关系抑制素A和B、雌二醇与卵泡生长动力学之间的关系：卵巢刺激在正常排卵女性中的应用

Femke P Hohmann1, Joop S E Laven1, Frank H de Jong2 and Bart C J M Fauser1,3

1Division of Reproductive Medicine, Department of Obstetrics and Gynecology, 2Division of Endocrinology, Department of Internal Medicine, Erasmus Medical Center, Rotterdam, The Netherlands and 3Department of Reproductive Medicine, University Medical Center, Utrecht, The Netherlands

(Author correspondence should be addressed to Joop S E Laven; Email: j.laven@erasmusmc.nl)

摘要

目的：调查在不同疗程中皮质素的卵巢刺激在正常排卵女性中的应用

设计和方法：在未受刺激的周期和各种外源性FSH干预期间，连续激素测定和评估卵泡数量。受试者随机分为以下组别：单次高剂量（375 IU）的FSH干预（A组）、连续5天低剂量（75 IU/day）干预（B组）或从周期第3天、5天或7天开始的日常低剂量（75 IU/day）干预（C、D和E组）。

结果：延长FSH窗口期增加了小窦卵泡数量和血浆抑制素B水平。如果这种干预导致多卵泡生长，则中卵泡期抑制素B（P = 0.001）以及晚期卵泡期抑制素B和抑制素A水平显著增加，与单卵泡周期或自然周期相比。虽然中卵泡期抑制素B水平与卵泡数量呈正相关（P < 0.05），但抑制素B和雌二醇血清浓度仅与预排卵卵泡数量呈正相关（P < 0.001和P < 0.01）。

结论：现有数据扩展了我们对卵泡动力学、血浆抑制素和FSH在卵巢刺激期间的关系理解。然而，中卵泡期抑制素B与卵泡数量的增加并不容易识别出处于多卵泡风险的女性。

*European Journal of Endocrinology* 152 395–401

引言

抑制素主要由卵巢的卵泡细胞产生，是卵泡刺激素（FSH）的分泌抑制剂（1）。抑制素是两种二聚体糖蛋白，由生殖器官生产，由α亚单位与βA或βB亚单位连接形成βAα和βBα异二聚体，分别称为抑制素A和抑制素B（2）。抑制素A似乎在正常排卵周期的晚期卵泡和黄体期的正常月经周期中是主要的，而抑制素B是早期和晚期卵泡期的主要形式。

最近的正常排卵期女性研究已经明确地证明了抑制素B主要由小卵泡和早期卵泡期的卵泡分泌（4）。抑制素B水平的快速上升与FSH和LH的中周期峰同步。之后，抑制素B水平进一步下降至中周期黄体期的最低水平（5, 7）。抑制素A水平的下降是导致FSH血清水平在黄体期增加的主要调节因素，并有助于FSH血清水平的动态变化（8–11）。抑制素B水平的快速上升与FSH血清水平的下降以及黄体期的单卵泡选择有关（12）。
differential pattern of inhibin A and inhibin B secretion is established during early puberty and remains constant throughout reproductive life (13).

Since the size of the cohort of recruited follicles appears to be related to the size of the primordial follicle pool (14), inhibin B may constitute a suitable marker of ovarian ageing (15, 16). Moreover, inhibin B serum levels have been suggested to predict poor response to ovarian hyperstimulation in in vitro fertilization (IVF) patients (17). Unfortunately, more detailed analyses concluded that early follicular phase inhibin B serum levels are only of limited value in predicting response during ovarian hyperstimulation (18–21). Dynamic inhibin B testing with FSH stimulation (22, 23) or gonadotropin releasing hormone (GnRH) agonist administration (24) appears to correlate better with ovarian response. A good correlation was also observed between inhibin B concentrations during ovarian hyperstimulation and the number of oocytes retrieved (25, 26).

However, most, if not all, of the aforementioned studies used GnRH agonist to suppress endogenous gonadotropins and consequently baseline inhibin B levels are decreased (27). Hence, results from these studies might not be readily applicable to stimulation protocols used for ovulation induction or minimal ovarian hyperstimulation in conjunction with intrauterine insemination during which GnRH analogs are not usually applied. The current study was designed to study the relationship between serum concentrations of inhibin A and inhibin B and the number of developing follicles during various ovarian hyperstimulation protocols without previous down regulation using a GnRH agonist.

Materials and methods

Subjects

This study was approved by the local Ethics Review Committee. A total group of 63 healthy volunteers was selected from responders to advertisements in local newspapers and interviews on the local radio and television. Written informed consent was obtained from each participant, and all subjects were paid for participation, as previously published (28, 29).

