Nutritional research in World War 2: The Oxford Nutrition Survey and its research potential 50 years later

Rachel R. Huxley[1]*, B. B. Lloyd[2], M. Goldacre[1] and H. A. W. Neil[1]
[1]*Division of Public Health & Primary Health Care, University of Oxford, Oxford, UK*
[2]*Magdalen College, Oxford, UK*

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To investigate the nutritional status of the population of the UK during the Second World War, nutritional surveys were commissioned in 1941. These included surveys of two groups of pregnant women: the first comprised 120 working-class women who were studied in the spring of 1942, and a second group of 253 women in 1944. Both groups were followed up until after delivery. Detailed biochemical assessments were performed on each subject. Our statistical analysis of the haematological data showed that nearly 25 % of women from the 1942 group were deficient in protein, over 60 % were deficient in Fe and vitamin A, and over 70 % had severe vitamin C deficiency. The findings were reported to the Ministries of Health and Food who instigated a food supplementation policy at the end of 1942 that entitled pregnant women in the UK to extra rations of fruit, dairy produce and to a supply of cod-liver-oil tablets. A second group of 253 pregnant women were studied 15 months later which enabled the effects of this programme to be investigated. Supplementation reduced the proportion of women with vitamin A concentrations below the normal range from 63 % to 38 %, and vitamin C from 78 % to 20 %, but protein and Fe concentrations were not increased but actually declined. These findings continued to exert an influence over government food policy for pregnant women until the abolition of rationing in 1954.

Maternal nutrition: Nutritional deficiencies: Supplements

During the Second World War, the British Government instigated a national food policy of rationing, which aimed to maintain the minimum nutrient intake for the population compatible with health. To monitor the possible effects of rationing, the Government commissioned Dr Hugh Sinclair, an Oxford physiologist and nutritionist, to form a survey group to study the nutritional status of the UK population. Sinclair established the Oxford Nutritional Survey (ONS) (Sinclair, 1951) and began conducting surveys in May 1941. These were performed on population sub-groups considered most at risk of malnutrition, and included pregnant and lactating women.

In this present paper, we provide an historical account of some results from the two prevalence surveys that investigated the nutrition of pregnant women in the UK between 1942 and 1944. The results influenced British wartime food policy and continued to exert an influence until the abolition of food rationing in 1954.

In the last decade many epidemiological studies have been published linking impaired fetal growth with chronic diseases in adult life including hypertension and type 2 diabetes. One of the main determinants of fetal growth is maternal nutrition in pregnancy. Moreover, evidence from both human and animal studies suggests that it is the balance of macronutrients, such as carbohydrate and protein (both animal and vegetable), that a woman consumes which is important, rather than the actual quantity. However, few studies have been able to examine directly the effects of maternal nutrition in pregnancy on the health of adult offspring. The offspring from the two groups of pregnant women recruited by the ONS have now been traced so that the possible effects of maternal nutrient deficiencies on fetal outcome and disease in later life can be further investigated.

Description of the Oxford Nutrition Survey

Study population

Two groups of pregnant women were recruited and followed up until after delivery between April and August 1942 and March and August 1944 respectively. The 1942 group consisted of a sample of 120 working-class pregnant women selected from the Ruskin Maternity Hospital in Oxford, UK, who were in their third trimester of pregnancy.

Abbreviation: ONS, Oxford Nutrition Society.

* **Corresponding author:** Rachel Huxley, fax +44 (0)1865 226720, email rachel.huxley@dphpc.ox.ac.uk

The 1944 group was recruited from the Radcliffe Infirmary Maternity Hospital in Oxford, UK and comprised 253 mainly working-class women, in the first (14 %), second (44 %) or third trimester (42 %) of pregnancy.

