

Low-sodium diet in pregnancy: effects on blood pressure and maternal nutritional status

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In ninety-four Dutch nulliparous women the effects of a low-Na diet in pregnancy on blood pressure, energy and nutrient intake, Ca metabolism, Zn and Mg status and body composition were studied longitudinally. The women were randomly divided into an intervention group (n 41), which used a low-Na diet (mean urinary Na excretion 61 mmol/24 h) from week 14 of pregnancy until delivery and a control group (n 53; mean urinary Na excretion 142 mmol/24 h). No effect of the diet on blood pressure was observed. The use of a low-Na diet resulted in significantly reduced intakes of energy, protein, carbohydrates, fat, Ca, Zn, Mg, Fe and cholesterol. However, the women on the low-Na diet appeared to be able to adapt quite well to the reduced intake since Ca, Zn and Mg homeostasis was maintained. In the case of Ca and Mg this was probably due to the observed reduced urinary excretions of these nutrients. Non-significant reductions in weight gain (1.5 kg) and fat-mass gain (0.9 kg) over pregnancy were found in the women on the low-Na diet. No significant effects of the diet on birth weight or placental weight were observed.

Pregnancy: Sodium: Blood pressure: Nutritional status

The present study was part of a multicentre controlled randomized study, in which the prophylactic effect of a low-Na diet during pregnancy on hypertensive disorders was evaluated (B. J. A. Van Buul, E. A. P. Steegers, G. D. Van der Maten and T. K. A. B. Eskes, unpublished results). Thus far not much consideration has been given to the (patho)-physiological consequences of a change in Na intake for mother and fetus. Therefore, each centre also studied different possible side-effects of the low-Na diet. In the present study the results for the additional variables studied at the hospital Groot Ziekengasthuis are described. The aim of the study was to investigate, besides an effect on blood pressure, the effects of a low-Na diet in pregnancy on maternal energy and nutrient intake, Ca metabolism, Zn and Mg status, weight gain and body-fat storage. Since there are indications that nutrition, mineral and trace element status and body composition are related to pregnancy outcome, in affecting these variables a low-Na diet may have implications for the health of the mother and fetus (Institute of Medicine, 1990).

SUBJECTS AND METHODS

Study design

Ninety-four nulliparous women visiting the antenatal clinic of the hospital Groot Ziekengasthuis were studied longitudinally from early pregnancy until 6 weeks post-partum. Pregnancies were dated using the first day of the last menstrual period. After baseline measurements, at week 13 of pregnancy, the women were randomly assigned (by closed envelope system) to an intervention group (I-group), which used a low-Na diet from week 14 of pregnancy onwards until delivery, and a control group (C-group), which continued its *ad libitum* dietary intake. Blood pressure, heart rate, food consumption, blood and urinary analyses, body weight and skinfold thicknesses were measured during pregnancy and post-partum. In addition, infant birth weight and placental weight were obtained. The protocol was approved by the Ethical Committee of the hospital.

Subjects

One hundred and twenty-one pregnant women consented to participate after being given extensive oral and written information. They were all Caucasian, nulliparous women with singleton pregnancies. None of the participating women had a personal history of hypertension or used any medication at the entry of the study, except for four women equally divided over both groups investigated, who continuously used vitamin-mineral-trace element supplements. During the study no vitamin, mineral or trace element-containing supplements were prescribed except for ferrous (twenty-five women in each group) and pteroylglutamic (folic) acid (three women in the I-group and four women in the C-group) tablets for the treatment of anaemia. Mg-containing antacids were used by four women in the I-group and eight women in the C-group (containing maximum 700 mg Mg/d). Sixteen of the original fifty-seven women in the I-group were excluded for various reasons; nine women refused further cooperation because they experienced the diet as too difficult an exercise, one woman developed a hyperemesis, three women used ritodrine for several weeks (a tocolytic agent, which may result in increased Na and water retention; Armson *et al.* 1992) and three obese women ($\text{BMI} \geq 30 \text{ kg/m}^2$; it has been suggested that obese people may not report their habitual food intake validly (Cameron & Van Staveren, 1988) and measurement of skinfold thicknesses is less reliable in obese subjects (Weststrate & Deurenberg, 1988)). In the C-group eleven of the sixty-four women were excluded; one woman withdrew for personal reasons, one woman switched over to a low-Na diet because of a hypertensive disorder, three women used ritodrine for several weeks and six women were excluded because of obesity. As a result, the data for forty-one women in the I-group and fifty-three women in the C-group were analysed. Characteristics of the participants are shown in Table 1. No significant differences were observed between the I- and C-groups with regard to these characteristics.

Dietary intervention

Throughout pregnancy women in the I-group received dietary instructions from and guidance by a trained dietician. The dietary instructions were based on a dietary Na intake of approximately 20 mmol (about 500 mg/d). The women received a brochure listing the products that were allowed or forbidden, a brochure with recipes and a list with the Na content of several products. Practical advice was given regarding shopping locations and commercial products available. The women in the C-group were instructed to maintain

Table 1. *Maternal and infant characteristics*
(Mean values and standard deviations)

	Intervention group		Control group	
	Mean	SD	Mean	SD
No. of women	41		53	
Age (years)*	29	5	28	4
Height (m)*	1.679	0.056	1.675	0.065
Body weight (kg)*	64.7	8.4	65.8	9.0
Body mass index (kg/m ²)*	22.9	2.1	23.5	2.9
Body fat mass (kg)*	19.7	4.7	21.3	5.2
Length of gestation (d)	279	10	278	10
Smokers during pregnancy (%)	34 (n 14)		21 (n 11)	
Vaginal delivery (%)	95 (n 39)		94 (n 50)	
Spontaneous delivery (%)	76 (n 31)		62 (n 33)	
Boys/girls	22/19		27/26	
Birth weight (g)	3236	481	3207	459
Baby length (mm)	500	20	490†	20
Baby head circumference (mm)	330	20	340	20
Arterial pH cord blood	7.21‡	0.08	7.22†	0.08
Arterial base deficit cord blood (mmol/l)	8‡	5	7†	4
Placental weight (g)§	480	104	486	85
Breast feeding (%)	49 (n 20)		53 (n 28)	

* At entry of study (week 13 of pregnancy).

† n 48.

‡ n 39.