Inclusion criteria were: (i) a history of regular menstrual cycles (cycle length 25–32 days); (ii) age range of 19 to 35 years; (iii) body mass index (BMI) 18–27 kg/m²; (iv) mid luteal progesterone concentrations (assessed 7 days prior to expected menses) of at least 18 nmol/l and (v) no previous use of medication or oral contraceptives during at least 3 months prior to the study. Patients with a past history of any endocrine disease or infertility were excluded. All participants either used non-steroidal contraception (intrauterine devices, condoms or prior tubal ligation) or refrained from sexual intercourse during the study period.

Interventions

The first 23 subjects were studied during a natural cycle, followed by an intervention cycle (study 1, groups A and B). The remaining 40 volunteers were studied during a single intervention cycle (study 2, groups C, D, E) (28, 29).

The natural cycle was assessed by means of daily transvaginal ultrasound scans (TVS) and daily blood sampling starting on day 12 after the assessed LH surge in the pre study cycle and concluding on the day of ovulation as assessed by TVS. Normal ovulation was confirmed by assessment of elevated progesterone levels (>18 nmol/l) 6 or 7 days later (30). The LH surge in the pre study cycle was determined using a urinary LH self-test (Clear-plan One Step, Unipath Ltd., Bedford, Beds, UK) starting 10 days after the onset of the previous menses.

Study 1 (groups A and B) For the subjects who were followed during a natural cycle, a second series of daily TVS and blood sampling started at day 10 (LH + 10) after the LH surge in the control cycle. Women were randomly assigned to group A or B as published previously (28). All participants received exogenous urinary FSH (Metrodin-HP; Serono Benelux BV, The Hague, The Netherlands) from the same batch. Group A received a single dose of 375 IU urinary FSH s.c. at day LH + 14, effectively increasing the FSH concentrations above the presumed threshold without affecting the length of the FSH window (31). Group B received a similar total dose in 5 consecutive injections of 75 IU/day urinary FSH s.c. at day LH + 19, thereby preventing decremental serum FSH concentrations in the mid to late follicular phase and thus widening the FSH window. FSH was administered shortly after the daily blood withdrawal. Daily TVS as well as blood sampling were continued until the day of sonographically assessed ovulation. Normal ovulation was confirmed by assessment of elevated progesterone levels 7 days later.

Study 2 (groups C, D and E) The remaining 40 subjects were randomly assigned to groups C, D and E as published previously (29). All these subjects received a daily fixed dose of 75 IU recombinant FSH (recFSH; Gonal-F, Serono Benelux BV) starting on day 3, 5 or 7 respectively, until the day of human chorionic gonadotrophin (hCG) administration. As soon as the largest follicle reached a diameter of 18 mm or more a single dose of 5000 IU hCG (Profasi, Serono Benelux BV) was administered i.m. at 2200 h to induce ovulation. TVS as well as blood sampling were performed on a two daily basis starting on cycle day 3 until the largest follicle reached a diameter of 15 mm or more. Thereafter, ultrasound scans and blood sampling were performed daily until sonographically assessed ovulation. Ovulation was
confirmed by blood sampling and TVS 8 days after hCG administration.

Sonographic imaging was performed using a 6.5 MHz transvaginal transducer (model EUB-415/420; Hitachi Medical Corporation, Tokyo, Japan). The ovaries were localized and scanned as described previously (32). Follicle diameter was calculated as the mean diameter (measured in two dimensions when <9 mm and measured in three dimensions when >9 mm), as published previously (30, 32). A dominant follicle was defined as a follicle with a diameter of 10 mm or more, whereas a pre-ovulatory follicle should measure 15 mm or more. This distinction is clinically important since not all follicles measuring 10 mm or more reach the pre-ovulatory stage. Sonographically assessed ovulation was defined as a decrease in size of >50% of the largest follicle (≥18 mm).

**Hormone assays**

Blood samples were obtained by venepuncture and processed within 2 h after withdrawal. Serum was stored at −20°C until assayed. Serum levels of LH and FSH were measured using luminescence based immunoassays (Immulite, Diagnostic Products Corp., Los Angeles, CA, USA) whereas serum estradiol (E2) levels were measured using coated tube radioimmunoassays provided by the same supplier. Standards used in the gonadotrophin assays were based on WHO 2nd IRP 78/549 and WHO 1st IRP 68/40 for FSH and LH respectively. Sensitivities of the assays were 0.1 U/l for LH and FSH, and 10 pmol/l for E2. Intra- and interassay coefficients of variation were less than 5% and 6% for LH, less than 5% and 7% for FSH and less than 5% and 7% for E2 respectively.

