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Effect of using commercial pre-packaged baby foods on the Fe intake of 7–8 months old infants

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Abstract

Objectives: To examine the potential effect on Fe intake of 7–8 months old infants if pre-packaged baby foods (PBF) were used as the sole source of complementary foods.
Design: Based on the 7-d recommended feeding plan for 7–8 months old infants in Hong Kong (moderate Fe-fortified rice cereal with home-cooked meals), twenty-four modelling scenarios were created which comprised of two milk use modes (breastmilk *v.* infant formula), three modes of rice cereal use (no-rice cereal; non-Fe-fortified rice cereal and Fe-fortified rice cereal) and four baby foods usage modes (home-cooked meals; low-Fe PBF only; high-Fe PBF only and mixed PBF). The PBF were randomly selected in each of the models and substituted the original meals/snacks. The average daily Fe intakes of the modelled meal plans were compared with the Chinese estimated average requirement (EAR) and recommended nutrient intake (RNI) for Fe.
Setting: Modelling study.
Participants: Not applicable.
Results: In general, the infant-formula-based complementary feeding pattern (CFP) had higher average daily Fe intake when compared with breastmilk-based CFP. The Fe intakes of all scenarios under the breastmilk-based CFP were below the RNI and EAR, except for the fortified rice cereal meal plans with high-Fe or mixed PBF. For infant-formula-based CFP, the Fe intakes were close to or above the RNI regardless of types of PBF or rice cereal used.
Conclusions: The inclusion of fortified rice cereal was important in maintaining adequate Fe intake for infants, especially for breast-fed infants. The replacement of home-cooked meals by low-Fe PBF could potentially put infants at risk of Fe deficiency.

Keywords
Fe
Pre-packaged baby foods
Complementary feeding
Modelling
Infants

The Fe stores of a newborn infant deplete at approximately 6 months of age[1]. For breast-fed infants, since breastmilk alone does not provide adequate Fe to support the rapid growth of the infant, health authorities around the world unanimously recommend solid complementary foods should be introduced at approximately 6 months of age to supply additional dietary Fe[2–4]. While most infant formulas for 6–12 months old infants have a higher level of Fe fortification compared with those for 0–6 months old infants, the bioavailability of Fe in infant formulas is far lower than that in breastmilk[5] and hence complementary foods still play a key role in providing adequate Fe.

Ideally, these complementary foods should be home-made with Fe-rich ingredients, such as red meat and green leafy vegetables[2]. In Hong Kong, infants usually start complementary feeding at approximately 4–6 months of age, and common home-made complementary foods include smooth purees of dark green leafy vegetables and pome fruits, although rice congee with minced meat is also common[3]. The use of Fe-fortified rice cereal is also commonly recommended[3]. However, dual-income families are the norm in Hong Kong and many developed countries, and it may be difficult for parents to prepare all complementary foods at home. Some parents may resort to use

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pre-packaged baby foods (PBF) as a replacement, which are ready to eat and convenient. Market research suggests that PBF usage in Hong Kong and around the world is trending upwards[6].

While it is theoretically possible to provide adequate Fe to the infants by using foods or PBF naturally rich in Fe, in practice, the identification of Fe-rich foods may be difficult for parents, as the display of Fe content on the nutrition label of infant foods is not mandatory in Hong Kong, unless it is Fe-fortified[7]. Our previous audit of PBF available in Hong Kong showed that only <20 % of PBF were Fe-fortified, including approximately half of the cereals, which were a major source of Fe for infants first introduced to solids[8]. Frequent usage of PBF as complementary foods may therefore put infants at risk of inadequate Fe intake. Although a study in the 1980s showed that the prevalence of Fe deficiency in infants in Hong Kong is low[9], during that period Fe-fortified infant formulas were the predominant choice of milk, and there was less reliance on PBF. The shift in infant feeding practices and the greater use of PBF in recent years may have resulted in a higher prevalence of Fe deficiency in infants in Hong Kong, although no recent data on this are available. This study, therefore, aims to examine the potential effect on Fe intake of 7–8 months old infants if their parents rely on PBF as the sole source of complementary foods using a modelling study design. We hypothesise that this will lead to inadequate Fe intake.