§ Measured without cord and membranes.

|| n 40.

their usual eating pattern. To the women in both groups no instructions were given by the dietician regarding the adequacy of their diet, nor did they receive any dietary advice from their obstetricians.

Blood pressure and heart rate

Systolic, diastolic and mean arterial blood pressure and heart rate were measured at the right arm, after 4 min rest, with an automatic microcomputer-assisted instrument using the oscillometric technique (Dinamap 1846 SX, Critikon Inc., Tampa, USA). Blood pressure and heart rate were measured twice in the sitting position followed by twice in the left lateral recumbent position, each time with an interval of 4 min. The mean values of blood pressure and heart rate in the sitting position and in the left lateral recumbent position were calculated and used for further analyses.

Food consumption

Food consumption was measured over seven consecutive days by the weighed record technique (Cameron & Van Staveren, 1988). The women weighed and recorded each item of food or drink immediately before consumption and all plate waste, edible and inedible, at the end of the meal. Weighing was done on an electronic kitchen scale that allowed zeroing-out of a series of foods weighed on the same plate (Type 39308, Tefal SA,

Rumilly, France; weighing range 0–4000 g, accuracy ± 1 g). Recipes had to be written down accurately and the individual portion had to be weighed. The women were instructed to describe all the recorded products in detail (e.g. fresh or frozen, raw or cooked, brand names). If weighing was not possible, the women recorded the consumed food and drink items in household measures or in number eaten. The amount of salt added during cooking or at the table and the daily intake of medicines were not recorded. At the end of each study period the dietician reviewed the records with the women for accuracy and completeness. After the conversion of the recorded food and drink items into food codes according to the Dutch food encoding system (Stichting Nevo, 1986), the average daily intake of energy and nutrients was calculated using the Dutch computerized food composition table (Stichting Nevo, 1986). For Fe-fortified products the codes of the identical products without the extra Fe were used. Fe-fortified products contain excessive amounts of Fe and were only used by a few women in the second half of their pregnancy. Therefore, including the extra Fe would complicate the interpretation of the Fe intake at a group level. Additional data on Na-restricted foods and on Zn and Mg values of foods were added to the food composition table. Values were based on different literature sources. When no data on Zn and/or Mg contents were available, values for similar foods were used, thus avoiding systematic underestimation of Zn and Mg intake due to missing data.

Blood sampling and analysis

Blood samples were taken after an overnight fast at weeks 13, 16, 20, 24, 28, 32, 36 and 40 of pregnancy. Blood was collected in heparinized vacuum tubes for the measurement of ionized Ca, in EDTA vacuum tubes for the measurement of haemoglobin and packed cell volume, in Li-heparin gel vacuum tubes for the measurement of total Ca and albumin and in vacuum tubes without additives for the measurement of parathyroid hormone, Zn (metal-free vacutainer, BD, Rutherford, NJ, USA) and Mg (acid-rinsed tubes). Anaerobic conditions were preserved throughout collection and analysis as long as possible. Particular attention was paid to avoid environmental Zn and Mg contamination during blood collection and analysis by using stainless steel needles, acid-rinsed glassware and pipettes. The blood in the plain tubes were allowed to clot at room temperature and centrifuged at 2500 g for 10 min, after which the serum was separated. The measurements were done immediately, with the exception of parathyroid hormone for which a sample of the serum was stored at -20° until assayed. Haemolytic samples were excluded. Plasma total Ca was measured using orthocresolphthalein complex (EPx, Abbott, Chicago, USA) (Connerty & Briggs, 1966). Circulating ionized Ca was measured by a Ca-specific electrode (Corning 288, Ciba Corning, Halstead, Essex). Serum parathyroid hormone, which was only measured at weeks 13, 20, 28 and 36 of pregnancy, was determined by a commercially available immunoradiometric assay directed to the intact human parathyroid molecule (DPC, Los Angeles, USA). Serum Zn and Mg were measured by flame atomic absorption spectrophotometry (PU 9000, Pye Unicam, Cambridge, Cambs.) (Perkin-Elmer Corporation, 1971). Albumin was measured by use of the bromocresol green-dye binding technique (EPx, Abbott, Chicago, USA) (Gustafsson, 1976). The overall coefficients of variation (combined within-run and between-run variability) for circulating total Ca, ionized Ca, parathyroid hormone, Zn, Mg and albumin was calculated as 1.8, 7.7, 10.2, 4.0, 2.5, and 2.1% respectively. Haemoglobin and packed cell volume were obtained by a haematological cell counter (NE-8000, Sysmex, Kobe, Japan).

Urinary sampling and analysis

Urine samples (24 h) were collected in plastic containers (2.5 litres, rinsed with 1 M HCl) for the determination of volume, Ca, Zn, Mg, Na and creatinine. They were handed in at the same time as blood samples were taken plus at 1 and 6 weeks post-partum. Urinary Ca, Zn and Mg were obtained by flame atomic absorption spectrophotometry (PU 9000, Pye Unicam) (Perkin-Elmer Corporation, 1971). Urinary Na was determined by flame photometry (Corning 460, Ciba Corning). Urinary Na excretion was not only expressed as mmol/24 h, but also per unit of creatinine excreted, to avoid possible errors arising as a result of incomplete collection. The urinary creatinine was determined by the colorimetric method of Jaffé (VP, Abbott, Chicago, USA) (Tietz, 1976). The overall coefficients of variation for urinary Ca, Zn, Mg, Na and creatinine were 2.1, 4.0, 2.5, 1.6 and 2.0% respectively.

Maternal body weight and fat mass

Body weight was measured on an electronic scale (Mettler TE/J, Mettler Instrumente AG, Greifensee, Switzerland; weighing range 2.50–120.00 kg, accuracy 0.05 kg), with the women wearing minimal clothing. On all subjects skinfold thicknesses were measured at four sites of the body (triceps, biceps, suprailiac and subscapular; Durnin & Rahaman, 1967). The readings were done, generally by one person, on the left side of the body in triplicate using a Holtain caliper (Holtain Ltd, Crymych, Dyfed; correct to 0.2 mm). Body density of each individual was derived from the sum of the averages of the four skinfold thicknesses using the equations of Durnin & Womersley (1974). Body fat mass was calculated from body density and body weight using Siri's equation (Siri, 1956).

