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The influence of dietary sodium restriction on renal and ovarian renin and prorenin production during ovarian stimulation

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In a prospective study, the effect of dietary sodium restriction on plasma and follicular fluid renin and prorenin concentrations and on fertilization measures was investigated during ovarian stimulation. In all, 18 women undergoing ovarian stimulation for in-vitro fertilization and embryo transfer were randomly divided into groups with and without sodium restriction. Plasma renin and prorenin concentrations were higher in the low sodium group than in the normal sodium group. Neither follicular fluid renin and prorenin concentrations, nor the total amount of follicular fluid renin and prorenin per ovary differed significantly between the two groups. Oocyte yield and fertilization rates were similar in both groups. These rates were correlated with neither renin nor prorenin concentrations in follicular fluid. We conclude that sodium restriction did not influence cyclic plasma variations of renin or prorenin or follicular fluid renin and prorenin concentrations. In addition, fertilization rates were not affected by sodium restriction.

Key words: follicular fluid/IVF and embryo transfer/ovarian renin–angiotensin system/ovarian stimulation/sodium

Introduction

Renin is essential for the regulation of a series of reactions leading to the formation of angiotensin II. Angiotensin II is a key hormone in blood pressure regulation and in water, sodium, and potassium homeostasis (Sealey and Laragh, 1995). The kidney is the main, if not the only, source of plasma renin and is also a major source of plasma prorenin, the inactive precursor of renin (Derkx et al., 1976; Sealey et al., 1977). In plasma, ~90% of the total renin concentration circulates as prorenin (Derkx et al., 1983).

Extrarenal synthesis and release of prorenin into the circulation has been demonstrated in various organs, including the ovary (Glorioso et al., 1986; Derkx et al., 1987; Iskowitz et al., 1987). In response to stimulation by gonadotrophic hormones, prorenin is produced and released into the circulation by the theca cells (Do et al., 1988) at the time of ovulation (Sealey et al., 1987) and during pregnancy (Derkx et al., 1986). Both ovulation induction and ovarian stimulation may result in ovarian hyperstimulation syndrome (OHSS; Navot et al., 1992). In its most pronounced form, this iatrogenic syndrome is characterized by massive ovarian enlargement, ascites, pleural effusion, oliguria, hypercoagulability, disturbances in serum electrolytes and stimulation of the renin–angiotensin system (Navot et al., 1987; Ong et al., 1991). Therefore it is conceivable that the ovarian renin–angiotensin system may play a role in the pathogenesis of this syndrome.

Dietary sodium restriction has been advocated as a treatment modality for OHSS (Shapiro et al., 1977; Haning et al., 1985; Balasch et al., 1991). The primary purpose of this pilot study was to examine the effect of dietary sodium restriction on renal and ovarian renin and prorenin production during ovarian stimulation.

Materials and methods

Patients and stimulation protocol

A total of 18 healthy Caucasian women, participating in a programme for in-vitro fertilization (IVF) and embryo transfer, were included in this study. The study was approved by the hospital’s ethical committee and written consent was obtained from each patient. Patients were randomly divided into two groups: those receiving an ad libitum dietary intake of ~100–150 mmol Na\textsuperscript{+}/day (normal sodium diet) (n = 10) and those who were given a sodium-restricted diet of 10–20 mg Na\textsuperscript{+}/day (low sodium diet) (n = 8). Dietary instructions were given by dieticians. The low sodium diet started 10 days before the onset of the ovarian stimulation and was maintained until the end of the IVF cycle (pregnancy test or menstruation).

The mean ± SD age of the patients in the normal sodium group was similar to that of patients in the low sodium group: 33.8 ± 3.7 and 33.6 ± 2.8 years respectively.

The indications for IVF in the normal sodium group (primary infertility n = 6) were: tubal disease (n = 4), severe endometriosis (n = 1), male factor (n = 2), unexplained (n = 2) and combined factors (n = 1). Indications for IVF in the low sodium group (primary infertility n = 3) were: tubal disease (n = 5), severe endometriosis (n = 2) and male factor (n = 1). In both groups there was one patient with only one ovary.

