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Conclusions and recommendations of the WHO Consultation on prevention and control of iron deficiency in infants and young children in malaria-endemic areas

World Health Organization Secretariat on behalf of the participants to the Consultation*

Preamble

Iron deficiency and iron-deficiency anemia are common in young children, and there is substantial evidence that iron deficiency has adverse effects on child health and development. Therefore, provision of additional iron to infants and young children who are iron deficient should be a public health priority.

Two large trials, coordinated and supported by the World Health Organization (WHO), were conducted in Zanzibar, Tanzania, and in Nepal to evaluate the impact of zinc and/or iron–folic acid supplementation on the mortality and severe morbidity of preschool children [1, 2]. In Zanzibar, an area of stable, perennial, and intense transmission of *Plasmodium falciparum* malaria, routine iron–folic acid supplements given with or without zinc resulted in an increased rate of severe adverse events in children (morbidity and mortality). A concurrent substudy suggested that the adverse events occurred in supplemented children who were not iron deficient. In Nepal, the trial showed no difference in mortality or the incidence of the common infections between children receiving iron–folic acid with or without zinc, and those who received zinc alone or a placebo. The results from the study in Zanzibar, Tanzania [1], raised the issue of the safety of administering additional iron to infants and young children in areas of malaria endemicity and its public health implications. An Expert Consultation was convened by WHO to examine this issue in Lyon, France, 12–14 June 2006.

Specifically, the objectives of the Consultation, which focused on infants and young children in malaria-endemic areas, were to review the scientific evidence on the safety and efficacy of different ways of administering iron to control iron deficiency and iron-deficiency anemia, and to provide guidance on the safest, most feasible, and most effective ways of delivering additional iron to control iron deficiency

and anemia in such areas.

Summary

The Consultation reached consensus on several important issues related to providing additional iron to infants and young children in malaria-endemic areas. The conclusions in this report apply specifically to regions where malaria is endemic.

In this report, “iron supplements” refers to medicinal iron supplements given orally to population groups for the prevention and control of iron deficiency. “Iron therapy” refers to medicinal iron supplements given orally or parenterally for treatment of iron deficiency of individual patients. “Iron preparations for home fortification” refers to iron mixed with foods at home. Such iron preparations may be in the form of a powder, crushable tablet, or fat-based spread. “Processed foods fortified with iron” refers to food fortified with iron during food processing.

In malaria-endemic regions

Strategies to control iron deficiency should be carried out in the context of comprehensive and effective health care, including the provision of insecticide-treated nets and vector control for the prevention of malaria, and prompt recognition and treatment of malaria and its complications with effective antimalarial and antibiotic drug therapy. They should also include control of other prevalent parasitic diseases and infections and the promotion of exclusive breastfeeding for the first 6 months of life, followed by consumption of nutrient-dense and/or processed fortified complementary foods [3–5].

Universal iron supplementation (i.e., use of medicinal iron as pills or syrups) should not be implemented without the screening of individuals for iron deficiency, because this mode of iron administration may cause severe adverse events in iron-sufficient children.

The safety of iron preparations administered through home fortification of complementary foods for infants

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and young children, i.e., powders, crushable tablets, and fat-based spreads, is uncertain in malaria-endemic areas. Although there is reason to believe that those preparations may be safer than iron supplements, they cannot be recommended until this has been demonstrated.

An option would be to administer additional iron to infants and young children as processed complementary foods fortified with iron. Although the safety of their use in malaria-endemic areas has not been documented, this is likely to avoid the potential adverse effects of a large bolus of iron taken in a single dose, since the iron would be consumed in smaller amounts throughout the day and therefore absorbed more slowly.

Infants and young children who have malaria and are diagnosed with iron deficiency [6] or severe anemia,* should be treated with antimalarial and, where appropriate, antibiotic therapy as well as iron therapy, which should always be administered with food. The reservations concerning the harmful effects of universal iron supplementation do not diminish the need for adequate iron therapy when iron deficiency is diagnosed.

Because widespread folate deficiency is not known to be a problem in infants and young children, and supplemental folic acid may interfere with the efficacy of antifolate antimalarial drug therapy, supplemental folic acid or foods fortified with folic acid should not be given to infants and young children in areas where antifolate antimalarial drugs are used.