Materials and methods

Sampling of PBF for Fe content determination

From a previously audited representative sample of 472 PBF[8], 73 PBF were randomly selected using the 'RANDBETWEEN(1472)' function in MS Excel. They were then purchased from local brick and mortar stores in Hong Kong and analysed for their Fe content. The PBF were categorised according to Dreyfuss *et al.*[10], with slight modifications to accommodate the types of PBF available in Hong Kong, as previously described[8]. In brief, the PBF were classified as cereals (*n* 8), snacks or finger foods (*n* 23; including nine biscuits or cookies or rolls or balls or rusks, two puffs or hoops, four crackers or wafers or rice cakes, two yoghurt or coconut milk, four juice or tea, one soft candy or candy, and one oat bar), sweet purees (*n* 24), savoury purees (*n* 16) and others (*n* 2; including one plain noodles and one non-pureed-form mixed meal). These categories were chosen to reflect the physical form of the food, the requirement of further preparation before consumption and their likely use (snack *v.* main meal)[8].

Determination of Fe content of the sampled PBF

The PBF samples were prepared according to the AOAC official method 999.10 (version 9.1.08)[11]. In brief, the sampled PBF (*n* 1 each, measured in triplicate) were well mixed, then 0·3 g of samples were weighed by an electronic balance accurate at 4 decimal points. The samples were then digested with 67–69 % nitric acid, specific for trace metal analysis (NORMATOM®, VWR Chemicals) and 34·5–36·5 % hydrogen peroxide under high temperature (180°C) and high pressure (45 bar) using a microwave digestion system (ETHOS One High Performance Microwave Digestion System, MILESTONE) for 30 min. The digested samples were then diluted a hundred-fold with 2 % nitric acid (NORMATOM®, VWR Chemicals) and fed into an inductively coupled plasma MS (ICP-MS) machine (Agilent Technologies 7900 ICP-MS with Agilent Technologies SPS 4 Autosampler, Agilent Technologies) for the determination of Fe content[12]. The Fe content was obtained using the ICP-MS MassHunter software (Agilent Technologies). The tested PBF were then categorised into either low-Fe or high-Fe PBF, using a cut-off generated based on the Fe content of 7458 food items in the USDA Food Composition Database[13]. The USDA database was used instead of the one from the Centre for Food Safety in Hong Kong[14] due to the higher number of foods available and more regular updates. The cut-off was based on the 50th percentile of the Fe content amongst the food items, which was 1·28 mg/100 g, where an Fe content ≤ 1·28 mg/100 g was considered low, and vice versa. We opted to base the cut-offs on all food items available rather than just infant foods because a considerable proportion of infant foods especially infant formula are Fe-fortified and thus would bias the classification (e.g. many non-Fe-fortified PBF with Fe-rich ingredients may be classified as low Fe). We have also estimated the contribution to total Fe from haem *v.* non-haem Fe based on the ingredients list (e.g. based on presence/absence of red meats and their position on the ingredients list). Portion size of the food was not considered as using per 100 g values will allow a fairer comparison.

Modelling of the impact of different modes of PBF usage on the average daily Fe intake

The 1-week menu and recipes for 7–8 months old infants in the 7-d Healthy Meal Planning Guide for 6 to 24 months old children provided by the Family Health Service from the Department of Health of Hong Kong[3] was used as the recommended feeding plan for two complementary feeding patterns (CFP) – breastmilk-based and infant-formula-based. Since no information regarding the Fe level of breastmilk of local lactating women and the popularity of local infant formula and Fe-fortified cereals were available, we opted to use the generic breastmilk (0·067 mg Fe/225 g serving), infant formula (2·25 mg Fe/225 g serving) and Fe-fortified rice cereal (moderate Fe content of 20·6 mg Fe/100 g dry weight) from the AUSNUT2011–2013 food list[15] in the recommended feeding plan of the modelling.

Based on this recommended feeding plan, 12 modelling scenarios were created for each CFP (i.e. a total of 24

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Table 1 Complementary feeding scenarios modelled in this study

