The assessment of dietary iron bioavailability using the piglet as an animal model for the human infant

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ABSTRACT

The bioavailability of five different iron sources added to a bovine milk based formula was investigated in the anaemic, suckled piglet. These iron sources were ferrous pyrophosphate (FP), ferrous sulphate (FS), milk protein-iron complex (MPIC), ferrous lactate (FL), and haemin (Hm). Forty eight male piglets were removed from the sow at five days of age and randomly assigned to one of six treatment groups (n=8). Iron depletion was achieved in two ways: firstly, by withholding the iron injection usually given to these piglets at birth, and secondly, by feeding the piglets an iron-deficient formula throughout an eleven day adjustment/iron-depletion period. The five formulas containing the supplementary iron and one formula containing no iron (control diet) were bottle-fed to the piglets (336g of liquid formula/kg bodyweight/day) seven times daily for a 25 day repletion period. Analysis of the formulas revealed that iron levels in each of the five iron treated formulas varied over a range of 6.0-8.3 mg/100g of powdered formula.

Iron bioavailibility was assessed in the piglets by a haemoglobin repletion assay. Blood was collected from the anterior vena cava of the piglets on days 0, 11, 24, and 36 of the trial, and the piglets were weighed every three to four days throughout the 25 day repletion period. Blood haemoglobin concentration, haematocrit, unsaturated iron binding capacity, and piglet liveweights were used as indicators of iron status in the piglets. Haemoglobin Repletion Efficiency (HRE%), a measure of the proportion of ingested iron that is incorporated into haemoglobin in the body, was calculated to correct for differences in the iron content of the formula and differences in iron intake by the piglets. The HRE% for the FP, FS, MPIC, FL, and Hm fortified formulas were 23.5, 35.8, 38.0, 32.9, and 3.2%, respectively. There were no significant differences, however, in the mean blood haemoglobin concentrations, haematocrits, HRE% and UIBC for piglets fed the FS, MPIC, or the FL fortified formulas half way through, and at the end, of the repletion. This implied that there were no differences in the bioavailability of these iron sources. In contrast, these parameters were all significantly lower ($P>0.05$), for the piglets fed either the FP or the Hm formulas. Based on relative biological value, the bioavailability of each iron source, when ranked in order from highest to lowest, was MPIC<FS<FL<FP<Hm. These findings have important implications for the development of iron-enriched milk products destined for human consumption.

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GENERAL INTRODUCTION

Today, iron deficiency is one of the most prevalent nutritional deficiencies among infants and young children in both industrialised and developing countries (Kuvibildila *et al.*, 1984; FAO/WHO, 1988; Zeigler and Fomon, 1996; Looker *et al.*, 1997). The effects of iron deficiency on erythropoiesis, work capacity, cognitive performance (Pollitt, 1997), behaviour (Andraca *et al.*, 1997), and more recently cell mediated immunity (Kuvibildila *et al.*, 1984; Walter *et al.*, 1997) are well documented. These effects highlight the need for early detection and treatment of iron deficiency and its associated anaemia during this age of increased risk.

Infants and young children have an increased risk of deficiency because of the demands imposed in times of increased growth. The growth of the body necessitates an increase in the total volume of blood to keep pace with its size. Moreover, there is a steady increase in the haemoglobin content per unit blood volume from age six months. A greater demand for iron comes also, from the expanding muscle mass during growth. At birth, the full-term human infant is endowed with iron stores sufficient to satisfy the body's demand for iron for the first four to six months of life. The infant can be fed a low iron diet during this time without demonstrating overt signs of iron deficiency. After the first four to six months, however, the depletion of iron stores that results from increased growth rates and a diet low in iron, introduces a high risk of iron deficiency to the infant. While the high bioavailability of breast milk iron confers a partial protection against deficiency, the quantity of iron absorbed from an unsupplemented diet, from about four months of age onwards, is no longer sufficient to meet the needs of infants (Saarinen, 1978; Dallman *et al.*, 1980).

The fortification of foods with iron offers a suitable means of prevention and treatment of iron deficiency and its associated anaemia. Infant formula provides an appropriate vehicle for iron fortification for infants who are not breast-fed because it is consumed by these infants in large quantities. Iron fortification of infant formulas and cereals was introduced in the 1960's (Zeigler and Fomon, 1996). Today, the level of fortification of infant formula typically ranges from 8-12mg/L, primarily in the form ferrous sulphate or ferrous lactate. The iron sources of choice are those with acceptably high bioavailability. The absorption of dietary iron depends on the bioavailability of the iron which is, in turn, affected by various dietary factors. It is, therefore, important to get reliable estimates of the bioavailability of different iron sources under appropriate conditions.

The objective of this study was to test the bioavailibility, to the human infant, of iron from different sources. Central to this objective was the use of a suitable animal model for infant iron nutrition.