Infant and placental weight

Immediately after delivery the weight of the infant was measured by the nurse in the delivery room on a spring balance (type Piccolo, Berkel, Rotterdam, The Netherlands; accuracy ± 10 g) or electronic scale (type 680MKII, Berkel, accuracy ± 5 g). The placental weight was measured without cord and membranes on a spring balance (Soehnle, Murrhardt, Germany; accuracy ± 10 g) by the physician on duty or his intern.

Statistics

Longitudinal data were analysed by ANOVA for repeated measurements designs. If a significant effect of stage of pregnancy or stage post-partum occurred, Tukey's studentized range test was used to compare mean values. At certain stages of pregnancy and post-partum changes from baseline values were also tested by paired *t* tests. To test differences (in changes from baseline values) between two groups two-sample *t* tests were performed. The Shapiro-Wilk test was used to evaluate whether the data were a random sample from a normal distribution. Data for some maternal and infant characteristics (smoking, vaginal delivery, infant sex and breast feeding) were arranged in contingency tables and tested by the χ^2 test. In all tests, *P* values were considered significant at the 5% level. Data analysis was carried out using the program provided by SAS (SAS Institute Inc., 1989, 1990).

RESULTS

Urinary sodium excretion

Urinary Na excretion during pregnancy and post-partum is shown in Fig. 1. Before intervention, at week 13 of pregnancy, mean urinary Na excretion was 148 (SD 62) mmol/24 h in the I-group and 142 (SD 54) mmol/24 h in the C-group. The difference was not significant. During the period of intervention, while in both groups no significant changes in urinary Na excretion were observed, mean urinary Na excretion was 61 (SD 30) mmol/24 h for the I-group and 142 (SD 40) mmol/24 h for the C-group ($P < 0.0001$). Post-partum values of urinary Na excretion were not different from those at week 13 of pregnancy. Urinary Na excretion rates expressed per mmol creatinine excreted (Fig. 1) paralleled those expressed as mmol/24 h. Mean urinary Na:creatinine ratios before the start of the intervention were comparable in the I- and C-groups, with values of 12.2 (SD 3.9) and 12.3 (SD 3.6) respectively. During the period of intervention the mean Na:creatinine ratio was 5.8 (SD 3.3) in the I-group, which was significantly different from the 12.7 (SD 2.2) in the C-group ($P < 0.0001$).

Blood pressure and heart rate

Results for systolic and diastolic blood pressure in the sitting position are shown in Fig. 2. During pregnancy the lowest systolic and diastolic blood pressure values were found at week 20 for both groups studied. The change in blood pressure and heart rate over pregnancy was calculated by subtracting blood pressure and heart rate at week 13 of pregnancy from the last recorded blood pressure and heart rate during pregnancy. Based on

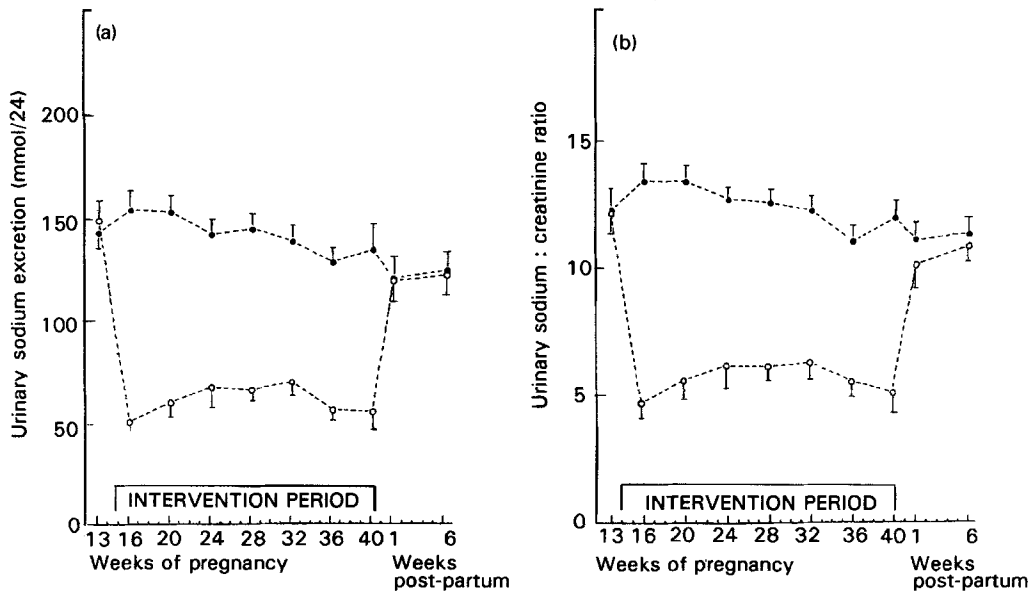


Fig. 1. Urinary sodium excretion during pregnancy and post-partum expressed in (a) mmol/24 h and (b) per unit of creatinine excreted in women consuming a low-sodium diet (intervention group, ○) and a control group (●). Values are means with their standard errors represented by vertical bars. Until week 36 of pregnancy and at 6 weeks post-partum: control group n 53; intervention group n 41. At week 40 of pregnancy: control group n 18; intervention group n 15. At week 1 post-partum: control group n 44; intervention group n 35.

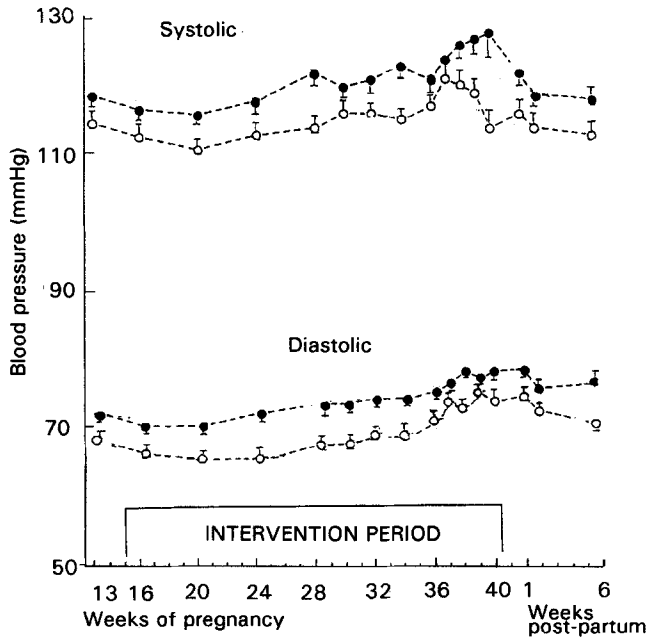


Fig 2. Systolic and diastolic blood pressure values, measured with subjects in the sitting position during pregnancy and post-partum in women consuming a low-sodium diet (intervention group, ○) and a control group (●). Until week 36 of pregnancy and at 6 weeks post-partum: control group, n 53; intervention group, n 41. At weeks 37, 38, 39 and 40 of pregnancy respectively: control group, n 51, 46, 36, 18; intervention group, n 38, 37, 25, 15. At weeks 1 and 2 post-partum respectively: control group, n 44, 49; intervention group, n 35, 39. Values are means with their standard errors represented by vertical bars.