Assessment of nutritional deficiencies

Dietary and haematological assessments were performed to evaluate nutritional status. Each subject was interviewed by a dietitian and completed a questionnaire about their usual average household food consumption. The dietary assessment provided little additional information because it was non-specific and was concerned predominantly with the quantity of food the general household consumed in 1 week. A venous blood sample (20 ml) was obtained for haematological and biochemical assays; haemoglobin, haematocrit, red blood cell count, protein, phosphatase, riboflavin, vitamin C, carotene and vitamin A. In addition, a dark-adaptation test using a slit-lamp microscope was performed on each subject. The test consisted of measuring the smallest amount of light which a subject could detect after a minimum of 20 min in complete darkness. The test field used on the retina was 2·5° in diameter fixated 6° above the fovea. The subject then looked into the mask of an adaptometer and fixed their eyes on a small red fixation point. The brightness of the test field was increased until the subject became aware of the flash of light. This was taken as threshold, which represented the number of rod cells in the retina required to detect the flash of light. The intensity of light seen was expressed in log/nLa, which is the log intensity of light detected in lamberts.

Laboratory methods

The laboratory assays that were conducted by the ONS are described together with a quantitative assessment where possible of their specificity and sensitivity. Reference range values for the measured substances are included. Vitamin C was measured colorimetrically after the plasma was oxidised and treated with a hydrazine (Roe & Kuether, 1943). This assay has good precision and a sensitivity of 0·05 mg/dl. Vitamin A was measured using the Carr–Price method (Kimble, 1939, cited in H. M. Sinclair, unpublished results) and carotene was estimated colorimetrically (Kimble, 1941, cited in H. M. Sinclair, unpublished results). These methods are imprecise and non-specific with a low sensitivity and are influenced by moisture. Protein was estimated by the biuret method. In this method the peptide bonds react with Cu ions in alkaline solutions and are measured colorimetrically (Kingsley, 1942, cited in H. M. Sinclair, unpublished results). This method has a sensitivity of 1–15 mg protein. Plasma phosphatase was measured colorimetrically and is based on the reaction between phosphate ions and Mo ions (King *et al.* 1942, cited in H. M. Sinclair, unpublished results). Sensitivity and specificity are low due to reagent instability, rapid deterioration of colours and poor linearity. Urinary riboflavin was measured fluorimetrically (Huff & Perlzweig, 1943). This assay lacks precision and sensitivity as the fluorimetric end-product is very unstable. Haematocrit was assessed using the densitometric method (Wintrobe, 1933, cited in H. M. Sinclair, unpublished results). It has high specificity, sensitivity and precision. The ONS used 'arbitrary' values for classifying subjects as 'normal', 'low' and 'very low'. These values were assigned by Sinclair, but there is good agreement between the range considered 'normal' by the ONS with more recent reference ranges quoted in the literature (Thomas, 1994).

Wartime data handling

The dietary, biochemical and demographic findings for each of the subjects were entered onto a separate case record. The data were subsequently transferred onto cards that recorded information by means of punched holes. These cards, which were divided into various sections, had two series of holes around the edges. This enabled the symptoms to be grouped into three categories, 'present, marked or severe', by placing a line between the inside and the outside holes if the condition was marked, or between the inside hole and the number if the condition was severe. In this way, each of the cards contained a detailed record of over 120 different variables. In 1996 the data from these cards were double-key entered onto a computer database and later analysed using SPSS (SPSS UK Ltd, Woking, Surrey, UK).

Current data handling and statistical analyses

The mean and standard errors were calculated for each of the measured variables in both groups. The difference between the means was obtained and the 95 % CI for the differences were calculated. The 25th centile for each variable was calculated for the 1942 group. The percentage of 1944 subjects at or below this value was then calculated as a means of assessing the effect of dietary supplementation introduced by the Department of Health in response to the earlier findings of the 1942 study.

Results

The dietary questionnaires were non-specific and were concerned predominantly with the quantity of food the general household consumed in 1 week, and are therefore not considered further in this paper.

Biochemical information was available on a total of 373 pregnant women and the results for the participants of two groups are shown in Table 1. In the 1942 group, less than 50 % of the subjects had values within the reference range for haematocrit, red blood cell count, vitamin A, vitamin C and phosphatase. By contrast, 75 % of the subjects had values within the reference range for protein, carotene, riboflavin and dark adaptation.

