americanus*, A*ncylostoma duodenale*), hookworm (*Hymelolepis nana*) and ascaris (*Ascaris lumbricoides*). It is believed that the burden of hookworm is the most important particularly on severe anemia and is mostly due to extracorporeal blood loss in the stools resulting from a parasite release of a coagulase in the blood. *A. duodenale* was found more harmful than *N. americanum* and Skeletee (2003) for example estimated that it can cause approximately 0.25 mL blood loss per parasite per day during pregnancy.

According to a study done in Kenyan preschool children, hookworm contributed to 4% of anemia cases in children and heavy infection with hookworm increases the risk of anemia by 5 (Brooker et al., 1999). However, the authors did not find any association between hookworm and hemoglobin concentration likely due to the relatively low prevalence of the infection. Indeed, the burden of hookworm is directly related to the intensity of infection, the infecting species and the individual's nutritional status.

Calis et al. (2008a) also reported that the likelihood of developing severe anemia was increased by 4.8 in hookworm infected Malawian preschool children. In West Africa, a risk mapping approach using geostatistical models estimated that 4.2% of anemia cases in preschool children could be averted by treating hookworm (Magalhaes & Clements, 2011). *Trichomonas trichiura*, the causal agent of Trichuris Dysentery Syndrome has been associated with growth failure and Anemia. The anaemic effect of *T. trichiura* is thought to be linked to the blood consumption by the worm, inflammation induced anemia and reduced dietary iron intake due to decreased appetite (Shaw & Friedman, 2011).

Intervention studies have shown positive associations between mass deworming and decreased prevalence of anemia, physical performance, cognitive scores, growth and general morbidity among children from developing countries. Further, there is evidence that effectiveness of iron interventions such as supplementation and dietary approaches may be reduced when activities aiming at controlling infections are not part of the strategies (Davidson *et al.*, 2005). Therefore, it is recommended to include deworming in interventions targeting iron status at the community level.

5.3 Human schistosomiasis

Three major species of schistosomiasis have been identified as the most prevalent worldwide and cause human disease. These species that are endemic in some rural areas of Africa include *Schistosoma haematobium S. mansoni and S. japonica* (Friedman et al., 2005; Dianou *et al.,* 2004). Although most attention has been on schoolchildren, some studies have examined the relationship between schistosomiasis and anemia in preschool children (Brooker et al., 1999; Magalhaes & Clements, 2011; Talata et al., 1998). Friedman et al. (2005) described four mechanisms underlying the relationship between schistosome infections and

anemia: 1) iron deficiency due to extracorporeal blood loss of iron; 2) splenic sequestration iii) auto-immune hemolysis and; 4) anemia of inflammation. It is also important to mention that infection may reduce appetite and disturb the intakes, absorption and metabolism of dietary iron.

5.4 HIV/AIDS

Anemia is a common hematological manifestation in Human immunodeficiency (HIV-infection), and has been identified as a marker for disease progression and survival (Calis et al., 2008b). A review of the global literature on HIV-related anemia in children by Calis et al. (2008b) revealed that mild to moderate anemia was more prevalent and hematocrit levels lower in HIV-infected children as compared to uninfected children. The authors also found that Anemia prevalence was higher in children with more advanced disease. However, blood loss and hemolysis are not common in HIV-infection. The suspected pathogenetic mechanisms for HIV-related anemia likely include decreased production of erythrocytes and subsequent inflammation. Further, based on findings from Uganda (Totin et al., 2002) and South Africa (Eley et al., 2002) that have suggested that iron deficiency anemia is equally affecting both HIV-infected and uninfected children, Shaw & Friedman (2011) concluded that HIV-related anemia is an Anemia of inflammation.

5.5 Bacteremia

The most common anemia inducing bacteria reported in the literature *is Helicobacter pylori* (Digirolamo *et al.* 2007; Dubois & Kearney 2005). *H. pylori* is thought to cause anemia through three mechanisms: 1) reduced iron absorption due to hypochlorhydria resulting from impaired secretion of gastric acid; 2) inflammation and; 3) competing iron demands of the bacteria and the host (Shaw & Friedman, 2011). Nontyphoid *Salmonella* has been also independently associated with anemia in children (Calis et al. 2008a; Dubois et al., 2005).