Scenario#	PBF type	Milk type	Rice cereal type
1*	Home-cooked meals	Breastmilk	Moderate Fe-fortified
2	Home-cooked meals	Breastmilk	Non-Fe-fortified
3	Home-cooked meals	Breastmilk	Fe-fortified
4*	Home-cooked meals	Infant formula	Moderate Fe-fortified
5	Home-cooked meals	Infant formula	Non-Fe-fortified
6	Home-cooked meals	Infant formula	Fe-fortified
7	Low Fe	Breastmilk	No-rice cereal
8	Low Fe	Breastmilk	Non-Fe-fortified
9	Low Fe	Breastmilk	Fe-fortified
10	Low Fe	Infant formula	No-rice cereal
11	Low Fe	Infant formula	Non-Fe-fortified
12	Low Fe	Infant formula	Fe-fortified
13	High Fe	Breastmilk	No-rice cereal
14	High Fe	Breastmilk	Non-Fe-fortified
15	High Fe	Breastmilk	Fe-fortified
16	High Fe	Infant formula	No-rice cereal
17	High Fe	Infant formula	Non-Fe-fortified
18	High Fe	Infant formula	Fe-fortified
19	Both low and high Fe	Breastmilk	No-rice cereal
20	Both low and high Fe	Breastmilk	Non-Fe-fortified
21	Both low and high Fe	Breastmilk	Fe-fortified
22	Both low and high Fe	Infant formula	No-rice cereal
23	Both low and high Fe	Infant formula	Non-Fe-fortified
24	Both low and high Fe	Infant formula	Fe-fortified

PBF, pre-packaged baby food.
*Recommended feeding plans from the Family Health Service of the Hong Kong Department of Health[3].

scenarios, Table 1). Three modes of rice cereal use were examined, namely no-rice cereal, non-Fe-fortified rice cereal and high-Fe-fortified rice cereal. Four PBF usage modes were examined, namely home-cooked meals (recommended feeding plan without the use of PBF), low-Fe PBF only, high-Fe PBF only and mixed PBF (use of both low- and high-Fe PBF). The no-rice cereal mode in recommended feeding plan was replaced with a moderate Fe-fortified rice cereal mode to reflect the original recommended feeding plan. For the no-rice cereal scenarios, all main meals, including the rice cereal meals in the home-cooked meals, were replaced by main-meal PBF (savoury purees and others). In the non-fortified rice cereal and fortified rice cereal scenarios, the original rice cereal was replaced with a non-Fe-fortified rice cereal (Organic Baby Rice, Organix, 1·63 mg Fe/100 g dry weight, analysed by ICP-MS as described above) and Fe-fortified rice cereal (DHA & Probiotic Rice Cereal, Gerber, 45·22 mg Fe/100 g dry weight, analysed by ICP-MS as described above), respectively. These rice cereals are commonly available in brick and mortar stores in Hong Kong.

For the different PBF usage scenarios, a PBF of the same type (e.g. PBF in the snacks or finger foods category were used to replace the original snacks) was randomly selected from the list of the tested PBF by using random numbers among either low-Fe PBF, high-Fe baby PBF or all PBF (mixed PBF). That is to say, the selected PBF must be in line with the PBF usage scenarios (e.g. only low-Fe PBF were selected for the low-Fe PBF scenarios). The PBF with the greatest random number substituted the original main meal/snack in the meal plan. The random numbers were then regenerated, and the next replacement was picked as described above. The process continued until all snacks and main meals were swapped. Serving sizes of snacks remained the same as the original snacks as suggested in the recommended feeding plan, while those of main meals were changed to the recommended serving size or pack size of the PBF to reflect the actual usage (e.g. one single pouch per meal). The original and modelled menus (see online Supplemental Tables S1–S24) were analysed using AUSNUT2011–2013 database[15] for non-PBF items and values from ICP-MS for the analysed PBF. The obtained average daily Fe intakes were then compared with the Chinese dietary reference intakes for Fe (estimated average requirement, EAR: 7 mg/d; recommended nutrient intake, RNI: 10 mg/d)[16].

Data analysis

Statistical analyses were performed using SPSS (version 25, IBM Corp. Ltd.). Since the ICP-MS data were non-normally distributed, Mann–Whitney U test was used to examine the difference in the median Fe content between PBF in different categories. Fisher's exact test was used to examine the difference in proportion of PBF in different categories classified as high Fe. Paired-samples t test was used to examine the differences in average daily Fe intake (total, haem and non-haem) between the recommended feeding plan and modelled scenarios. Due to the number of tests performed, a $P < 0{\cdot}05$ was considered marginally statistically significant, and a $P < 0{\cdot}001$ was considered statistically significant to minimise the likelihood of committing type I error[17,18]. All P-values were two-sided.

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Results

The tested PBF had a median (interquartile range) Fe content of 1·62 (0·53–2·58) mg/100 g, with a wide range from 0·00 to 45·22 mg/100 g (Table 2). Amongst them, cereals had the highest median Fe content (3·35 (1·99–8·30) mg/100 g), followed by snacks or finger foods (1·83 (1·03–2·99) mg/100 g). Overall, more than half (*n* 42, 57·5 %) of the PBF tested were high in Fe, of which 8 (11 %) were Fe-fortified. Interestingly, more sweet purees were classified as high Fe compared with savoury purees although this was not statistically significant (45·8 % *v.* 37·5 %).