In the 1944 group, most subjects had values within the reference range for protein, vitamin A, vitamin C, riboflavin, dark adaptation and phosphatase. By contrast, only a third of subjects had a haemoglobin score within the reference range and only 10 % of the participants had values within the reference range for haematocrit and red blood cell count. The results from the two groups are shown in Table 1. There were significant statistical differences between the 1942 and 1944 groups in all biochemical measurements ($P < 0{\cdot}001$) except for haematocrit ($P = 0{\cdot}47$) and carotene ($P = 0{\cdot}22$).

Table 1. Comparison of the biochemical results for the 1942 and 1944 groups of pregnant women in Oxford, UK*

	Units	Arbitrary standards		Subjects in normal range (%)		Mean value with standard error						25th centile for the 1942 group	1944 subjects at or below 25th centile (%)
						1942			1944				
		Low	Very low	1942	1944	Mean	SE	*n*	Mean	SE	*n*		
Haemoglobin	% Haldane	< 85	< 75	53·1	36·6	84·1	1·1	98	80·4	0·54	232	77·0	33·6
Haematocrit	%	< 40	< 35	15·0	7·3	35·7	0·32	94	36·0	0·19	234	33·5	18·4
Red blood cell count	millions/cm^2	< 4·5	< 4·0	31·3	11·6	4·3	0·06	81	3·9	0·05	86	4·0	61·6
Protein	g/100 ml plasma	< 6·3	< 5·5	77·1	50·8	6·6	0·04	106	6·3	0·02	236	6·3	49·2
Vitamin A	IU/100 ml plasma	< 70	< 35	36·6	62·0	63·4	2·3	70	76·8	1·6	229	52·0	18·3
Carotene	IU/100 ml plasma	< 70	< 35	100·0	97·8	167·1	5·5	74	177·2	4·3	231	131·0	26·8
Vitamin C	mg/100 ml plasma	< 0·5	< 0·1	22·6	81·9	0·27	0·03	109	0·81	0·02	216	0·01	0·0
Riboflavin	µg/100 ml urine	< 10	< 5	82·1	100·0	18·1	1·3	39	36·8	0·6	145	12·5	0·0
Dark adaptation	Log/nLa	> 2·1	> 2·5	88·6	98·8	1·95	0·02	108	1·71	0·01	160	2·10	1·0
Phosphatase	King phosphatase units/100 ml	> 10	> 16	4·0	68·0	21·4	0·92	102	8·5	0·53	147	25·3	2·7

*Data collected by HM Sinclair (unpublished results).

The 25th centile for each of the measured biochemical variables was calculated for the 1942 group. The proportion of subjects from the 1944 study at or below the 1942 values were calculated to determine whether supplementation had any significant effect on diet. Fig. 1 illustrates the differences between the two groups. It shows a greater proportion of women from the 1944 group having scores surpassing the 25th centile for vitamins A, C, riboflavin, phosphatase and dark adaptation. However, it also shows that a greater proportion of the 1944 group had scores lower than the 25th centile for haemoglobin, red blood cell count and protein.

Analysis of the infant birth weights of the participants in both the 1942 and the 1944 groups suggests that on average infants born to the 1942 group were 174·7 g (95 % CI 52·7, 296·7) heavier than those born to the 1944 group ($P = 0{\cdot}01$). The mean birth weight of infants born in 1942 was 3323 g (95 % CI 3238, 3408) compared with a mean birth weight of 3148 g (95 % CI 3060, 3236) in the 1944 study. The number of infants with birth weights below 2500 g was also significantly different ($P = 0{\cdot}04$); 2·7 % of infants in the 1942 group were at or below 2500 g compared with 13·7 % of infants in the 1944 group.

Discussion

The results from the 1942 study showed marked deficiencies in the plasma concentrations of vitamins A and C in over two-thirds of pregnant women. In a smaller proportion possible deficiencies in protein and Fe also occurred. Elevated phosphatase concentrations suggest that there may have been deficiencies in Ca and vitamin D, but the data are difficult to interpret as fetal bone formation elevates plasma phosphatase. The observed changes in the amount of macro- and micronutrients in the diets of pregnant women in 1942 and 1944 are in agreement with the values quoted by the first report of the National Food Survey Committee. Between 1942 and 1945 the estimated consumption in urban working-class households of milk, eggs, fresh fruit and vegetables increased whilst the consumption of meat fell. Consequently, the average consumption of energy, Ca, vitamin A, vitamin C, vitamin D and riboflavin were higher in 1944 than in 1942, whilst protein consumption fell and Fe intakes remained unchanged (Ministry of Food, 1951).