Although not investigated, it is possible that other species that can cause bloody dysentery such as *Shigella* and *Enteroinvasive E. coli* contribute to anemia. Comorbid conditions such as fever and respiratory infection often resulting from bacterial infection have been correlated with anemia (Stoltzfus *et al.,* 2000; Howard *et al.,* 2007). Diarrheal illness is associated with loss of iron and decreased absorption of nutrients needed to maintain normal Hb status. It is also likely that as demonstrated for other nutrient deficiencies, diarrhea shares many common causes with anemia (Tomkins, 1986).

Further due to the high susceptibility of HIV-infected children to opportunistic infection, bacteria may also act as synergetic factors in HIV-related anemia. A number of studies have reported biological synergisms between pathogens for disease progression (Ezeamama et al., 2008; Robertson et al., 1992). Ezeamama et al. (2008) investigated the effect of codistribution of schistosomiasis, hookworm and trichuris infection on paediatric anemia and found that hookworm and *S. japonicum* infections were independent risk factors for anemia and that co-infections of hookworm and either *S. japonicum* or *T. trichiura* were associated with higher levels of anemia than would be expected if the effects of these species had only independent effects on anemia. More recently, Magalhaes & Clements (2011) found that hookworm/S. haematobium coinfection significantly increased the likelihood of pediatric anemia as compared to individual infestation with one of these pathogens.

6. Inflammation and chronic diseases

Anemia of inflammation also termed the anemia of chronic disease (ACD) is the second most prevalent type of anemia after anemia of iron deficiency. It is observed in patients with chronic infectious disease (tuberculosis, meningitis, pulmonary infection to name a few), non-infectious chronic conditions (rheumatoid arthritis, Crohn disease, burn patients, etc.) or chronic neoplasic conditions (leukemia, carcinoma, Hodgkin disease, etc.) (Weiss & Goodnough, 2005). The pathophysiological mechanisms are not well understood, but it is believed that they are similar to the indirect pathways by which infection causes anemia. Anemia of chronic inflammatory diseases is immune driven and includes several pathways regulated by different immune and inflammatory mediators (Weiss & Goudnough, 2005):

- decreased red blood cell half-life because of dyserythropoiesis, red blood cell damage and increased erythrophagocytosis (TNF-α);
- inadequate erythropoietin responses for the degree of anemia in most, but not all (e.g. systemic-onset of juvenile chronic arthritis) (IL-1 and TNF-α);
- impaired responsiveness of erythroid cells to erythropoietin (IFN-γ, IL-1, and TNF-α);
- inhibited proliferation and differentiation of erythroid cells (IFN-γ, IL-1, TNF-α, and α-1-antitrypsin); and
- pathological iron homeostasis caused by increased DMT-1 (IFN-γ) and TfR (IL-10) expression in macrophages, reduced ferroportin 1 expression (IFN-γ and IL-6-induced high hepcidin levels) in enterocytes (inhibition of iron absorption) and macrophages (inhibition of iron recirculation), and increased ferritin synthesis (TNF-α, IL-1, IL-6, IL-10) (increased iron storage).

In a review published in New England Journal of Medicine, Weiss & Goudnough (2005) carefully discussed these mechanisms and summarized them in a single figure (Figure 2).

Recent studies have identified hepcidin as the main iron regulatory hormone in human (Andrews & Schmidt, 2007, Ganz, 2003). Hepcidin is an antimicrobial hormone that is synthesized in response to liver iron levels, inflammation, hypoxia and anemia. The persistence of inflammation results in excess hepcidin which in the circulation binds ferroportin on enterocytes and macrophages. The excess of hepcidin lowers iron absorption and prevents iron recycling, which results in hypoferremia and iron-restricted erythropoiesis, despite normal iron stores (functional ID), and anemia of chronic disease. In acute inflammation-related anemia (e.g. trauma or surgery), inflammatory responses are mediated by cytokine production mainly IL-6 and IL-8 (Weiss & Goudnough, 2005). Indeed, during inflammation, cytokines such as interleukin IL-6 stimulates the human hepcidin gene (HAMP) which in turns induces hepcidin secretion in the hepatocytes (Nicolas *et al.*, 2002; Nemeth *et al.*, 2004). In contrast, decreased hepcidin expression due to iron deficiency, anemia and hypoxia may lead to hereditary haemochromatosis (HH type I, mutations of the HFE gene) and type II (mutations of the hemojuvelin and hepcidin genes). In persisting iron deficiency due to decreased iron absorption and/or chronic blood loss, anemia of chronic disease evolves to anemia of chronic disease with a true iron deficiency (ACD + ID).