Patients were treated with a gonadotrophin-releasing hormone (GnRH) agonist in a flare-up protocol. From day –13, leuprolide acetate, a short-acting GnRH agonist (Lucrin; Abbott, Amstelveen, The Netherlands), was given 1 mg s.c. daily and continued until...
The Netherlands) were administered daily. Stimulation was monitored by serum oestradiol concentrations and transvaginal, ultrasonographic follicle measuring. Ovulation was induced by the administration of 10 000 IU human chorionic gonadotrophin (HCG) i.m. (Pregnyl; Organon) 6 days after serum oestradiol concentrations reached 1.0 nmol/l. Oocyte retrieval (day 0) was performed 34–35 h later. The luteal phase was supported by 1500 IU HCG i.m. (Pregnyl; Organon) on days +3 (the day of embryo transfer), +6, +9 and +12 after oocyte retrieval.

Physiological parameters

Body weight was assessed in kg to one decimal place (SECA-alpha, Modell 770; Wigro, Nieuwegein, The Netherlands) with the patient wearing clothing but no shoes. After 5 min of rest, while the patient was in a sitting position, blood pressure was measured with an automatic device (BOSO-prestige automatic; Bosch + Sohn, Juningen, Germany). The results of three measurements were averaged.

Body weight and blood pressure were measured at the start of the cycle and on days –4, 0 (oocyte retrieval), +3, +6, +9 and +12.

Sampling of follicular fluid, blood and urine

Follicular fluid

The number of follicles and the follicular diameter (mean of three directions) were measured with an ATL Ultramark 4 (Advanced Technology Laboratories, Scientific Medical Systems, Dordrecht, The Netherlands) just before oocyte retrieval. Follicles were divided into three groups according to their mean diameter: ‘small’ with a mean diameter of ≤9 mm, ‘medium’ with a mean diameter of 10–15 mm inclusive, and ‘large’ with a mean diameter of >15 mm.

Oocyte retrieval was performed with an ultrasound-guided single lumen follicle aspiration needle (Cook, 17 gauge, length 35 cm; William A. Cook Australia, Queensland, Australia). Follicular fluid was collected in scaled tubes and the volume was measured separately for each follicle. After separation of the oocyte, follicular fluid was centrifuged within 5 min at 2000 g for 10 min, and then stored in polystyrene tubes at −70°C.

Blood sampling

Blood was obtained from an antecubital vein, between 08:00 and 12:00 h, after the patient had been recumbent for at least 30 min. Blood sampling was performed on the same occasion as the measurement of body weight and blood pressure and at the end of the cycle. Vacutainers containing disodium ethylenediamine-tetraacetate (final concentration 10 mmol/l) were used and kept at room temperature for no longer than 10 min until plasma was separated by centrifugation at 2000 g for 10 min. Plasma samples were stored at −70°C in polystyrene tubes until further analysis. On the day of oocyte retrieval, blood was collected for assessing the oestradiol concentration.

Urine sampling

Compliance with the diet was checked by measuring the sodium:creatinine ratio in urine samples three times during the cycle: days –4, 0 (day of oocyte retrieval) and +9.

Renin, prorenin and oestradiol assays

Renin and prorenin assays

Plasma and follicular fluid prorenin were converted to renin by the addition of trypsin (Derks et al., 1983). Sepharose-bound trypsin was used at a final concentration of 500 mg/l for 24 h at 4°C. Trypsin was then removed by centrifugation. With this trypsin concentration, maximal conversion of the prorenin to renin was obtained without further breakdown of the renin or prorenin. The recovery of added purified kidney renin was >95%.

Both trypsin-activated prorenin and the native renin were measured using an immunoradiometric assay (Diagnosics Pasteur, Marnes La Coquette, France; Simon et al., 1992). The primary monoclonal antibody recognizing prorenin and renin was bound to magnetizable beads. The secondary monoclonal antibody, which reacted equally well with kidney renin, plasma renin and trypsin-activated prorenin but not with prorenin, was iodinated. The results of this assay were expressed in pg/ml. The lower limit of detection was 3.5 pg/ml. Intra- and interassay coefficients of variation were <6% and <9% respectively. The renin standard used in this kit was calibrated against the World Health Organization renin standard 68/356 (Bangham et al., 1975). One pg of this standard equals 1.6×10⁻⁶ IU.