these calculations, systolic, diastolic and mean arterial blood pressure in the sitting position increased significantly over pregnancy in the I-group (by 6, 6 and 7 mmHg respectively) and the C-group (by 7, 6 and 7 mmHg). Also in the left lateral recumbent position systolic, diastolic and mean arterial blood pressure increased significantly over pregnancy in the I-group (by 3, 4 and 6 mmHg respectively) and the C-group (by 5, 5 and 6 mmHg). Non-significant increases in heart rate over pregnancy were observed in the I-group (by 2 and 1 beats/min in the sitting and left lateral recumbent positions respectively) and in the C-group (by 2 and 0 beats/min in the sitting and left lateral recumbent positions respectively). The changes in systolic, diastolic and mean arterial blood pressure and heart rate over pregnancy were not significantly different between the I- and C-groups. Based on the differences in blood pressure and heart rate between week 13 of pregnancy and 6 weeks post-partum, no significant differences were found in blood pressure and heart rate at 6 weeks post-partum, in both positions measured, between the I- and C-group.

Energy and nutrient intake during pregnancy and post-partum

Daily energy and nutrient intakes during pregnancy in the I- and C-groups are shown in Tables 2 and 3. ANOVA on energy and nutrient intake did not show significant changes during the period of intervention within the I- and C-groups. Therefore mean intake over this period (at weeks 20, 28 and 36 of pregnancy) was taken and subsequently the changes in intake between intervention period and baseline (week 13 of pregnancy) were calculated (see Tables 2 and 3). Based on the changes in the I- and C-groups, the daily intakes of

Table 2. Daily energy and macronutrient intakes during pregnancy for women consuming a low-sodium diet (n 41, intervention group, I) and controls (n 53; C)‡
(Mean values and standard deviations)

	Group	Pre-intervention (week 13)§		Intervention (mean of weeks 20, 28, 36)		Difference		Recommended value
		Mean	SD	Mean	SD	Mean	SD	
Energy (MJ/d)	I	9.3	1.7	8.0	1.5	-1.3*††	1.6	9.3
	C	8.4	1.6	8.8	1.5	0.4*	1.3	
Protein (g/d)	I	77	18	65	10	-12*††	16	70
	C	72	17	73	15	1	13	
Protein (% energy)	I	14	2	14	2	0	2	
	C	15	3	14	2	0	2	
Carbohydrates (g/d)	I	255	47	235	57	-20*††	46	
	C	239	53	250	52	11*	39	
Carbohydrates (% energy)	I	47	5	50	5	3*††	5	55
	C	48	6	48	5	0	5	
Fat (g/d)	I	99	26	78	17	-21*††	22	
	C	86	21	90	19	5	19	
Fat (% energy)	I	39	5	36	4	-3*††	5	30-35
	C	38	5	38	4	0	4	
Alcohol (g/d)	I	0.7	1.8	1.1	2.2	0.4	1.7	
	C	0.1	0.3	0.3	0.8	0.3*	0.9	
Alcohol (% energy)	I	0.2	0.7	0.4	0.8	0.2	0.6	
	C	0.0	0.1	0.1	0.2	0.1*	0.2	

* Difference between pre-intervention and intervention values was significantly different from zero, $P < 0.05$.

†† Mean difference was significantly different from that for group C, $P < 0.01$.

‡ For details of subjects, see Table 1.

§ n 52 at week 13 of pregnancy for group C.

|| Voedingsraad (1992).

energy, protein, carbohydrates, fat, Ca, Na, Zn, Mg, Fe and cholesterol were significantly reduced during the period of intervention in the I-group, when compared with the C-group. In addition, during the intervention period in the I-group the percentage of energy from fat was significantly reduced, followed by a significant compensatory increase in the percentage of energy from carbohydrates, when compared with the C-group.

Blood and urinary values during pregnancy

Table 4 shows the results for circulating total Ca, ionized Ca, parathyroid hormone, Zn, Mg, haemoglobin, packed cell volume and albumin, and urinary Ca, Zn and Mg at weeks 13, 32 and 36 of pregnancy for the I- and C-groups. Significant decreases in circulating total Ca, ionized Ca, Zn, Mg, haemoglobin, packed cell volume and albumin, and significant increases in circulating parathyroid hormone and urinary Mg excretion during pregnancy were found in the C-group. Urinary Zn excretion increased during the second half of pregnancy, but it only reached statistical significance at week 40 of pregnancy, when compared with values taken before week 36. With the exception of urinary Ca and Mg excretion, no significant differences in changes over pregnancy in blood and urinary values were observed between the I- and C-groups. Based on the changes over pregnancy, urinary Ca and Mg excretions were significantly reduced during intervention in the I-group, when compared with the C-group.