The potential pathophysiological mechanisms governing the relationships between iron metabolism and infection, and the risk of severe adverse events after iron administration, were also discussed, but it was felt that there are insufficient data to draw conclusions that would justify changing public health programs. Further research on this topic is required.

Conclusions of the Consultation

Relationships among iron metabolism, malaria, and infection in infants and young children

Iron deficiency is the most common acquired disorder of iron balance. It is particularly common in the first 2 years of life, when the primary cause is insufficient intake of bioavailable (absorbable) iron to meet the high requirements for growth.

Iron is a mineral that plays a vital role in human metabolism. Iron deficiency is associated with increased risk of serious morbidity. Evidence from animal and human experiments indicates that iron deficiency affects motor, cognitive, and emotional development

by impairing myelination and by altering neurotransmitter receptor (particularly dopamine) function and neuronal metabolism. Iron status should be adequate to support hematopoiesis, neurological development, and immune function.

Virtually all body iron exists in one of two forms: as an integral component of functional proteins or tightly bound to transport or storage proteins. Free iron is potentially toxic. Complex mechanisms exist to regulate iron transport, storage, and metabolism in order to prevent the release of free iron. When bolus doses of iron are administered parenterally or orally, especially without food, they may increase plasma iron concentrations and transferrin saturation and exceed the binding capacity of transferrin, leading to the appearance of non-transferrin-bound iron (NTBI). NTBI is potentially toxic because it may promote free radical formation and be more readily available to pathogens.

Iron supplements administered orally can alter the gut flora by changing the balance between beneficial organisms and pathogens. It has been suggested that local iron overload in the intestine can also adversely affect the immune system. The recent observations from the study in Zanzibar, Tanzania [1], indicate that oral iron–folic acid supplements may increase the risk of morbidity from malaria and/or the bacterial infections that complicate malaria in children under 3 years of age.

On the other hand, iron-deficient children appear to be at increased risk for severe morbidity in Zanzibar, Tanzania [1], and to benefit from iron–folic acid supplements. The most plausible explanation for this apparently paradoxical finding may be that there are two processes at work. Iron deficiency may impair the immune response while an iron bolus increases the risk of forming potentially toxic NTBI. Iron-deficient children may be protected from the latter effect because iron is removed more rapidly from the plasma due to their higher tissue requirements for iron.

Inflammation, in response to infection, induces dramatic changes in the handling of iron that are thought to be mediated primarily through hepcidin** production. These include lowered release of iron from stores, reduced intestinal iron absorption, and a fall in plasma iron concentration. There is reason to believe that this process has a protective effect, since iron plays an important role in the interaction between host and pathogens. Numerous *in vitro* studies and experimental animal models demonstrate that the virulence of pathogens is less if the host tissue can reduce the pathogen's

* The clinical diagnosis of severe anemia is made on the presence of "severe palmar pallor" [10].

** Hepcidin is an antimicrobial peptide produced by the liver that plays a major role in the regulation of iron metabolism. It modulates iron release from iron stores and intestinal iron uptake, facilitating increased iron absorption during iron deficiency and decreased iron absorption during iron repletion in adults.

acquisition of iron. However, the evidence indicating that systemic iron deficiency can enhance this protection against infection in humans is inconclusive.

In malaria, there are complex interactions between the parasite, iron status, and the immune response. These probably do not depend solely on access of the parasite to free plasma iron in the intraerythrocytic phase of infection. The host's immune system may be modified. Moreover, little is known about the effect of iron status on the hepatic phase of malaria.

In malaria-endemic areas, there is evidence that an elevated plasma zinc protoporphyrin/heme (ZPP/H) ratio may identify iron-deficient children who will benefit from oral medicinal iron supplementation.

There is some evidence that providing additional folic acid may interfere with the efficacy of antifolate antimalarial drugs. However, it is unlikely that the folic acid content of the iron–folic acid supplements used in the study in Zanzibar, Tanzania [1] was responsible for the adverse effects. Nevertheless, there is no convincing evidence of widespread folate deficiency among children in Africa [6] nor of a benefit of folic acid supplementation for children with anemia. Thus, in the treatment of infants and young children with iron deficiency and iron-deficiency anemia who are receiving antifolate antimalarial drug therapy for malaria treatment, it is advisable to use a medicinal iron supplement that does not also contain folic acid.