All samples from each patient were always run in the same assay. The concentration of prorenin in plasma or follicular fluid was calculated by subtracting the results obtained before trypsin activation from those after activation (= renin + prorenin).

Oestradiol assay

Serum samples were assayed with a commercially available oestradiol radioimmunoassay kit (Sorin Biomedica, Amsterdam, The Netherlands). Intra- and interassay coefficients of variation were 2.9% (mean oestradiol concentration 260 pmol/l) and 10.8% (mean oestradiol concentration 290 pmol/l) respectively.

Statistical analysis

To obtain approximately normal distributions, plasma and follicular renin and prorenin, follicular fluid volume and the sodium:creatinine ratio were transformed logarithmically. Therefore outcomes were expressed as geometric means with a 95% confidence interval (CI) or as otherwise indicated. Differences in plasma concentrations of renin and prorenin during the ovarian stimulation cycle in the groups with the low and normal sodium diets were analysed with repeated measures of analysis of variance (ANOVA; Dixon, 1990). The effect of the low sodium diet on the plasma concentrations of renin and prorenin was expressed as a percentage increase (with the 95% CI of this increase) compared with the plasma concentrations during a normal sodium diet.

The effects of a low sodium diet on follicular fluid renin and prorenin concentrations were analysed using a mixed-model ANOVA. For other data, t-tests or non-parametric tests were used when appropriate. Spearman's correlation coefficients were calculated. Proportions were compared with Fisher's exact test. P values <0.05 (two-sided) were considered statistically significant.

Results

Clinical parameters of IVF outcome

In the group with the normal sodium diet the results of one patient were not included because her IVF cycle was cancelled due to inadequate ovarian response. In both groups there was one patient who did not have an embryo transfer because of failed fertilization. The groups were comparable with regard to the duration of ovarian stimulation, i.e. 11.8 (SD 1.9) days for the women with a normal sodium diet and 11.8 (SD 1.9) days for the women with a low sodium diet. In addition, the dose of HMG was similar in both groups: 2.30 (SD 0.70) and 2.37 (SD 0.41) IU HMG/kg/day respectively.

Serum oestradiol concentrations on the day of oocyte retrieval were 3.2 (SD 1.4) nmol/l in the group with the normal sodium diet and 2.9% (mean oestradiol concentration 260 pmol/l) and 10.8% (mean oestradiol concentration 290 pmol/l) respectively.
Effect of a low sodium diet on body weight and blood pressure

The urinary sodium excretion expressed as the sodium:creatinine ratio in urine was significantly lower in the low sodium group than in the normal sodium group (Table I).

At the start of the cycle, body weight did not differ significantly between the two groups. Mean body weight in the normal sodium group increased from 62.9 (SD 10.7) kg at the start of the study to 63.5 (SD 11.3) kg on the day of oocyte retrieval (not significant); it did not change significantly until the late luteal phase. Women in the low sodium group started their sodium-restricted diet 10 days before the start of their cycle so as to reach a steady low sodium state. During this period they lost 1.0 kg (SE of difference 0.2; P < 0.01), but during the whole cycle their weights remained stable. The mean values at the start of the ovarian stimulation and at oocyte retrieval were 57.1 (SD 7.1) and 57.3 (SD 6.7) kg respectively.

On the day of oocyte retrieval the mean systolic blood pressure in the normal sodium group was higher than in the low sodium group [121 (SD 16) and 111 (SD 13) mm Hg respectively], but this difference was not significant. In addition, no significant difference in the mean diastolic blood pressure was demonstrated on the day of oocyte retrieval: 70 (SD 11) and 67 (SD 8) mm Hg respectively.

Changes in the plasma concentrations of renin and prorenin

Figure 1 depicts the time-course of the changes in the plasma concentrations of renin and prorenin during the ovarian stimulation cycle. The effect of the phase of the cycle on the circulating plasma concentrations of renin and prorenin was highly significant (P < 0.001).