The potential limitations of the contemporary assay performance should be considered. The haemoglobin, haematocrit, red blood cell count, plasma vitamin C and protein assays are likely to have had acceptable accuracy and reproducibility. However, the methods used for measurement of urinary riboflavin, vitamin A, carotene and phosphatase were found to have a low level of precision compared with modern assays. However, since nearly 400 women were studied, there was adequate statistical power to demonstrate statistically significant differences ($P < 0{\cdot}001$) in all biochemical measurements excluding haematocrit and carotene.

The results of the 1942 survey were reported to the National Standing Committee on Medical and Nutritional Problems (Lloyd, 1991). In an unpublished internal ONS report, Sinclair stated that the Ministries of Health and Food responded in December 1942 by issuing orange juice and cod-liver oil. In April 1943, capsules or tablets were made available as an alternative to cod-liver oil to pregnant

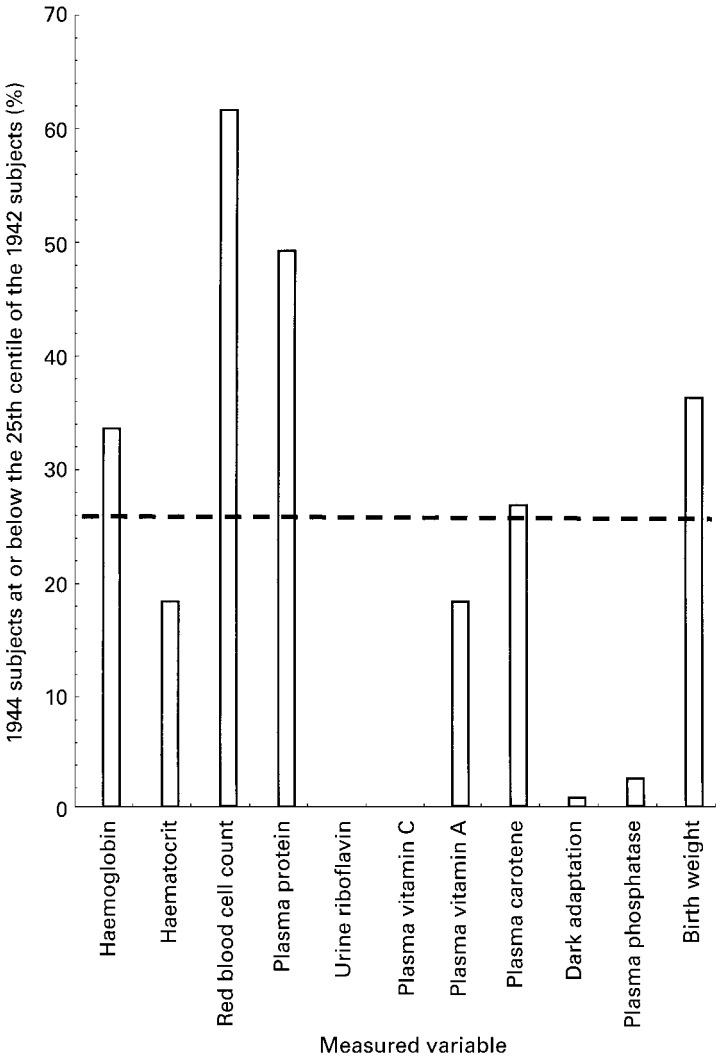

Fig. 1. Effects of dietary supplementation during World War 2 on biochemical and physiological measures of nutrition in pregnant women: assessment of a group of women in 1944 in comparison with the 25th centile of a group surveyed in 1942 (data collected by H. M. Sinclair, unpublished results).

women (HM Sinclair, unpublished results). These contained 4000 IU vitamin A and 800 IU vitamin D. In July 1943 the scheme was extended to include extra rations of 7 pints (3·98 litres) of milk per week in addition to the usual allocation, together with extra eggs and meat. They were also accorded the same priority as children for oranges. A larger study was undertaken 15 months later specifically to examine the effects of this initiative in another group of pregnant women (HM Sinclair, unpublished results). The majority of women from this second study had significantly higher plasma levels of vitamins A, C and riboflavin, and improved dark-adaptation scores, possibly reflecting an increased dietary intake of vitamin A. Plasma phosphatase concentrations were significantly lower in this group, suggesting that there was a deficiency in vitamin D and Ca in the earlier group, which was subsequently corrected by extra milk and egg rations.

