Fetal plasma testosterone correlates positively with cortisol

R Gitau, D Adams, N M Fisk, V Glover

Background: Fetal exposure to testosterone has been implicated in programming childhood behaviour, but little is known about the determinants of fetal testosterone concentrations.

Aims: To investigate the relation between fetal testosterone and maternal and fetal cortisol.

Methods: Clinically indicated blood samples taken from 44 human fetuses (mean gestational age 27 weeks, range 15–38), together with paired maternal samples, were analysed for testosterone and cortisol concentrations.

Results: Male fetuses had significantly higher concentrations of testosterone than females. Female but not male fetal concentrations rose significantly with gestational age. Fetal testosterone correlated positively with both fetal cortisol and maternal testosterone concentrations. Multiple regression showed that maternal testosterone and fetal cortisol were independently correlated with fetal plasma testosterone in both sexes.

Conclusion: Unlike the norm in the adult, where testosterone production is often inhibited by cortisol, in the fetus there is a positive link between the two.

The level of fetal exposure to testosterone in utero may be important for programming later behaviour. Animal models have shown that fetal testosterone acts in a dose dependent manner to programme the male fetal brain for its masculine role.1 In mice, genital development and later behaviour depend on intrauterine position in the litter, suggestive of a testosterone effect.2 In humans, girls with congenital adrenal hyperplasia, which results in a deficiency of cortisol but an excess of testosterone, show some masculinisation, including a greater tendency to “rough and tumble” play and selection of masculine toys.3 They also have altered laterality.4 Grimshaw and colleagues5 showed that amniotic fluid testosterone concentrations correlated with the amniotic fluid testosterone concentrations.89

Prenatal stress has been shown in rodents models to have an effect on sex typical behaviour of the offspring.10 Ward has shown that stressing the pregnant dam reduced the crucial testosterone surge at days 18–19 in male fetuses and also resulted in feminisation of adult sexual behaviour in male offspring.11 However, prenatal stress also results in reduced maternal behaviour in female offspring.12 In humans, maternal anxiety in pregnancy is linked with an increased likelihood of behavioural problems in childhood, including hyperactivity/attention deficit in boys.13 It is also linked with an increased incidence of mixed handedness in the child.14,15 As altered laterality (left and mixed handedness) is more common in boys than girls, and is also increased in congenital adrenal hyperplasia,4 it might be related to an increased level of exposure to testosterone.

In adult humans there is evidence that cortisol production and testosterone are inversely related, and that stress can suppress testosterone production.16 17 We have previously reported a linear correlation between maternal and fetal cortisol concentrations.18 19 If fetal cortisol and testosterone were inversely related, as in the adult, this would make any masculinisation of the fetus secondary to maternal prenatal stress hard to explain. One would expect the reverse, a feminising effect.

It is therefore of interest to understand the relation between the function of the hypothalamo-pituitary-adrenal (HPA) axis and testosterone production in the fetus. In this study we investigated the correlates of fetal plasma testosterone with the primary aim of characterising the relation between fetal testosterone and cortisol concentrations. Fetal blood samples were taken at clinically indicated fetal blood sampling. When possible, maternal blood samples were taken at the same time for comparison. Although previous studies have examined testosterone concentrations in fetal blood and amniotic fluid,20 21 none have examined the relation between testosterone and cortisol in the fetus.

METHODS

Experimental subjects

Forty four women with pregnancies undergoing clinically indicated fetal blood sampling, and/or intrauterine blood/platelet transfusion at the Centre for Fetal Care, Queen Charlotte’s and Chelsea Hospital, London, UK were recruited (mean gestational age 27 weeks, range 15–38). Twenty eight fetuses were normal; six had an anomalous karyotype (triosomy 18, n = 3; trisomy 21, n = 3) and 10 had some non-hydropic structural anomaly (abnormal heart, n = 5; anencephaly, n = 1; brain tumour, n = 1; ectodactyly, n = 1; IUGR, n = 2). Cortisol results from some of these fetuses have been reported previously.19 If samples were obtained from an individual fetus on more than one occasion, only the first was used. The sex of the fetus was known for 40 of these subjects.