It is also important to keep in mind that the links between anemia and infection are bilateral and may be mutually beneficial. Indeed iron deficiency may protect against adverse effects of infections on iron status (Denic & Agarwal 2007; Sazawal *et al.*, 2006; Oppenheimer, 2001; Weinberg 1984).
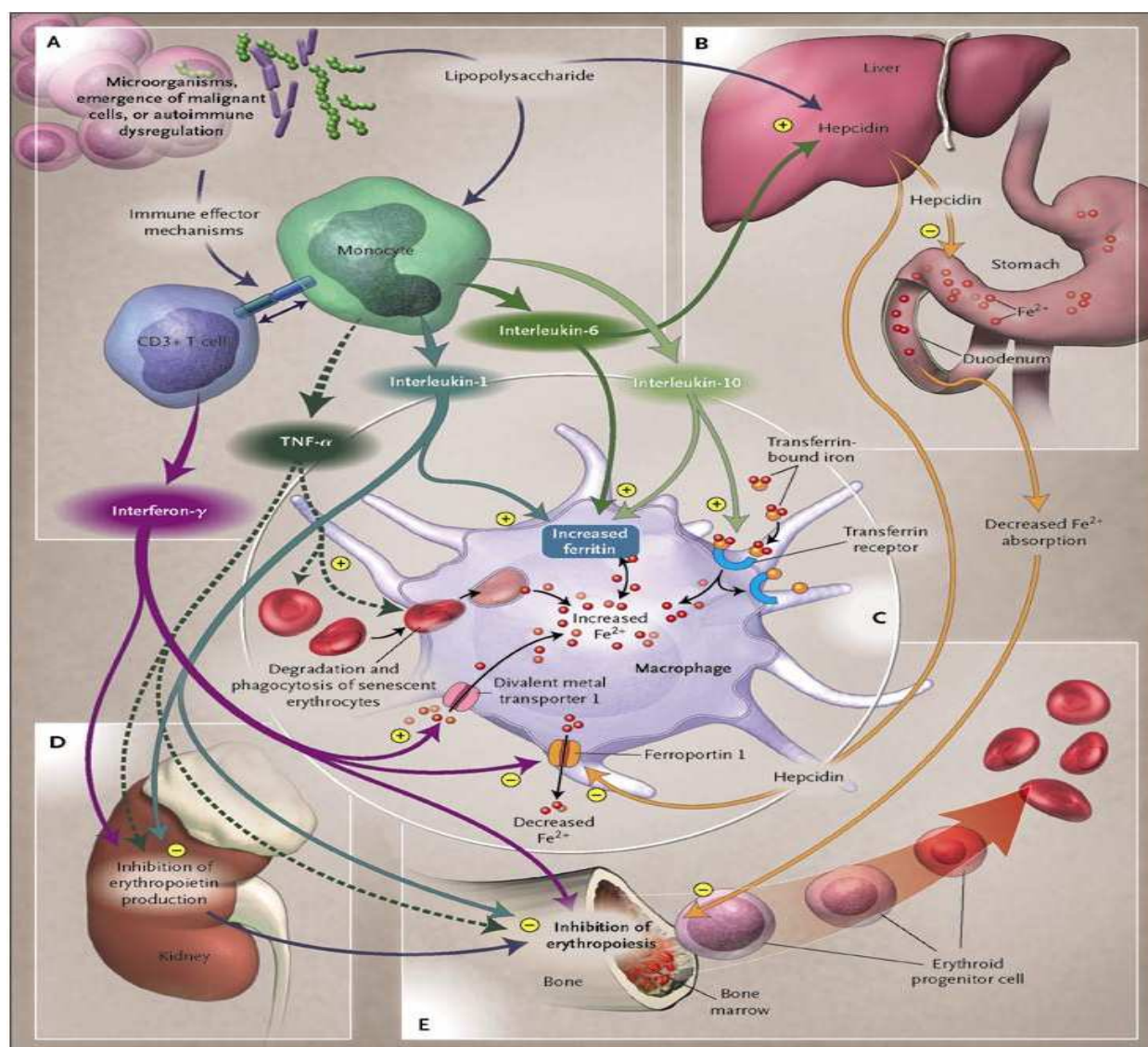
Fig. 2. Pathophysiological mechanisms of anemia of chronic diseases (Weiss & Goudnough, 2005) - reproduced with the permission from the authors and the New England Journal of Medicine -