These biochemical data provide a unique insight into the diets of pregnant women in the UK during the Second World War. However, comparisons between the two groups need to be interpreted with caution because they differed in the stage of pregnancy. All the women in the 1942 group but only 42 % of the women in the 1944 group were in the third trimester of pregnancy when the assessments were made. Haemodilution would have led to an underestimate of the biochemical indices of nutrient intake in the 1942 group and an overestimate of the effects of supplementation in the 1944 group. Nevertheless, the women in the 1942 group had significantly higher haemoglobin, red blood cell and protein levels compared with women in the 1944 group. This suggests that despite supplementation, subjects in the 1944 group had a higher prevalence of anaemia and protein deficiency, which may indicate an increasing scarcity of meat with the increasing duration of the war, and indeed according to Government figures the average consumption of meat fell from 1942 to 1945 (Ministry of Food, 1951).

Between 1941 and 1946, the ONS conducted surveys on over 15 000 individuals, typically collecting information on over 100 variables. Surveys were conducted in Britain and in other European countries, including the Netherlands, where data were collected on the Dutch Famine, which occurred between November 1944 and March 1945 when the Nazi regime imposed a food blockade on the country. Since these studies were conducted before the advent of computers, most of the collected data (over 2 million items of data) remained unanalysed, and almost none of the findings have been published. We are using the data from the ONS 50 years later to investigate the effects of biochemical indices of maternal nutrition on levels of CHD risk factors in the adult offspring from these two wartime groups of pregnant women.

Few studies have investigated the effect of maternal undernutrition in pregnancy on offspring (Stanner *et al*. 1997; Ravelli *et al*. 1998). However, there is considerable evidence from animal studies that feeding pregnant dams a low protein–energy diet produces offspring that have impaired glucose tolerance (Dahri *et al*. 1991) and raised blood pressure (Langley-Evans *et al*. 1996). In human subjects, prenatal exposure to famine, particularly during mid to late gestation, has recently been linked to decreased glucose tolerance in adult life. This was demonstrated in a study of 700 people born during the 5-month period of severe famine in the Netherlands in 1944–45 (Ravelli *et al*. 1998). On the basis of these results, it was suggested that fetal undernutrition may 'programme' permanent changes in insulin–glucose metabolism. However, a study on the offspring of the Leningrad Siege Study found no evidence of an association between fetal nutrition and impaired glucose tolerance in adult life (Stanner *et al*. 1997). Thus, the question of an association between maternal nutrition and glucose tolerance in adult offspring remains unresolved. We are investigating this hypothesis by studying the middle-aged offspring of members of the 1942 and 1944 groups of the ONS. If changes in insulin–glucose metabolism are shown to occur in the offspring of these two groups of mildly undernourished pregnant women, the implications may be important for the offspring of mothers consuming diets deficient in essential nutrients during pregnancy. These deficiencies may occur with diets characterised by intakes high in processed food and low in fruit and vegetables, typical of modern eating habits (Gibney *et al*. 1989).

In summary, the initial survey conducted in 1942 by Sinclair provided clear evidence of deficiencies in various vitamins, protein and Fe in pregnant women. The subsequent survey in 1944 demonstrated that additional food rations significantly reduced the prevalence of vitamin deficiencies, although there was little effect on Fe and protein levels. The results of the ONS were never published and no record of any statistical comparison between these two groups has been found in Sinclair's extensive archives. Our reanalysis however, using the original biochemical data, confirm the conclusions of the 1942 survey which demonstrated the need for additional food supplementation in pregnancy. These findings influenced government food policy for pregnant women until the abolition of rationing in 1954.

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