The changes in the plasma concentrations of renin and prorenin after ovarian stimulation did not run in parallel. On the day of oocyte retrieval there was a 3- to 4-fold increase in plasma prorenin concentrations in both groups. However, the plasma renin concentration did not change at this stage of the cycle. In the luteal phase, plasma prorenin concentrations gradually decreased to basal values. In contrast, plasma renin concentrations gradually increased 2-fold by day +9 of the cycle and then returned to basal values.

In both phases of the ovarian stimulation cycle plasma renin and prorenin concentrations were higher in the patients with the low sodium diet compared with those with the normal sodium diet. The geometric mean plasma renin concentrations in the low sodium group were on average 60% (95% Cl 33–92%) higher compared with the normal sodium group. Moreover, the differences between both groups appeared to depend significantly (P < 0.001) on the day of the luteal phase. However, the deviations from parallelism did not appear major.

In general, plasma prorenin concentrations were significantly (P = 0.03) higher (mean difference 28% with 95% CI 2–95%) in the low sodium group compared with the normal sodium group. In contrast to renin, the differences for prorenin between the groups did not vary significantly during the cycle.

There were no significant correlations between plasma renin or prorenin concentrations on the one hand and blood pressure, changes in body weight and urinary sodium:creatinine ratios on the other.

Follicular fluid prorenin and renin

Follicular development

The number of follicles per ovary was significantly (P = 0.02) lower in the normal sodium group than in the low sodium
Table II. Follicular fluid renin and prorenin concentrations (pg/ml) in various sizes of follicle

<table>
<thead>
<tr>
<th>Follicle size category (mm)</th>
<th>Sodium diet(^a)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Normal</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>Renin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All sizes</td>
<td>77</td>
<td>253</td>
<td></td>
</tr>
<tr>
<td>(9-15)</td>
<td>20</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>(71-89)</td>
<td>30</td>
<td>297</td>
<td></td>
</tr>
<tr>
<td>(107-842)</td>
<td>44</td>
<td>219</td>
<td></td>
</tr>
<tr>
<td>(89-988)</td>
<td>41</td>
<td>209</td>
<td></td>
</tr>
<tr>
<td>(50-699)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;9 mm</td>
<td>27</td>
<td>187</td>
<td></td>
</tr>
<tr>
<td>(2788-41 545)</td>
<td>114</td>
<td>8752</td>
<td></td>
</tr>
<tr>
<td>Prorenin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All sizes</td>
<td>77</td>
<td>10 762</td>
<td></td>
</tr>
<tr>
<td>(9-15)</td>
<td>20</td>
<td>13 833</td>
<td></td>
</tr>
<tr>
<td>(359-998)</td>
<td>30</td>
<td>13 303</td>
<td></td>
</tr>
<tr>
<td>(4170-42 441)</td>
<td>44</td>
<td>8400</td>
<td></td>
</tr>
<tr>
<td>(1614-30 891)</td>
<td>41</td>
<td>8415</td>
<td></td>
</tr>
</tbody>
</table>

Results are expressed as geometric means and 95% confidence intervals. The analysis was performed with a mixed analysis of variance.\(^a\)The differences in renin and prorenin concentrations between the normal sodium diet and the low sodium diet were not significant for all various sizes of follicles. Neither were there significant differences in renin and/or prorenin concentrations between the various sizes of follicles within the normal sodium diet group or the low sodium diet group.

The total amount of follicular fluid renin and prorenin per ovary was estimated by the addition of the total amount of (pro)renin of each follicle, as calculated by the volume of follicular fluid \(\times\) (pro)renin concentration per follicle. Neither the total follicular fluid renin content nor the total follicular fluid prorenin content per ovary differed significantly between the two groups (Table III).

Summary of results: Follicular fluid renin and prorenin concentrations in follicles yielding an oocyte or not did not differ significantly between the two groups. The same applied to whether or not the oocyte was fertilized. For this reason the data from both groups were combined and are presented in Table IV. No significant differences were found in follicular fluid renin or prorenin concentrations between follicles yielding an oocyte or not. The presence or absence of fertilization appeared to make no significant difference in the follicular fluid renin or prorenin concentrations of follicles yielding an oocyte.