Dimeric inhibin A and B levels were assessed using an immuno-enzymometric assay obtained from Serotec (Oxford, Oxon, UK), as described previously (6). The detection limit of the assay, defined as the amount of inhibin equivalent to the signal of the blank +3 s.d. of this signal, was 3.4 ng/l for both inhibin A and B. Intra- and interassay coefficients of variation were less than 8% and 15% for inhibin A and less than 8% and 14% for inhibin B respectively. All samples from one subject were run within the same assay.

**Data analysis**

The early follicular phase was defined as dayLH+14 – dayLH+18 for the natural cycle and for groups A and B (intervention study 1) and as cycle day (CD) 1 – CD 5 for groups C, D and E (intervention study 2). The mid and late follicular phases were defined as dayLH+19 – dayLH+23 and dayLH+24 – dayLH surge (natural cycle, groups A and B) and CD 6 – CD 10 and CD 11 – dayHCG (groups C, D and E) respectively. Data are presented as means and s.d. if distributed normally or as median and ranges if distributed otherwise. The early, mid or late follicular phase value of a subject is chosen to be the mean value in each phase, in order to prevent overrating of individual subjects in the calculations. Student’s t-test statistics were performed on normally distributed data. Whenever a non-parametric distribution was found, groups were compared using the Mann-Whitney U-test. Comparisons of outcome measures between more than 2 groups were performed using the Kruskal-Wallis H-test for continuous data and using the χ² test for binary variables. Comparisons of data over time between groups were carried out using analysis of variance (ANOVA). Correlation coefficients given are Spearman’s. P values are two-sided and 0.05 was considered to indicate statistical significance. Data were analyzed using a commercially available software package (SPSS, Chicago, IL, USA).

**Results**

**Baseline characteristics**

Sixty-three normo-ovulatory women entered the study protocol. In the first study, 11 and 12 subjects were assigned to groups A and B respectively. In the second study, 13, 13 and 14 subjects were allocated to groups C, D and E respectively. With regard to the distribution of age, cycle length and baseline endocrine levels were measured using coated tube radioimmunoassays provided by the same supplier. Standards used in the gonadotrophin assays were based on WHO 2nd IRP 78/549 and WHO 1st IRP 68/40 for FSH and LH respectively. Sensitivities of the assays were 0.1 U/l for FSH and LH, and 10 pmol/l for E2. Intra- and interassay coefficients of variation were less than 5% and 6% for LH, less than 5% and 7% for FSH and less than 5% and 7% for E2 respectively.

Dimeric inhibin A and B levels were assessed using an immuno-enzymometric assay obtained from Serotec (Oxford, Oxon, UK), as described previously (6). The detection limit of the assay, defined as the amount of inhibin equivalent to the signal of the blank +3 s.d. of this signal, was 3.4 ng/l for both inhibin A and B. Intra- and interassay coefficients of variation were less than 8% and 15% for inhibin A and less than 8% and 14% for inhibin B respectively. All samples from one subject were run within the same assay.

**Hormone concentrations**

Differences in mean early, mid and late follicular phase levels of inhibin B, inhibin A, E2 and FSH between the natural cycle and the intervention groups A, B, C, D and E are depicted in Fig. 1. In the natural cycle, inhibin B levels showed a significant rise from the early follicular phase to their highest levels in the mid follicular phase (P < 0.01). Inhibin A and E2 levels increased significantly in the late follicular phase (P < 0.001 and P < 0.001 respectively). In group A, FSH serum concentrations showed a significant decrease from the early to mid follicular phase (P = 0.001), with a subsequent decrease in inhibin B concentrations from the early to late follicular phase (P < 0.05). Groups B, C and D (all starting exogenous FSH in the early follicular phase or at the beginning of the mid follicular phase) all showed an increase in inhibin B levels from the early to mid follicular phase (P < 0.05) without significant changes in FSH concentrations. Although inhibin B levels in group E showed an increase from the early to late follicular phase (P < 0.01), the increase started later with a significant increase from the mid to the late follicular
Table 1 Baseline characteristics (median and range) in 63 healthy female normo-ovulatory volunteers participating in the study with various intervention regimens with exogenous FSH.