The mean daily Fe intakes based on different modelled scenarios are illustrated in Fig. 1. In general, the infant-formula-based CFP (range: 9·93–20·01 mg/d) had higher average daily Fe intake when compared with breastmilk-based CFP of the same rice cereal and PBF usage mode (range: 1·81–11·09 mg/d); and non-haem Fe was the predominant form of Fe in the diet. Reductions in Fe intakes were observed when the home-cooked meals and moderate Fe-fortified rice cereal in the recommended feeding plan (breastmilk-based CFP: 4·01 mg/d, infant-formula-based CFP: 12·62 mg/d) were replaced with low-Fe PBF with no-rice cereals (breastmilk-based CFP: 2·20 mg/d, infant-formula-based CFP: 9·93 mg/d) or non-fortified rice cereals (breastmilk-based CFP: 2·36 mg/d, infant-formula-based CFP: 10·72 mg/d), but such reductions appear to have been offset by the use of high-Fe PBF or mixed PBF. Only the PBF scenarios with Fe-fortified rice cereals had statistically significantly higher average daily total and non-haem Fe intakes than the recommended feeding plan of the same CFP mode (low-Fe PBF or mixed PBF *v.* recommended feeding pattern, $P < 0·05$; high-Fe PBF *v.* recommended feeding pattern, $P < 0·001$), except for the infant-formula-based CFP with low-Fe PBF where there is no significant difference in daily Fe intake from the recommended feeding plan ($P = 0·111$). Other tested scenarios were not statistically significantly different from the recommended feeding plan of the same CFP.

When assessed against the Chinese dietary reference intake for Fe, the Fe intakes of most of the breastmilk-based CFP scenarios were below EAR (7 mg/d). Only the fortified rice cereal meal plans had mean daily Fe intake above the EAR, and the combined use of high-Fe PBF and fortified rice cereals was the only scenario that resulted in an average Fe intake above the RNI (10 mg/d). For infant-formula-based CFP, the Fe intakes of all scenarios were above EAR and RNI, with the exception of the low-Fe PBF-based meal plan with no-rice cereal which was just 0·04 mg/d below the RNI.

Discussion

Our study showed that Fe intakes of infants were highly dependent on the Fe level of PBF, the use of fortified rice cereal, as well as the type of milk fed. In the case of breastmilk-based CFP, the use of high-Fe or mixed PBF could not achieve the Fe EAR nor the RNI without including fortified rice cereal as part of the diet. On the other hand, the infant-formula-based CFP scenarios modelled all had average daily Fe intakes close to or above the RNI regardless of whether PBF or rice cereals were Fe-fortified.

Owing to a rapid Fe-dependent growth rate during infancy, infants who fail to meet the Fe EAR or RNI, especially those with an Fe intake below EAR, are at a risk of Fe deficiency and Fe deficiency anaemia[19], which may lead to abnormal development and delayed growth, as well as numerous systemic abnormalities such as lower exercise capacity and higher infection susceptibility[20,21]. As the Fe stores of an infant would deplete at approximately 6 months of age, complementary foods have to be introduced when the infant is approximately 6 months old to provide additional dietary Fe. Ideally, these should be home-cooked with Fe-rich ingredients with a wide variety of texture and flavour to assist the sensory development of the infant as well as to establish good family eating habits. In developed societies such as Hong Kong where dual-income families are common, however, the use of PBF as a complementary feed is becoming increasingly common. Our analysis of the Fe content of PBF showed that approximately 40 % of the tested PBF contained ≤ 1·28 mg Fe/100 g. Furthermore, these commercial PBF tend to have a similar texture (i.e. pureed) which may negatively impact toddlers' achievements of developmental milestones[22], suggesting that they may not be a good choice for 7–8 months old infants first introduced to solids.

Table 2 Fe content* and proportion of high-Fe pre-packaged baby foods in different categories

Categories	*n*	Median	IQR (mg/100 g)	Range (mg/100 g)	High Fe† (%)	Fe-fortified (%)
Cereals	8	3·35	1·99–8·30	1·63–45·22	100·0	50·0
Snacks or finger foods	23	1·83	1·03–2·99	0·00–22·20	69·6	8·7
Sweet purees	24	1·09	0·31–2·14	0·00–3·49	45·8	0·0
Savoury purees	16	0·86	0·27–2·28	0·00–3·54	37·5	6·3
Others	2	12·33	–	0·99–23·67	50·0	50·0
Overall	73	1·62	0·53–2·58	0·00–45·22	57·5	11·0

*Fe content tested by inductively coupled plasma mass spectrophotometry.
†High Fe is defined as Fe content >1·28 mg/100 g.