Table 3. Daily micronutrient, cholesterol and dietary fibre intakes during pregnancy for women consuming a low-sodium diet (n 41; intervention group, I) and controls (n 53; C)†‡§
(Mean values and standard deviations)

	Group	Pre-intervention (week 13)		Intervention (mean of weeks 20, 28, 36)		Difference		Recommended value¶
		Mean	SD	Mean	SD	Mean	SD	
Calcium (mg/d)	I	1041	358	878	290	-163***††	281	800-1000
	C	1036	373	1061	354	35	282	
Sodium (mg/d)	I	2955	853	798	438	-2157***††	977	
	C	2830	619	2671	637	-145	610	
Potassium (mg/d)	I	3577	713	3729	701	152	618	
	C	3207	842	3296	813	101	562	
Zinc (mg/d)	I	10.3	2.4	8.2	1.5	-2.1***††	1.9	12-15††
	C	9.7	2.2	9.7	2.3	0.0	1.8	
Magnesium (mg/d)	I	311	72	283	61	-28***††	47	300-350
	C	278	70	290	69	12	52	
Iron (mg/d)	I	12.0	2.8	10.6	2.1	-1.4***††	2.0	11-19§§
	C	10.8	2.6	10.9	2.8	0.1	2.2	
Cholesterol (mg/d)	I	303	82	236	58	-68***††	87	
	C	269	71	260	56	-10	60	
Dietary fibre (g/d)	I	25	7	24	6	-1	5	
	C	21	6	22	6	1	5	

*** Difference between pre-intervention and intervention values was significantly different from zero, $P < 0.001$.

†† Mean difference was significantly different from that for group C, $P < 0.01$.

‡ For details of subjects, see Table 1.

§ Salt added during cooking or at the table, the daily intake of medicines and the extra Fe in Fe-fortified products are not included.

|| n 52 at week 13 of pregnancy in the C group.

¶ Voedingsraad (1992).

††† 1st trimester 12 mg/d, 2nd and 3rd trimesters 15 mg/d.

§§ 1st trimester 11 mg/d, 2nd trimester 15 mg/d, 3rd trimester 19 mg/d.

Weight gain over pregnancy

Maternal weight gain, as calculated from week 13 of pregnancy, is shown at various stages during pregnancy and post-partum in Fig. 3. Mean maternal weight gain over pregnancy (last recorded body weight during pregnancy minus body weight at entry to the study) was 10.7 (SD 4.1) kg in the I-group and 12.2 (SD 3.9) kg in the C-group. The difference in weight gain of 1.5 kg between both groups was not significant ($P = 0.07$).

Body weight and fat mass in early pregnancy and post-partum

Maternal body weight and fat mass at week 13 of pregnancy and at 2 and 6 weeks post-partum are shown in Table 5. In addition, changes in these variables at 2 and 6 weeks post-partum from week 13 of pregnancy are also given in Table 5. In the I- and C-groups body weights at 2 and 6 weeks post-partum were significantly increased, compared with week 13 of pregnancy. With the exception of a significant increase in fat mass in the C-group at 2 weeks post-partum, no significant changes in fat mass were observed at 2 and 6 weeks post-partum, when compared with week 13 of pregnancy, in either group studied. Based on the differences between post-partum and week 13 of pregnancy, body weight and fat mass

Table 4. Concentrations of different variables in the blood and urine of pregnant women consuming a low-sodium diet (intervention group, I) and controls (C) at weeks 13, 32 and 36 of pregnancy†

(Mean values and standard deviations)

	Group	Week 13			Week 32			Week 36			
		n	Mean	SD	n	Mean	SD	n	Mean	SD	
Circulating	Ca (mmol/l)	I	40	2.24	0.10	41	2.16*	0.11	40	2.16*	0.09
		C	53	2.25	0.09	53	2.14*	0.09	50	2.18*	0.08
	Ca ²⁺ (mmol/l)	I	24	1.17	0.06	27	1.14*	0.09	29	1.13*	0.07
		C	28	1.17	0.07	35	1.15*	0.06	37	1.14	0.06
	PTH (pmol/l)	I	40	0.74	0.57	-	-	-	40	1.32*	0.80
		C	53	0.59	0.52	-	-	-	48	1.35*	0.91
	Zn (µmol/l)	I	40	13.0	1.5	41	10.7*	1.2	40	10.2*	1.1
		C	53	13.0	1.6	53	10.4*	1.3	50	10.3*	1.5
	Mg (mmol/l)	I	40	0.79	0.07	41	0.74*	0.04	40	0.76	0.11
		C	53	0.79	0.06	53	0.74*	0.06	50	0.75*	0.06
	Hb (mmol/l)	I	41	7.8	0.6	41	7.3*	0.5	40	7.4*	0.4
		C	53	8.0	0.6	53	7.4*	0.6	50	7.5*	0.6
	PCV (l/l)	I	41	0.36	0.03	41	0.34*	0.02	40	0.34*	0.02
		C	53	0.36	0.03	53	0.34*	0.03	50	0.35*	0.03
Alb (g/l)	I	22	38.7	3.1	29	33.9*	2.2	28	33.5*	2.1	
	C	27	38.5	2.0	36	33.5*	2.3	34	33.8*	1.8	
Urinary	Ca (mmol/24 h)	I	41	7.26	3.03	40	6.06*†	3.01	41	4.58*†	2.99
		C	51	6.58	2.65	51	6.76	3.39	50	6.11	3.96
	Zn (µmol/24 h)	I	41	6.80	3.53	40	6.73	3.61	41	7.30	3.64
		C	51	7.25	3.59	51	7.43	3.30	50	8.14	3.79
	Mg (mmol/24 h)	I	41	5.16	1.39	40	5.07	1.45	41	4.77†	1.59
		C	51	4.44	1.55	51	4.78	1.73	50	5.06*	1.92

PTH, parathyroid hormone; Hb, haemoglobin, PCV, packed cell volume; Alb, albumin.

* Mean values were significantly different from those for week 13, $P < 0.05$.

† Mean change from week 13 was significantly different from that for the control group, $P < 0.05$.

‡ For details of subjects, see Table 1.

increments at 2 weeks post-partum in the I-group were reduced by 1.5 kg ($P = 0.058$) and 0.9 kg ($P = 0.142$) respectively, when compared with the C-group.

Birth weight and placental weight

No significant differences in infant birth weight or placental weight were found between the I- and C-groups (Table 1).