It is not clear how the adverse effects of iron–folic acid supplements interact with the age of the child. Breastfeeding and passively acquired immunity from the mother afford some protection against malaria and other infections, and mechanisms that regulate iron metabolism are not mature in infants under 6 months of age.

Genetic polymorphisms in proteins involved in iron transport and haptoglobin could increase the risk of severe adverse events due to iron supplementation in young children. On the other hand, thalassemias, some hemoglobinopathies, and glucose-6-phosphate dehydrogenase (G6PD) deficiency, which are common in malarious areas, are protective against malaria in young children and may therefore reduce the risk of severe adverse events due to iron supplementation.

It is unclear at present whether the risks of iron, and possibly folic acid, supplementation are specific to malaria and/or the bacterial infections that complicate malaria, or whether they apply to infections that are not related to malaria.

Evidence of benefits of interventions to improve iron status in infants and young children

In nonmalaria areas

In populations at risk for iron deficiency, there is strong evidence that all types of iron interventions reduce iron deficiency and iron-deficiency anemia and improve

motor development in children under 2 years of age, and moderately strong evidence that these interventions improve social and emotional development in infants aged 6 to 12 months.

Interventions that improve iron status and reduce anemia in pregnant women also increase birthweight and/or length, reduce the prevalence of low birthweight, and improve infant iron status.

Delayed cord clamping improves iron status in early infancy.

Additional iron given to older iron-deficient infants and toddlers may not completely prevent poorer long-term neurodevelopmental functioning. This is part of the justification for early iron interventions.

In malaria-endemic areas

There is evidence that iron supplements reduce serious morbidity in iron-deficient children if given with good health care, including treatment for malaria, other parasitic infestations, and infections.

Evidence of risks of interventions to improve iron status in infants and young children

In malaria-endemic areas, where there is limited malaria prevention and clinical care, universal iron supplementation is associated with an increased risk of severe adverse events.

In malaria-endemic areas, there are no established benefits of routine folic acid supplements, and they may interfere with antifolate antimalarial drugs. The risk–benefit ratio does not favor universal supplementation of these children with folic acid.*

There is some evidence that iron supplementation of iron-replete infants may cause moderately slower growth. It should be noted that these data are reported from nonmalaria areas and that they were from short-term studies.

Ways to deliver additional iron to infants and young children in nonmalaria areas

In nonmalaria areas, current WHO guidelines for the control of iron deficiency and iron-deficiency anemia still apply for infants and young children [7, 8]. However, they will be revised in the future to take into account new scientific evidence accumulated over the last decade.

Ways to deliver additional iron to infants and young children in malaria-endemic regions

In malaria-endemic areas, control of infectious diseases and malaria with insecticide-treated nets and

* There are specific conditions, such as sickle cell anemia, in which folic acid supplementation could be of benefit.

vector control, and treatment of malaria episodes with effective antimalarial therapy, are critical components of health care and should be instituted, together with promotion of exclusive breastfeeding through the age of 6 months followed by high-quality complementary feeding [4, 5].

For the first 6 months of life, breastmilk and the iron endowment at birth cover the iron needs of the infant born at term with normal birthweight, and whose mother had adequate iron status during pregnancy, after which other dietary sources of iron are required. After 6 months of age, meat is the best dietary source of iron, as the heme iron is highly bioavailable and meat also enhances the absorption of inorganic iron in the diet. If the intake of animal tissue is not high, infants require an alternative source of bioavailable iron in the form of processed fortified complementary foods.

Universal iron supplementation for children under the age of 2 years is not recommended in malaria-endemic areas. However, iron therapy may have an important positive impact on child survival if it is directed to iron-deficient children in the setting of appropriate treatment of malaria and the complicating bacterial infections. Prior screening to identify iron-deficient children should be a necessary component of any such intervention.

In order to avoid the potential interference of folic acid with the action of antifolate antimalarial medications, and given the fact that there is little evidence of folate deficiency in infants and young children, it would be advisable not to include folic acid in any type of micronutrient supplements or fortified processed foods provided to infants and young children in populations treated for malaria.