In Panel A, the invasion of microorganisms, the emergence of malignant cells, or autoimmune dysregulation leads to activation of T cells (CD3+) and monocytes. These cells induce immune effector mechanisms, thereby producing cytokines such as interferon-γ (from T cells) and tumor necrosis factor α (TNF-α), interleukin-1, interleukin-6, and interleukin-10 (from monocytes or macrophages). In Panel B, interleukin-6 and lipopolysaccharide stimulate the hepatic expression of the acute-phase protein hepcidin, which inhibits duodenal absorption of iron. In Panel C, interferon-γ, lipopolysaccharide, or both increase the expression of divalent metal transporter 1 on macrophages and stimulate the uptake of ferrous iron (Fe2+). The antiinflammatory cytokine interleukin-10 up-regulates transferrin receptor expression and increases transferrin-receptor–mediated uptake of transferrin-bound iron into monocytes. In addition, activated macrophages phagocytose and degrade senescent erythrocytes for the recycling of iron, a process that is further induced by TNF-α through damaging of erythrocyte membranes and stimulation of phagocytosis. Interferon-γ and lipopolysaccharide down-regulate the expression of the macrophage iron

transporter ferroportin 1, thus inhibiting iron export from macrophages, a process that is also affected by hepcidin. At the same time, TNF-α, interleukin-1, interleukin-6, and interleukin-10 induce ferritin expression and stimulate the storage and retention of iron within macrophages. In summary, these mechanisms lead to a decreased iron concentration in the circulation and thus to a limited availability of iron for erythroid cells. In Panel D, TNF-α and interferon-γ inhibit the production of erythropoietin in the kidney. In Panel E, TNF-α, interferon-γ, and interleukin-1 directly inhibit the differentiation and proliferation of erythroid progenitor cells. In addition, the limited availability of iron and the decreased biologic activity of erythropoietin lead to inhibition of erythropoiesis and the development of anemia. Plus signs represent stimulation, and minus signs inhibition (Weiss & Goudnough, 2005).

7. Genetic polymorphisms

Some hemoglobinopathies such as sickle-cell disease, thalassaemias, glucose-6-phosphate deshydrogenase are common in many developing countries (Deyde et al., 2002; Simpore *et al.*, 2003; Thurlow *et al.*, 2005*)*. These disorders are particularly found in malaria endemic areas and have been associated with Anemia. Glucose-6-phosphate deshydrogenase for example is correlated with chronic haemolytic Anemia (Lang *et al.*, 2002; van Bruggen *et al.*, 2002).

Sickle cell Anemia is highly prevalent in West Africa, with a frequency of the trait of 15% to 30% (WHO, 2006). Many studies suggested that these red cell polymorphisms are a human body adaptation against adverse effects of malaria. Sickle cell for example results from genetic mutation of allele A in allele S or C of the β chain to provide resistance against *Plasmodium* effect (Modiano *et al.* 2008; Rihet *et al.* 2004). In Gambia and Burkina Faso, it has been reported that sickle-cell trait is associated with protection against malaria, malaria Anemia and even cerebral Anemia (Hill, 1991; Modiano et al., 2008). In central Burkina Faso, the prevalence is expected to increase if the malaria prevalence does not decrease (Modiano et al., 2008).

Data from the National Health and Nutrition Examination Survey» (NHANES I, II et III) of the USA consistently show hemoglobin levels of Black Americans are usually lower than for their white and hispanic counterparts at all ages, regardless of the iron, health et socioeconomic status (Johnson-Spear & Yip, 1995). This finding has resulted in an adjustment of Haemoglobin cut-off for population origin 1 g/L below the normal cut-off for other population groups (Nestel et al., 2002). Although the causes of this difference is not well established, it is hypothesized that high prevalence of hemoglobinopathies such as thalassaemias and chronic inflammations as well as other genetic disorders may be important contributing factors (Beutler & West, 2005).

8. Socio-economic risk factors

The socioeconomic status, commonly measured by household income and/or household assets is a key determinant of anemia. There is strong evidence that that children living in low income household are at greater risk of anemia compared to those with higher income. Limited access to food and poor sanitation are often correlated to low income and to some extent, explain the higher risk of anemia among these children (Osorio et al., 2004). Moreover, the diet of children living in poor families is usually monotonous, even when there is enough

food to eat. A study by Ag Bendech et al. (1996) in Burkina Faso showed that even though almost all the family enrolled were having three meals per day, only children from the wealthiest families were taken two or three different meals while their peers from middle income and poor households had the same meals for breakfast, lunch and dinner. The authors also reported that animal source foods which are rich in bioavailable iron were limited, contributing to only 9% of the total protein intake in poor households, 19% in middle income households and up to 41% in wealthiest households (Ag Bendech et al., 1996).