DISCUSSION

The anthropometric and other characteristics (Table 1) of the women in the I-group and C-group were comparable and agreed well with those previously reported for Dutch pregnant women (Van Raaij *et al.* 1989; Spaaij *et al.* 1994). Also mean urinary Na excretion rates at entry to the study were comparable (148 (SD 62) and 142 (SD 54) mmol/24 h for the I- and C-groups respectively) and in line with those reported for Dutch non-pregnant women (Commissie Verminderend Gebruik Keukenzout, 1986). Despite the fact that randomization took place, significant differences were observed between the I- and C-groups in baseline values of some of the variables studied (diastolic blood pressure and mean arterial pressure in sitting and left lateral recumbent position, the intake of energy and several

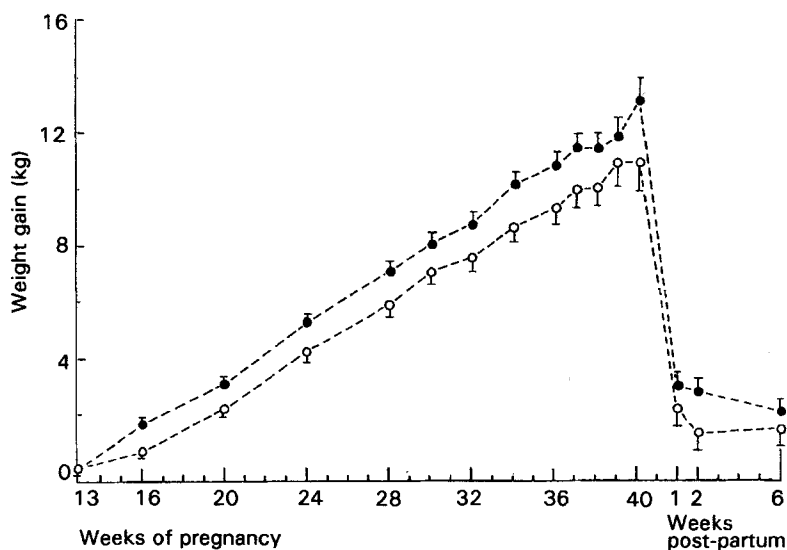


Fig 3. Maternal weight gain, calculated from week 13 of pregnancy, at various stages during pregnancy and post-partum in women consuming a low-sodium diet (intervention group, ○) and a control group (●) Until week 36 of pregnancy and at 6 weeks post-partum: control group, n 53; intervention group, n 41. At weeks 37, 38, 39 and 40 of pregnancy respectively: control group, n 51, 46, 36, 18; intervention group, n 38, 37, 25, 15. At weeks 1 and 2 post-partum respectively: control group, n 44, 49; intervention group, n 35, 39. Values are means with their standard errors represented by vertical bars.

Table 5. Body weight and fat mass measured at week 13 of pregnancy and weeks 2 and 6 post-partum, for women consuming a low-sodium diet (intervention group) and controls‡ (Mean values and standard deviations)

	Intervention group						Control group					
	Weight (kg)			Fat mass (kg)			Weight (kg)			Fat mass (kg)		
	n	Mean	SD	n	Mean	SD	n	Mean	SD	n	Mean	SD
Week 13 pregnancy	41	64.7	8.4	41	19.7	4.7	53	65.8	9.0	53	21.3	5.2
Week 2 post-partum	39	66.3	8.3	38	20.0	4.6	49	68.8	9.2	49	22.2	5.1
Week 6 post-partum	41	66.3	8.5	40	20.3	4.9	53	68.0	9.2	53	22.0	5.1
ΔWeek 2 post-partum	39	1.4*	3.8	38	0.0	3.2	49	2.9*	3.7	49	0.9*	2.6
ΔWeek 6 post-partum	41	1.6†	4.0	40	0.7	2.9	53	2.2†	3.8	53	0.7	2.9

* Change from week 13 of pregnancy to 2 weeks post-partum was significantly different from zero ($P < 0.05$).

† Change from week 13 of pregnancy to 6 weeks post-partum was significantly different from zero ($P < 0.05$).

‡ For details of subjects, see Table 1.

nutrients and urinary Mg excretion). The possibility that these differences occurred as a result of the exclusion of the women who refused further co-operation because they experienced the low-Na diet as too difficult an exercise was rejected, because after including their data most significant differences remained. In our opinion, the consequences of these differences for the results of the present study are limited, since in this longitudinal study only changes from baseline values were used for statistical testing.

Compliance with the diet

In the Netherlands there exists no consensus about the Na restriction that might be prescribed during pregnancy. It varies from 20–100 mmol Na/d. The most extreme form of Na restriction was chosen and therefore the aim of the dietary instructions was to arrive at a dietary Na intake of approximately 20 mmol/d. Although the mean urinary Na excretion during the period of intervention (61 mmol/24 h) clearly indicates that the subjects were not able to adhere to such a strict diet, these women still reduced their urinary Na excretion by more than half their usual amount (148 mmol/24 h) for a period of approximately 6 months of their pregnancy. Apparently, it is not easy to comply with such a strict intervention.

The calculated dietary Na intake in these women (based on food consumption data; 35 mmol/d) was more in agreement with the instructed daily Na intake than their urinary Na excretion (61 mmol/24 h). Several studies have reported that calculated dietary Na intake is less than urinary Na excretion (Caggiula *et al.* 1985; Clark & Mossholder, 1986; Nowson & Morgan, 1988). This can be explained by the inability to account for salt added during cooking or at the table during a food consumption study. However, this does not apply for the observed difference between calculated dietary Na intake and urinary Na excretion in the women on the low-Na diet, since they were not allowed to add salt during cooking or at the table. It is possible that the observed difference in these women was due to inaccurate information on the Na content of Na-restricted foods. However, the possibility that it resulted from under-reporting because of a desire to adhere well to the diet or from still adding salt during cooking or at the table can certainly not be excluded. In the C-group calculated dietary Na intake was 18 % less than urinary Na excretion (116 v 142 mmol/d), which is in line with the results of previous studies in non-pregnant subjects on an *ad libitum* diet (Caggiula *et al.* 1985; Clark & Mossholder, 1986). But, since the women in the C-group were not restricted in adding salt during cooking or at the table, the observed difference between calculated dietary Na intake and urinary Na excretion in these women can be explained, among other things such as an inadequate food composition table (because of biological variability of the Na content of food items), by the exclusion of this added salt during the food consumption study.

Effect of a low-sodium diet during pregnancy on blood pressure

The blood pressure values in the present study confirm the previously described blood pressure pattern during gestation: a decline during the second trimester with an increase thereafter up to term (MacGillivray *et al.* 1969; Moutquin *et al.* 1985). In other publications no such 'midpregnancy dip' was found, although an increase in blood pressure towards term was observed (Schwarz, 1964; Margulies *et al.* 1987). As expected, blood pressure values in the left lateral recumbent position were lower than in the sitting position (Schwarz, 1964; Gallery *et al.* 1977).