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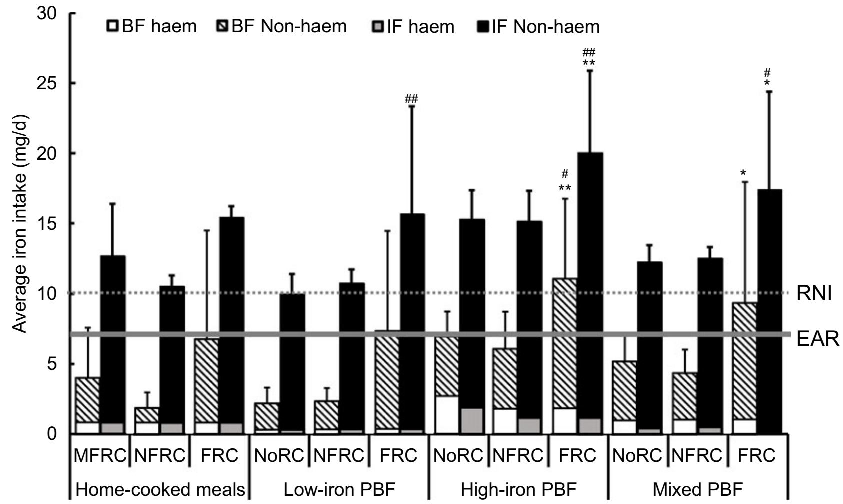

Fig. 1 Mean + SEM daily Fe intake of different complementary feeding scenarios. Solid horizontal line denotes Chinese EAR of Fe (7 mg/d); dotted horizontal line denotes Chinese RNI of Fe (10 mg/d). * and ** denote significant difference in daily total Fe intake at $P < 0.05$ and < 0.01, respectively, and # and ## denote significant difference in daily non-haem Fe intake at $P < 0.05$ and < 0.01, respectively, when compared with the recommended feeding plan (moderate Fe-fortified rice cereal + home-cooked meals) of the same CFP. CFP, complementary feeding pattern; EAR, estimated average requirement; FRC, Fe-fortified rice cereal; MFRC, moderate Fe-fortified rice cereal; NFRC, non-Fe-fortified rice cereal; NoRC, no-rice cereal; PBF, pre-packaged baby food; RNI, recommended nutrient intake

With the help of breast-feeding promotion programmes, the breast-feeding rate in Hong Kong is foreseen to climb[23]. Due to the intrinsically low Fe content in breast-milk, exclusively breast-fed infants may be at risk of Fe deficiency if their complementary feeds are not Fe-rich. A recent study in Taiwan showed that, when compared with formula-fed infants, breast-fed infants are 116 % and 320 % more likely to suffer from Fe deficiency and Fe deficiency anaemia, respectively[24]. Our modelling provided a possible explanation to such finding – we showed that for exclusively breast-fed infants, it is difficult to maintain an adequate Fe intake without the use of a fortified rice cereal, especially when low-Fe PBF were used to replace home-cooked meals. While most rice cereals available used to be Fe-fortified, we have previously reported that a sizable proportion of infant rice cereal currently available in Hong Kong are not Fe-fortified, and the information provided on the package does not allow easy identification of the Fe content or Fe fortification practices[8]. Our modelling results indicate the potential for inadequate Fe intake of breast-fed infants if non-fortified rice cereals are selected.

In contrast, the use of PBF to replace home-cooked Fe-rich meals is less of a concern for formula-fed infants, as infant formulas are commonly Fe-fortified. In Hong Kong, a majority of mothers still prefer infant-formula-based feeding for convenience[25,26], suggesting that Fe deficiency might not be a great concern in Hong Kong[26]. However, Woo *et al.* also suggested that there was a greater proportion of both breast-fed and formula-fed infants aged below 12 months having low-Fe intakes from complementary foods than older children[26]. This might be linked to the use of low-Fe PBF and non-fortified rice cereal.