Table III. Total ovarian amount of follicular fluid renin and prorenin (pg per ovary)

<table>
<thead>
<tr>
<th>Sodium diet</th>
<th>Normal</th>
<th>Low</th>
<th>(P) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Renin</td>
<td>3466</td>
<td>5874</td>
<td>NS</td>
</tr>
<tr>
<td>Prorenin</td>
<td>132 059</td>
<td>236 893</td>
<td>NS</td>
</tr>
</tbody>
</table>

Results are expressed as geometric means and 95% confidence intervals. The analysis was performed with the unpaired t-test. NS = not significant.

Table IV. Renin and prorenin concentrations (pg/ml) in follicular fluid related to oocyte yield and the presence or absence of fertilization

<table>
<thead>
<tr>
<th>Oocyte</th>
<th>Rene</th>
<th>Prorenin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present</td>
<td>84</td>
<td>209</td>
</tr>
<tr>
<td>Absent</td>
<td>107</td>
<td>240</td>
</tr>
<tr>
<td>(P) value</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Results are expressed as geometric means and 95% confidence intervals. The analysis was performed with the unpaired t-test. NS = not significant.

Summary of results: Follicular fluid renin and prorenin concentrations in follicles yielding an oocyte or not did not differ significantly between the two groups. The same applied to whether or not the oocyte was fertilized. For this reason the data from both groups were combined and are presented in Table IV. No significant differences were found in follicular fluid renin or prorenin concentrations between follicles yielding an oocyte or not. The presence or absence of fertilization appeared to make no significant difference in the follicular fluid renin or prorenin concentrations of follicles yielding an oocyte.
Correlations between plasma (pro)renin concentrations and follicular parameters

The plasma prorenin concentration on the day of oocyte retrieval was correlated with the number of follicles ($r = 0.56$, $P < 0.02$), the serum oestradiol concentration ($r = 0.72$, $P < 0.01$) and the total amount of ovarian follicular fluid prorenin per person ($r = 0.57$, $P < 0.02$). Plasma renin concentration was not significantly correlated with the aforementioned parameters.

Discussion

Effect of a low sodium diet on plasma concentrations of renin and prorenin during ovarian stimulation cycles

Renin is formed within the juxtaglomerular cells in the kidney. Sodium depletion is a classic stimulus of the synthesis of renin (Sealey and Laragh, 1995). When the renal formation of renin is enhanced for prolonged periods, the rate of synthesis of the renin precursor prorenin is also increased (Derkx et al., 1983; Derkx and Schalekamp, 1988). Therefore chronic dietary sodium restriction results in an elevation of the plasma concentrations of renin and prorenin (Derkx and Schalekamp, 1988).

Our study shows that women undergoing ovarian stimulation also respond with a rise in plasma renin and prorenin concentration when the sodium content of the diet is reduced. Moreover, the increase in plasma renin and prorenin concentration persisted throughout both phases of the ovarian stimulation cycle.

A mid-luteal rise in plasma renin concentration has been described previously during ovarian stimulation cycles as well as during the normal menstrual cycle (Brown et al., 1964; Sealey et al., 1987). In our study, this mid-luteal increase in plasma renin concentration was present not only in the women with the normal sodium diet but also in those with the low sodium intake. This rise in renin concentration is considered to be caused by the natriuretic effect of progesterone and is of renal origin (Brown et al., 1964).

Ovarian prorenin but not renin seems to be produced and released into the circulation in response to luteinizing hormone and HCG, as demonstrated by observations during spontaneous menstrual cycles (Sealey et al., 1987; Blankestijn et al., 1990), during pregnancy (Derkx et al., 1986; Sealey et al., 1986) and in women undergoing ovarian stimulation (Derkx et al., 1987; Itskovitz et al., 1987). In our study we demonstrated that in patients with the normal sodium diet, as well as in patients with the low sodium diet, the plasma prorenin concentration was positively correlated with the number of follicles, the serum oestradiol concentration and the ovarian prorenin concentration on the day of the oocyte retrieval. In contrast to prorenin, renin was not correlated with the aforementioned parameters.