The non-significant differences in changes in systolic and diastolic blood pressure over pregnancy between the I- and C-groups were only 1 and 0 mmHg in the sitting position and 2 and 1 mmHg in the left lateral recumbent position, indicating that the low-Na diet had no effect on the course of blood pressure during pregnancy. This is in line with three recent studies in which no effect of salt restriction in pregnancy on blood pressure was found (McEniery *et al.* 1985; Brown *et al.* 1987; Steegers *et al.* 1991). However, in the study of Brown *et al.* (1987) subjects who developed hypertension were excluded and in the study of McEniery *et al.* (1985) compliance was not controlled.

The present study had a statistical power of 80% to detect a difference in change in diastolic blood pressure over pregnancy between the I- and C-groups of 6 mmHg. It was calculated that a reduction in mean diastolic blood pressure from 78 (SD 8) mmHg (= diastolic blood pressure observed pre-delivery in the C-group) to 72 (SD 8) mmHg in pregnant women would reduce the expected incidence of gestational hypertension (diastolic blood pressure ≥ 90 mmHg) from 6.7% to 1.2%.

Using the definition of hypertensive disorders of pregnancy by Davey & MacGillivray (1988), two women (4.9%) in the I-group and three women (5.7%) in the C-group developed gestational hypertension and/or proteinuria (NS). However, one should bear in mind that one woman who had developed gestational hypertension was excluded from the study because she switched over to a low-Na diet. Thus, in fact four women (7.5%) in the C-group developed a hypertensive disorder, which is still not significantly different from the I-group.

Effects of a low-sodium diet in pregnancy on energy and nutrient intake

The intakes of energy and nutrients in the C-group were slightly lower than reported in other studies on Dutch pregnant women (Van den Berg & Bruinse, 1983; Steegers *et al.* 1991). This is possibly the result of the fact that in these studies dietary data were obtained by dietary histories (Cameron & Van Staveren, 1988).

The use of a low-Na diet during pregnancy caused a significant reduction in intake of energy, protein, carbohydrates, fat, Ca, Zn, Mg, Fe and cholesterol. Nowson & Morgan (1988), studying the effect of a low-Na diet on energy and nutrient intake in non-pregnant mildly hypertensive subjects, also observed significant reductions in the intake of energy, carbohydrates, protein, fat, Ca and Mg after the start of the intervention. However, in their control group also significant reductions in the intake of most of these nutrients were found and the differences in reductions between the low-Na diet group and the control group were not tested statistically. A different method of dietary assessment was used during the pre-diet phase, which might have been responsible for the observed changes in dietary intake in both the control group and the low-Na diet group. Significant reductions in intake of energy, macronutrients and Ca were also observed in pregnant women on a low-Na diet in the study of Steegers *et al.* (1991). In this study no micronutrient other than Ca was investigated.

The observed reduction in intake of nutrients in the present study was probably mainly due to the observed reduced energy intake. When the nutrient intake was expressed per 4.2 MJ energy (1000 kcal; nutrient density) only significant reductions in the nutrient densities for fat and Na were observed in the women on a low-Na diet, when compared with the C-group. The nutrient densities for carbohydrates, K, Mg, Fe and dietary fibre were even significantly increased.

These results suggest that a low-Na diet during pregnancy increased the risk of an inadequate supply of energy and several nutrients to the mother and fetus. This particularly applied for the observed reduction in the intakes of Zn and Fe, since the intakes of these two nutrients by the pregnant women in the C-group were already 35% and 43% respectively below the Dutch recommended dietary allowances (Voedingsraad, 1992).

The effect of a low-sodium diet in pregnancy on calcium metabolism and zinc and magnesium status

The observed changes in circulating total Ca, ionized Ca, parathyroid hormone, Zn, Mg and urinary Zn excretion during pregnancy in the C-group have been described earlier (De

Jorge *et al.* 1965; Vir *et al.* 1981; Hambidge *et al.* 1983; Campbell-Brown *et al.* 1985; Pitkin, 1985; Sheldon *et al.* 1985; Tuttle *et al.* 1985; Verhaeghe & Bouillon, 1992). However, urinary Mg excretion increased significantly during pregnancy, in contrast to the study of Roelofson *et al.* (1988), in which no significant change during pregnancy was observed.

Although the use of a low-Na diet resulted in a significantly reduced Ca intake, it had no effect on circulating total Ca or ionized Ca. Also, unexpectedly, no effect of the diet on circulating parathyroid hormone was found, whereas parathyroid hormone is a major factor in Ca homeostasis maintaining circulating Ca levels within narrow limits (Guyton, 1991). A significant reduction in urinary Ca excretion was found in the pregnant women on the low-Na diet. This decrease in urinary Ca excretion could have been due to the reduction in Ca intake, but such an effect is mediated by alterations in, among other things, the secretion of parathyroid hormone (Lemann *et al.* 1979) and this was not found in the present study. The decrease in urinary Ca excretion could also have been due to the reduction in urinary Na excretion, since there are indications in non-pregnant subjects that there is a direct positive relationship between the excretion of Na and Ca by the kidneys (Breslau *et al.* 1982; Castenmiller *et al.* 1985). This direct effect of the reduction in urinary Na excretion on urinary Ca excretion could have counterbalanced the reduction in dietary Ca intake and could explain, at least partly, why no significant changes in other indices of Ca metabolism were observed.