Our findings highlight the importance of Fe fortification in infant formula, rice cereal and other PBF in helping infants getting adequate Fe, which is in agreement with other studies[27,28]. However, the current labelling regulation in Hong Kong does not allow easy identification of Fe-rich PBF, as the display of Fe level on the nutrition label is not mandatory[7]. Our previous study revealed that only 16·7 % of PBF audited displayed Fe content on the nutrition label[8]. Government agencies should mandate Fe labelling on PBF to assist parents in selecting Fe-rich PBF. Before this happens, parents should be reminded of the importance of selecting a fortified rice cereal if they are breast-feeding their babies.

While many of the modelled scenarios did not have statistically different average daily Fe intake compared with the recommended feeding plan, it should not be viewed as the absence of an issue. To achieve statistical significance with large day-to-day variance in Fe intake, the number of days modelled have to be substantially increased. However, this is unlikely to add more information to our findings, as it is apparent that many of the modelled scenarios have average daily Fe intake lower than the EAR. Nonetheless, the observation that some combinations of CFP resulted in an Fe intake above the RNI should not be ignored. Studies have reported that high Fe intake among infants who are initially Fe-replete may result in decreased growth[29,30], reduced absorption of other trace elements[31,32], adverse alterations in the gut microbiome[33,34], as well as impaired cognitive and motor development[35]. Excess unabsorbed Fe in the gastrointestinal tract has also been hypothesised to induce the generation of reactive oxygen species, possibly leading to inflammation[36].

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We caution the readers to the limitations of our study. First, the simplification of actual CFP modelled in this study limited our ability to fully estimate the real-life impact of PBF usage on the Fe intake of 7–8 months old infants. We only modelled two exclusive milk-feeding modes (breastmilk only and infant formula only); yet, a combined use of both types of milk is common[26]. This demonstrates the need to simulate a combined milk consumption pattern to better understand the changes in Fe content among different CFP, but a reasonable assumption is that the actual effect on Fe intake would fall somewhere between the two exclusive modes of milk feeding. Second, the method of replacing of meals in the PBF-based complementary feeding scenarios and the rice-cereal-containing meals in the meal plan was done in an all-or-nothing approach. To precisely reflect the actual CFP, the replacement should have been carried out in a gradual manner, e.g. one or two main meals were substituted within a day, and the same action was repeated for the whole week. Nonetheless, our results showed the worst-case scenarios, and it could be reasonably assumed a lesser effect on Fe intake would result from less frequent use of low-Fe PBF. Third, when PBF were used to replace main meals in the modelling, we utilised the serving size or the pouch size, which differs from the serving size used in the recommended feeding plan. We also assumed that all meals/snacks are fully consumed. These may have led to errors in our estimates of average daily Fe intake. Fourth, we only assessed the absolute intakes of Fe, but not Fe bioavailability, which can vary significantly with milk and complementary food sources. For example, Fe absorption of breastmilk is estimated to be 50 %, compared with 10 % for infant formula and fortified infant foods[37], although the exact absorption depends on the source of Fe and the infants' Fe status. In addition to the widely known differences in the bioavailability of haem *v.* non-haem Fe[38], the co-presence of absorption enhancers such as breastmilk, meat proteins and vitamin C[38] or inhibitors such as phytate in wholegrain cereals[39], as well as the relative solubility of the form of non-haem Fe (e.g. ferric pyrophosphate (less soluble) *v.* ferrous fumarate (more soluble))[40] would also affect the eventual bioavailability present in the PBF. Last, we did not consider the true biological requirement which varies between infants in our modelling; however, diets that only provide an Fe intake below EAR are likely to only meet the requirements of <50 % of the infants in the population per the definition of dietary reference intake, and therefore our modelling provides important insights into the likely risks associated with high PBF usage. The relatively high estimated dietary Fe requirements for infants, driven by the low availability of fortified Fe, has however been questioned[37].

Conclusions

The inclusion of fortified rice cereal as part of the complementary feeds is important in maintaining the average daily Fe intake of infants, especially those being fed with breastmilk, at levels above the EAR and RNI because of the added Fe. In the absence of fortified rice cereal, the full replacement of home-cooked meals with PBF could potentially put infants at risk of Fe deficiency, especially when low-Fe PBF are chosen. While the inclusion of foods high in haem Fe should always be encouraged over the use of PBF, further effort should be put into educating the parents about the significance of incorporating high-Fe PBF in infants' diet if they are used as an alternative to home-cooked meals. PBF should be required to display Fe content to assist parents in making informed food choices. Data on the current rate of Fe deficiency in young infants in Hong Kong are urgently needed.

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Supplementary material

For supplementary material accompanying this paper visit https://doi.org/10.1017/S1368980021003025

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