<table>
<thead>
<tr>
<th>Intervention group</th>
<th>Study 1</th>
<th>Study 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A (n = 11)</td>
<td>B (n = 12)</td>
</tr>
<tr>
<td>Age (years)</td>
<td>28 (25–33)</td>
<td>28 (20–34)</td>
</tr>
<tr>
<td>Cycle length (days)</td>
<td>28 (27–30)</td>
<td>29 (27–30)</td>
</tr>
<tr>
<td>FSH (IU/l)*</td>
<td>5.1 (3.9–6.0)</td>
<td>5.1 (3.6–7.7)</td>
</tr>
<tr>
<td>E2 (pmol/l)*</td>
<td>156 (102–230)</td>
<td>143 (106–259)</td>
</tr>
<tr>
<td>Inhibin A (ng/l)*</td>
<td>98 (29–221)</td>
<td>154 (68–234)</td>
</tr>
<tr>
<td>Inhibin B (ng/l)*</td>
<td>5 (2–9)</td>
<td>5 (2–6)</td>
</tr>
</tbody>
</table>

* All baseline endocrine parameters were assessed on cycle day 3 (pre-intervention cycle for group A and B, intervention cycle for groups C, D and E).

Follicle growth and serum inhibin concentrations

In the natural cycle the rise in serum inhibin B levels coincided with a similar increase in the number of small antral follicles with diameters ranging from 5 to 11 mm (Pearson’s correlations between inhibin B and follicles ranging from 5 to 9 mm and from 9 to 11 mm: r = 0.423, P < 0.001 and r = 0.316, P = 0.01 respectively). Inhibin A increased only after a follicle of 15 mm or larger was detected during the late follicular phase (Pearson’s correlations between inhibin A and follicles ranging from 15 to 16 mm and from 17 to 18 mm: r = 0.357, P < 0.05 and r = 0.427, P < 0.01 respectively).

Interventions C, D and E all resulted in a significant increase (P < 0.01) in the number of follicles measuring 10 mm or more. In total, 24 subjects (60%) from groups C, D and E showed multi-follicular growth (defined as >1 follicle measuring >10 mm at the day of hCG administration). In multi-follicular cycles, mid follicular inhibin B levels were significantly elevated compared with mono-follicular cycles (median mid follicular inhibin B 245 ng/l (range 75–830) vs 147 ng/l (range 57–291) for multi- and mono-follicular cycles, P = 0.001). In the late follicular phase median inhibin B, inhibin A and E2 levels were elevated in multi-follicular cycles compared with the mono-follicular cycles (median late follicular inhibin B 230 ng/l (range 50–902) vs 113 ng/l (range 76–298), P < 0.05; inhibin A 75 ng/l (range 14–185) vs 39 ng/l (range 14–57), P < 0.01 and E2 886 pmol/l (range 221–2188) vs 664 pmol/l (range 310–807), P < 0.05 respectively).

Table 2 shows the relation between median early, mid or late follicular phase levels of inhibin B, inhibin A, FSH and E2 with the number of follicles of different size categories in the five intervention cycles. Only the early follicular inhibin B concentration correlated
slightly with the number of small follicles at the end of the follicular phase. In contrast, in the mid follicular phase inhibin B levels, as well as inhibin A levels, correlated with the number of developing larger follicles. In the late follicular phase a strong correlation was found between inhibin B, inhibin A and E2 levels and the number of larger follicles at the end of the follicular phase.

**Discussion**

The present study in normo-ovulatory women confirms that inhibin B is indeed mainly produced by small antral follicles and hence inhibin B levels increase during the early to mid follicular phases. Thereafter, inhibin B levels decline during the late follicular phase. Inhibin A is predominantly produced by the pre-ovulatory follicle and serum concentrations are therefore high during the late follicular phase. An increase in FSH stimulation during the early follicular phase induces an increased growth of small antral follicles and hence elevated inhibin B concentrations. If this increase in FSH is long enough to extend the FSH window (the period during which FSH levels are above the threshold for ovarian stimulation (31, 33)), the intervention can result in ongoing multi-follicular growth and hence an increase in both inhibin B and inhibin A. However, if the selection of the single dominant follicle is not affected, serum inhibin B levels return to normal and inhibin A levels remain comparable with serum levels in the natural cycle.

In the natural cycle serum inhibins showed the expected pattern. After the initial rise in FSH a number

---

**Table 2** Pearson’s correlations (r) between median early-, mid- and late-follicular phase levels of inhibin B, inhibin A, FSH and E2 and the number of follicles of different size categories in the late follicular phase of various intervention cycles in 63 normo-ovulatory women.