Despite a marginal intake of Zn in the women on the low-Na diet, no significant effect of the diet on serum Zn was observed. In the study of Campbell-Brown *et al.* (1985) significantly lower plasma Zn concentrations during pregnancy were found in Hindus (vegetarian and meat eating) compared with Europeans and it was suggested that these reflected their lower average dietary Zn intake (7.5, 10.2 and 11.6 mg/d for vegetarian Hindu, meat eating Hindu and European pregnant women respectively). The lower dietary Zn intake in the Hindus probably already existed before pregnancy. In the present study Zn intake was only reduced during the second and third trimesters of pregnancy. In non-pregnant subjects experimental Zn depletion resulted in decreased serum Zn concentrations. However, the intake of Zn during depletion was much lower in these subjects than in the pregnant women on the low-Na diet in the present study (0.28–3.5 mg/d v. 8.2 mg/d) (Prasad *et al.* 1978; Baer & King, 1984). Several studies in non-pregnant subjects have reported that urinary Zn responds to variations in dietary Zn and that renal mechanisms operate to preserve Zn homeostasis (Prasad *et al.* 1978; Baer & King, 1984; Taylor *et al.* 1991). However, in the present study no significant effect of the low-Na diet on urinary Zn excretion during pregnancy was found. The difference between the I- and C-groups in the percentage of women taking Fe supplements during pregnancy (61% and 47% of the women in the I- and C-groups respectively), although non-significant, might have influenced the results on Zn status. Since Fe-supplementation has been reported to adversely affect Zn status (Hambidge *et al.* 1987), this also might have added to a negative effect of the low-Na diet on maternal Zn status.

The observed reduced Mg intake in pregnant women on a low-Na diet did not result in a significant effect of the diet on serum Mg concentration. However, a statistically significant reduction in urinary Mg excretion was observed in the women on the low-Na diet. This might have been due to an adaptation to the reduced dietary Mg intake by the kidneys. It has been reported previously that the kidney is an important organ in maintaining Mg homeostasis (Ebel & Günther, 1980; Wester, 1987). It is also possible that, comparable to the observed reduced urinary Ca excretion, the reduced urinary Mg excretion in the women on the low-Na diet was due to the reduced urinary Na excretion.

Hills *et al.* (1959) showed that urinary Na and Mg excretion are positively related, independent of dietary Mg intake. When the data on serum and urinary Mg were analysed after exclusion of the women using Mg-containing antacids, in both groups studied the same patterns in serum and urinary Mg were observed as described earlier. An effect of the diet on packed cell volume (as an indicator for haemodilution) and/or plasma albumin could have influenced the results on the blood values studied, but such an effect was not observed in the present study.

Thus, the results suggest that, although a low-Na diet during pregnancy may reduce the dietary intakes of Ca, Zn and Mg, it will not have an effect on several indices of Ca metabolism, nor will it adversely affect maternal Zn and Mg status. Serum concentrations of Zn and Mg are variables frequently used to assess Zn and Mg status, because they are easy to measure and because there is a lack of more sensitive and reliable indices. However, the fact that they may not always reflect total body Zn and Mg limits the interpretation of the results on serum Zn and Mg in the present study (Solomons, 1979; Ebel & Günther, 1980).

Pregnancy weight gain, fat accumulation and pregnancy outcome in women on a low-sodium diet

The weight gain over pregnancy observed in the C-group (12.2 kg from week 13 of pregnancy) is in accordance with that mentioned by Hytten (1991). Weight retentions in the C-group at 2 and 6 weeks post-partum are also in agreement with earlier reports (Taggart *et al.* 1967; Durnin *et al.* 1987; Van Raaij *et al.* 1989). The significant observed increase in fat mass over pregnancy of 0.9 kg in the C-group is comparable with those observed in earlier studies in which corresponding measurement periods and the skinfold method were used (Durnin *et al.* 1987; Thongprasert *et al.* 1987; Tuazon *et al.* 1987; Van Raaij *et al.* 1989). The infant birth weights and placental weights are in agreement with those described in other Dutch studies (Kloosterman, 1970; Van Raaij *et al.* 1989; Spaaij *et al.* 1994).

The low-Na diet reduced maternal weight gain non-significantly over pregnancy by 1.5 kg. This is not in line with the findings from a comparable study (Stegers *et al.* 1991) in which a much larger reduction in maternal weight gain (about 6 kg) in pregnant women on a low-Na diet was observed.

In the present study also no significant effect of the low-Na diet on fat accumulation over pregnancy was found. The estimate of fat mass increase during pregnancy was based on the difference in fat mass between 2 weeks post-partum and week 13 of pregnancy. The degree of hydration of the subcutaneous tissues influences the thickness of the skinfolds, and the accumulation of water during pregnancy may therefore reduce the validity of the estimates of fat mass from skinfold thicknesses (Hytten, 1991). However, it is unlikely that such bias occurred, since skinfold thicknesses were only measured in early pregnancy and post-partum assuming that at these time periods the accumulation of water is negligible. Some authors have shown that some skinfolds increase more than others during pregnancy, indicating that fat deposition during pregnancy is not equally spread over all adipose tissues (Taggart *et al.* 1967; Forsum *et al.* 1989). This is particularly so for the mid-thigh skinfold. The mid-thigh region is not included in the traditional four-site measurement (Durnin & Womersley, 1974), which has been used in the present study. Therefore fat accumulation during pregnancy and the difference in fat accumulation between the two groups studied may have been underestimated. On the other hand, Butte *et al.* (1985) concluded that specific equations for lactating women are not necessary.

The low-Na diet did not affect birth weight. The present study had a statistical power of 90 % to detect a reduction in birth weight of 10 % in the I-group, when compared with the C-group. No effects of the diet on other variables of pregnancy outcome were found (Table 1).

Conclusions

Although the practice has been abandoned in many countries, in the Netherlands a low-Na diet is still commonly prescribed during pregnancy as a preventive and therapeutic measure in hypertensive disorders. Possible side-effects of such a practice have only very rarely been studied. The results of the present study indicate, in the first place, that despite extensive instructions and guidance, a low-Na diet aiming at 20 mmol/d is not practicable for healthy pregnant out-patients. Furthermore, the use of a low-Na diet in pregnancy resulted in a reduced intake of energy and several nutrients. Nevertheless, the pregnant women appeared to be able to adapt quite well to this reduced intake, since Ca, Zn and Mg homeostasis was maintained. In the case of Ca and Mg this was probably due to the observed reduced urinary excretions of these nutrients. Maternal weight gain was not significantly reduced and there was no effect of the low-Na diet on infant birth weight, which is generally considered to be the best measure of the quality of pregnancy (Hyttén, 1991). Therefore, the results of this study did not show negative side-effects of Na restriction in healthy well-nourished Dutch pregnant women, although it still cannot be excluded that a low-Na diet in pregnancy may have effects on body stores of Ca, Zn and Mg. However, in the light of lack of a beneficial effect of the low-Na diet on blood pressure and the incidence of hypertensive disorders, the prescription of such a diet as a prophylactic measure is not useful.

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