TABLE 1. Strategies to control the iron status of infants and young children in malaria-endemic areas

Age group	Settings where screening system to detect iron deficiency and health services are available	Settings where screening system to detect iron deficiency is not available
Under 6 months		
Low-birthweight and premature infants	<p><i>Control of iron deficiency</i> Delayed cord clamping Iron supplements for 3 months starting at 2 months of age » Iron supplements should only be given in conjunction with the measures to prevent and control malaria (see below) » It is advisable not to give supplemental folic acid</p> <p><i>Prevention and control of malaria</i> Provision of insecticide-treated nets and vector control for prevention of malaria, and treatment of malaria illness with effective antimalarial drug therapy</p> <p><i>General health care, including:</i> Exclusive breastfeeding Infection/parasitic disease control</p>	<p><i>Control of iron deficiency</i> Delayed cord clamping Iron supplements for 3 months starting at 2 months of age » Iron supplements should only be given in conjunction with the measures to prevent and control malaria (see below) » It is advisable not to give supplemental folic acid</p> <p><i>Prevention and control of malaria</i> Provision of insecticide-treated nets and vector control for prevention of malaria, and treatment of malaria illness with effective antimalarial drug therapy</p> <p><i>General health care, including:</i> Exclusive breastfeeding Infection/parasitic disease control</p>
Full-term, normal-birthweight infants	<p><i>Control of iron deficiency</i> Delayed cord clamping Iron therapy for 3 months starting at 2 months of age only to infants detected with iron deficiency » Iron therapy should only be given in conjunction with the measures to prevent and control malaria (see below) » It is advisable not to give supplemental folic acid</p> <p><i>Prevention and control of malaria</i> Provision of insecticide-treated nets and vector control for prevention of malaria, and treatment of malaria illness with effective antimalarial drug therapy</p> <p><i>General health care, including:</i> Exclusive breastfeeding Infection/parasitic disease control</p>	<p><i>Control of iron deficiency</i> Delayed cord clamping Iron therapy for 3 months starting at 2 months of age only to infants with clinical symptoms of severe anemia » Iron therapy should only be given in conjunction with the measures to prevent and control malaria (see below) » It is advisable not to give supplemental folic acid</p> <p><i>Prevention and control of malaria</i> Provision of insecticide-treated nets and vector control for prevention of malaria, and treatment of malaria illness with effective antimalarial drug therapy</p> <p><i>General health care, including:</i> Exclusive breastfeeding Infection/parasitic disease control</p>

continued

Although the plasma zinc protoporphyrin/heme (ZPP/H) ratio still needs further investigation to be fully validated in malaria-endemic areas, it remains the preferred indicator to be used to screen children for iron deficiency, as it has been shown to identify iron-deficient children who may benefit from iron supplementation.

A summary of the strategies to improve the iron status of infants and young children in malaria-endemic regions is provided in **table 1**.

During the first 6 months of life

Maternal iron status during pregnancy affects fetal storage of iron, and effective strategies to improve the iron status of pregnant women will increase body iron stores of the infant at birth.

Cord clamping at delivery should be delayed, as this improves the iron status of infants.

Preterm and low-birthweight infants are at higher risk for iron deficiency and iron-deficiency anemia, and current WHO recommendations advise that they should be supplemented with iron [7, 8]. Since malaria infection occurs in early infancy and is especially dangerous at this age, in malaria-endemic areas iron supplements should only be given to preterm and low-birthweight infants who sleep under insecticide-treated nets, and where all episodes of malaria illness can be promptly treated with effective antimalarial drug therapy according to national guidelines. Iron supplementation should be started at 2 months of age for a period of 3 months.

After the first 6 months of life

Processed complementary foods fortified with iron have the advantage of providing a physiological dose of iron, potentially distributed throughout the day, which avoids the adverse gastrointestinal and morbidity effects of a bolus dose. To ensure efficacy without exceeding the recommended upper levels of intake, the formulation of fortified complementary foods should follow WHO guidelines [9]. Education about the best complementary feeding practices should also be provided [4].

Processed complementary foods fortified with folic acid should be avoided in order to avoid the potential interference of folic acid with antifolate antimalarial medications.

Iron preparations administered through home fortification, such as powders, crushable tablets, and fat-based products, should not be used in malaria-endemic areas. If these are added to a single meal, the dose of iron is still relatively high, and it is possible that this may have a similar effect to a bolus of iron supplement. However, further research is urgently needed on the safety of these methods of iron administration in malaria-endemic areas, because they are just as efficacious as iron supplements for treating and preventing iron deficiency and therefore could be an option where processed complementary foods are not available.