Plasma prorenin concentrations remained high in the early luteal phase and then gradually declined in both groups of patients.

Thus, in conclusion, sodium intake per se does not seem to affect the time-course of the changes in the plasma concentration of renin and prorenin during the ovarian stimulation cycle. The higher plasma concentrations of renin and prorenin in the women with the low sodium diet can be explained by an increased renal release of these proteins.

Effect of a low sodium diet on follicular fluid renin and prorenin concentrations during ovarian stimulation cycles

Mean follicular fluid renin-like activity has been found to be much higher in stimulated than in unstimulated cycles (Derkx et al., 1987). The prorenin concentration in follicular fluid during ovarian stimulation cycles is 10–40 times higher than in plasma (Glorioso et al., 1986; Derkx et al., 1987; Itskovitz et al., 1987).

The question as to whether a low sodium intake may influence the follicular fluid concentrations of renin and prorenin during ovarian stimulation can be answered negatively. We found no differences in the concentrations of renin and prorenin in the various size categories of follicles, and no differences in the amount of total renin or prorenin per ovary. This finding was not unexpected because a sodium-sensing system, such as the macula densa in the kidney, is not present in the ovary.

It is generally accepted that the ovary secretes only prorenin and not renin into the circulation (Paulson et al., 1989). However, the renin concentration in follicular fluid is higher than in plasma (Glorioso et al., 1986; Derkx et al., 1987; Itskovitz et al., 1987). It is possible that in vivo proteolytic enzymes in the follicular fluid may convert prorenin into renin. However, this discrepancy may also be explained by methodological problems of the renin assay. In our study we measured renin and trypsin-activated prorenin by using an immunoradiometric assay (Simon et al., 1992). This assay uses a monoclonal antibody that reacts with renin but does not cross-react with prorenin. It is possible that this monoclonal antibody does cross-react with truncated forms of prorenin which are present in follicular fluid. This may lead to falsely elevated values for renin, especially when the prorenin concentrations are very high, as is the case in follicular fluid.

Prorenin may also be inadvertently activated at low temperature (cryoactivation) during the storage and handling of plasma or follicular fluid samples (Pitarresi et al., 1992).

On theoretical grounds one can argue that the ovary may have a mechanism for the selective uptake of kidney-derived plasma renin and prorenin. However, such a mechanism is unlikely for the ovary because here we have shown that the total ovarian renin and prorenin content in women with a low sodium diet was not increased despite an increase in the circulating plasma renin and prorenin concentrations.

Effect of low sodium intake on follicular development, the oocyte and fertilization

We do not have an explanation for the differences in the number of follicles between the women with the normal sodium diet and those with the low sodium diet. An ongoing study including more patients is necessary to confirm this finding. Because the numbers in the two groups of patients were small, chance is as yet the only explanation.

Sodium intake does not seem to affect oocyte yield and/or fertilization during ovarian stimulation, as demonstrated by our results.
In accordance with the results of Paulson et al. (1989), our data did not show a correlation between follicular fluid renin and prorenin concentrations, oocyte yield and/or fertilization. Itskovitz et al. (1991) suggested a relationship between follicular fluid renin concentration and fertilization that resulted in pregnancy, but the follicular fluid renin concentration did not discriminate between oocytes that were fertilized and oocytes that were not fertilized or were fertilized abnormally.

In conclusion, this is the first report describing the effect of sodium restriction on plasma and follicular fluid concentrations of renin and its precursor prorenin during ovarian stimulation. Plasma renin and prorenin concentrations were higher in women with a low sodium diet. This rise can be explained by an increased renal release of renin and its precursor. However, the cyclic changes in plasma renin and prorenin concentration in the women undergoing ovarian stimulation were not influenced by the low sodium diet. In addition, sodium deprivation did not influence follicular fluid renin and prorenin concentrations. Finally, sodium restriction does not seem to impair the objectives of ovarian stimulation.

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