Parent's level of education constitutes another well documented determinant of anemia in children. Educated parents are more likely to have well paid job and also more likely to adopt healthier dietary behavior. In Brazil, Osorio's et al. (2004) found that mean hemoglobin level of children whose mothers attended secondary schools (9 years of schooling) was 11.5 g/dl, 11.2 for mothers with 5-8 years in school and 10.8 g/dl for mothers with less than 4 years of schooling. De Pee et al. (2002) report similar results among Palestinian children with risk of anemia twice higher for children from non-educated mothers. Even in developed countries, low level of education is associated with higher risk of anemia (Sargent et al., 1996; Soh et al., 2004).

Community level factors play an important role in the risk of anemia. Several studies have shown that living in rural areas increases the risk of child malnutrition (Kuate-Defo, 2001 ; Sommerfelt, 1991) and anemia (Bentley 2003; Osorio et al. 2001; Osorio et al., 2004; Ngnie-Teta et al., 2007). Altitude also affects the risk of anemia. Indeed, the amount of oxygen decrease with altitude, hence reducing the saturation ability of hemoglobin to capture oxygen (Cohen & Haas, 1999). This should be counterbalanced by an increased number of red blood cells. Therefore hemoglobin cut-offs have been adjusted for different age groups according to the altitude (Nestel *et al.,* 2002).

Due to increasing use of multilevel, modelling neighbourhood contribution to the risk of disease could now be quantified. A recent study in West Africa reported significant contribution of community factors of 14% to 19% to the prevalence of moderate-to-severe anemia (Ngnie-Teta et al., 2007; 2008). This reflects the variability in the risk of anemia attributable to the differences between communities, regardless of individual and households characteristics.

9. Conclusion

Anemia can result from deficiency of one or several micronutrients but also unfavourable environmental conditions and social determinants of health. Although quantitative and qualitative iron deficiency is thought to be the leading cause, infection such as malaria, schistosomiasis, hookworms, HIV and bacteria can contribute to up to 50% of the cases of anemia in developing regions where these conditions are common. Due to the multi-factorial conditions, the complexity of the risk factors of anemia, and potential interactions among them, a single strategy to control anemia in developing countries may have little success. Country level strategies to tackle anemia should include an emergency nutrition programme that will target severe anemia particularly in children under the age of two and children who live in rural areas, but also a broader nutrition and health programme that may to prevent and treat moderate to mild Anemia. Whatever strategy is used, nutrition education to increase animal sources in the diet where possible in order to enhance bioavailability of iron and to improve sanitation and basic hygiene are highly recommended as complementary measures.

10. Acknowledgement

11. References

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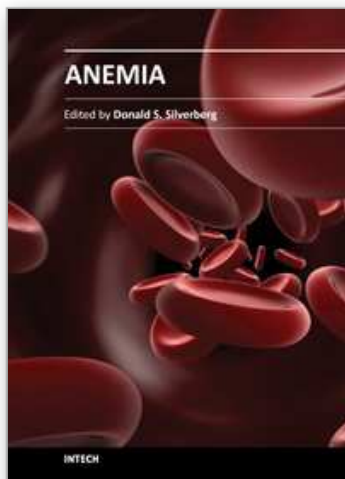
Anemia

Edited by Dr. Donald Silverberg

This book provides an up- to- date summary of many advances in our understanding of anemia, including its causes and pathogenesis, methods of diagnosis, and the morbidity and mortality associated with it. Special attention is paid to the anemia of chronic disease. Nutritional causes of anemia, especially in developing countries, are discussed. Also presented are anemias related to pregnancy, the fetus and the newborn infant. Two common infections that cause anemia in developing countries, malaria and trypanosomiasis are discussed. The genetic diseases sickle cell disease and thalassemia are reviewed as are Paroxysmal Nocturnal Hemoglobinuria, Fanconi anemia and some anemias caused by toxins. Thus this book provides a wide coverage of anemia which should be useful to those involved in many fields of anemia from basic researchers to epidemiologists to clinical practitioners.

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