Infants and young children with malaria and diagnosed with iron deficiency or severe anemia should be treated with effective antimalarial drug therapy and given oral iron therapy. Oral iron therapy should always be given with food.

TABLE 1. Strategies to control the iron status of infants and young children in malaria-endemic areas (continued)

Age group	Settings where screening system to detect iron deficiency and health services are available	Settings where screening system to detect iron deficiency is not available
6–24 months		
All infants and young children	<p><i>Control of iron deficiency</i> Processed complementary foods fortified with iron or, if not available, Iron therapy for 3 months only to infants and young children detected with iron deficiency</p> <ul style="list-style-type: none"> » Iron therapy should always be administered along with food and in conjunction with the measures to prevent and control malaria (see below) » It is advisable not to give supplemental folic acid <p><i>Prevention and control of malaria</i> Provision of insecticide-treated nets and vector control for prevention of malaria, and treatment of malaria illness with effective antimalarial drug therapy</p> <p><i>General health care, including:</i> Breastfeeding and adequate complementary feeding Infection/parasitic disease control</p>	<p><i>Control of iron deficiency</i> Processed complementary foods fortified with iron or, if not available, Iron therapy for 3 months only to infants and young children with clinical symptoms of severe anemia</p> <ul style="list-style-type: none"> » Iron therapy should always be administered along with food and in conjunction with the measures to prevent and control malaria (see below) » It is advisable not to give supplemental folic acid <p><i>Prevention and control of malaria</i> Provision of insecticide-treated nets and vector control for prevention of malaria, and treatment of malaria illness with effective antimalarial drug therapy</p> <p><i>General health care, including:</i> Breastfeeding and adequate complementary feeding Infection/parasitic disease control</p>

Research priorities

The effects of iron supplementation and iron therapy on malaria-associated morbidity are incompletely understood. The direct and indirect mechanisms need to be explored, especially the effects on the immune system and the hepatic phase of the malarial cycle, the relationship between iron status and the mode of iron delivery, preferably using standard protocols in a multisite trial, and the involvement of comorbidity during malaria in the adverse effects caused by iron. Continued research is needed to identify optimal methods for determining iron status in field studies. This research can be grouped into three categories, listed below in order of priority.

Mechanisms of adverse effects of iron administration

The impact of different types of iron preparations (powders, tablets, fortified foods, fat-based spreads), of the doses, duration, and frequency of administration (e.g., several times a day, daily, or weekly dose), and of different modalities of iron administration (with and without food) on:

- » The pharmacokinetics of iron uptake and metabolism (to minimize causing excessive levels of potentially toxic plasma iron, including NTBI);
- » Gut microflora and the immune system.

The role of comorbidity due to other infections in the adverse effects caused by iron administration in malaria.

The involvement of hepcidin and other iron regulatory proteins in response to iron administration, particularly in infants and young children.

Assessment of iron status in malaria-endemic areas

Identification of field-friendly indicators for screening preterm and low-birthweight infants for iron deficiency at 2 months of age.

Identification of predictor variables for screening

infants less than 6 months of age who are at high risk for iron deficiency.

Identification of affordable and field-friendly tools to screen for iron deficiency in children aged 0 to 24 months.

Assessment of the reliability of the ZPP/H ratio compared with other indicators of iron deficiency and risk, and development of an inexpensive, portable, reliable instrument to measure the ZPP/H ratio.

Ways to deliver additional iron: Risks and benefits

Evaluation of the effectiveness of different iron preparations for home fortification, including compliance.

Interaction between iron and other micronutrients, especially zinc, within programs to improve iron status of children, and the effects of the mode of delivery (medicinal oral supplements, iron preparations for home fortification, and processed fortified foods).

Relationship between iron supplementation of children and various preexisting infections (including malaria, tuberculosis, and HIV infection).

Short- and long-term impact of antenatal and postnatal iron supplements on child development outcomes, including growth and neurodevelopment, especially in malarious areas.

Benefit of antenatal iron supplementation to iron nutrition of the infant.

Feasibility and costs of strategies to administer iron to iron-deficient children.

Risk–benefit ratio of providing iron supplements to breastfed infants, including those with low birthweight.

Risk–benefit ratio of iron supplementation in children with hemoglobinopathies in malaria-endemic areas.

Review of the frequency of early clamping of the umbilical cord in different settings, home and institutional, and of the barriers to implementation of delayed cord clamping.

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