<table>
<thead>
<tr>
<th>Number of follicles</th>
<th>Number of follicles</th>
<th>Number of follicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>5–10 mm</td>
<td>10–15 mm</td>
<td>15–20 mm</td>
</tr>
<tr>
<td>Inhibin B (ng/l)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Early</td>
<td>0.260*</td>
<td>−0.256*</td>
</tr>
<tr>
<td>Mid</td>
<td>0.293*</td>
<td>0.352**</td>
</tr>
<tr>
<td>Late</td>
<td>0.128</td>
<td>0.536***</td>
</tr>
<tr>
<td>Inhibin A (ng/l)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Early</td>
<td>−0.103</td>
<td>−0.054</td>
</tr>
<tr>
<td>Mid</td>
<td>0.135</td>
<td>0.084</td>
</tr>
<tr>
<td>Late</td>
<td>0.106</td>
<td>0.370**</td>
</tr>
<tr>
<td>FSH (IU/l)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Early</td>
<td>−0.158</td>
<td>0.012</td>
</tr>
<tr>
<td>Mid</td>
<td>−0.044</td>
<td>0.202</td>
</tr>
<tr>
<td>Late</td>
<td>−0.162</td>
<td>0.018</td>
</tr>
<tr>
<td>E2 (pmol/l)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Early</td>
<td>−0.056</td>
<td>−0.099</td>
</tr>
<tr>
<td>Mid</td>
<td>0.162</td>
<td>0.044</td>
</tr>
<tr>
<td>Late</td>
<td>0.086</td>
<td>0.360**</td>
</tr>
</tbody>
</table>

*Day of LH surge (groups A and B): day of hCG (groups C, D and E). Level of significance: *P < 0.05; **P < 0.01; ***P < 0.001.
of small antral follicles is recruited and subsequently inhibin B is produced. Thereafter, the dominant follicle is selected and smaller follicles from the recruited cohort become atretic. Hence, inhibin B levels decrease (2, 3). Inhibin A and E2 levels increase after the dominant follicle selection (12, 22, 34). Inhibin B serum concentrations in the natural cycle showed a biphasic pattern in the mid to late follicular phase. This pattern correlated highly with the number of follicles measuring up to 11 mm, whereas the number of follicles larger than 11 mm was relatively constant in this phase of the cycle, suggesting that inhibin B mainly originates from follicles up to 11 mm. A similar relationship has been reported recently in menstrual cycles of normo-ovulatory women (35).

In the current study, inhibin B levels were increased in all intervention cycles during which exogenous FSH was administered. Moreover, in those cycles with mult follicular development the highest levels were recorded. When the FSH window is effectively broadened more small follicles will emerge from the recruitable pool (28). Since inhibin B is mainly produced by small antral follicles up to 12 mm in size it might constitute a marker for multiple follicle development (36). In the current study, inhibin B serum concentrations during the early and mid follicular phases were indeed significantly correlated with the number of small developing follicles. Moreover, mid and late follicular phase inhibin B levels were higher in those cycles which resulted in multi-follicular development, reflected in significant correlations in mid and late follicular phase inhibin B levels and the number of larger follicles at the end of the follicular phase (the day of the LH surge or the day of hCG administration). Apparently, mid and late follicular phase inhibin B concentrations during ovarian (hyper) stimulation constitute a marker for the number of developing follicles (25, 26).

Prediction of those women who may under- or over-respond to ovarian (hyper) stimulation protocols is of clinical importance. During ovarian stimulation (ovulation induction or ovarian hyperstimulation) it has been shown that the number of follicles measuring 12 mm or more at the day of hCG administration is strongly correlated with the incidence of high order multiple pregnancies (37, 38). Similarly, E2 serum concentrations are strongly correlated with adverse outcome (38). Since mid follicular inhibin B serum concentrations were correlated both with the number of follicles measuring 10 mm or more as well as with multi-follicular development, inhibin B might also constitute a predictor of multiple gestation during ovarian hyperstimulation. Ideally, such a predictor should be sufficiently accurate and distinct in time from the moment that stimulation protocols are commenced (39). Consequently, based on early follicular phase inhibin B serum levels, treatment might be optimized since women at risk for ovarian hyperstimulation syndrome and multiple pregnancies might be more easily identified prior to treatment. Unfortunately, in the current study as in others, the basal inhibin B serum levels did not correlate with the final pre-ovulatory number of follicles (18, 19, 39, 40). Moreover, early basal as well as stimulated inhibin B levels seem to reflect the potential follicular development of the ovary, but are not significantly associated with the final oocyte number which is mainly determined by the antral follicle count and the basal FSH serum concentration (39). Therefore, inhibin B constitutes a poor marker in the risk assessment of women who might over-respond to treatment.

In conclusion, the present data extend our understanding of the relationship between follicle dynamics, serum inhibins and FSH levels during multiple dominant follicle development resulting from ovarian hyperstimulation with exogenous FSH. However, although mid follicular inhibin B does correlate with the number of developing follicles, it does not facilitate the identification of women at risk for multiple follicle development.

References