The indications for fetal blood sampling were rapid karyotyping (n = 20) or suspected anaemia (n = 1), and for intrauterine transfusion, were fetal anaemia (n = 19) or thrombocytopenia (n = 4) in alloimmunised pregnancies. Eleven blood samples were collected at the placental cord insertion (PCI) and 33 at the intrahepatic vein (IHV). All baseline samples were collected prior to transfusion and within 10 minutes of needle entry, within which fetal cortisol concentrations are known not to rise.20 Neither fetal neuromuscular blockade nor analgesia was used. Mothers did not receive sedation. The purity of fetal samples was confirmed by comparison of fetal and maternal
mean corpuscular volumes and subsequent Kleihauer-Betke testing.

Ethical approval for the study was granted by the Hammersmith Hospitals Trust ethics committee, and written informed consent was obtained from all the mothers for the collection of additional blood samples for research purposes.

Blood samples
Following collection of clinical samples, up to 1–2 ml additional venous fetal blood was drawn into a syringe and placed in a chilled heparinised tube. Maternal blood (7 ml) was collected, when possible, by venepuncture into a heparinised Vacutainer (Becton Dickinson, Meylan Cedex, France) immediately before transabdominal needle insertion.

Blood samples were spun in a refrigerated centrifuge at 3000 g for 15 minutes at 4°C, to separate plasma, which was collected over ice and stored in aliquots at −80°C until subsequent batch assay.

Assays
Total plasma testosterone was assayed using a direct plasma radioimmunoassay (RIA) (DPC, Los Angeles, USA). The lower limit of sensitivity was 0.14 nmol/l, and the assay coefficient of variation 10.5%. Total cortisol concentrations were assayed using a standard solid phase RIA (DPC, Los Angeles, USA). The lower limit of sensitivity was 10 nmol/l and the assay coefficient of variation 5.3%. Maternal and fetal plasma sample pairs were analysed in the same assay run.

Statistics
Normally distributed data were analysed by standard parametric statistics using SPSS 10.0 for Windows (Chicago, IL), using paired or unpaired t tests or Pearson correlations as appropriate. Baseline fetal cortisol and testosterone and maternal and fetal cortisol and cortisol concentrations were all first normalised by ln transformation before any statistical analysis. The response to transfusion was analysed using Δ (post-transfusion stress hormone concentration – pre-transfusion stress hormone concentration) values. Probability values are based on two tailed analysis unless stated otherwise.

RESULTS
Table 1 shows the plasma hormone concentrations for the whole sample. An initial univariate analysis showed that fetal plasma testosterone did not correlate with pH, pCO₂, or pO₂. There was no difference in these parameters, or in fetal testosterone or fetal cortisol whether the fetus was normal or anomalous (all by two tailed Student’s t test). The results from normal and anomalous fetuses were therefore combined for further analyses.

Table 1 Maternal and fetal plasma testosterone and cortisol concentrations

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Geometric mean</th>
<th>Interquartile range</th>
</tr>
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<tbody>
<tr>
<td>Gestational age</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>44</td>
<td>27</td>
<td>23.5–32</td>
</tr>
<tr>
<td>Fetal testosterone (nmol/l)</td>
<td>44</td>
<td>1.4</td>
<td>0.75–2.5</td>
</tr>
<tr>
<td>Males</td>
<td>23</td>
<td>2.1</td>
<td>1.7–2.9</td>
</tr>
<tr>
<td>Females</td>
<td>17</td>
<td>0.78</td>
<td>0.45–1.3</td>
</tr>
<tr>
<td>Fetal cortisol (nmol/l)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Males</td>
<td>22</td>
<td>57</td>
<td>7–350</td>
</tr>
<tr>
<td>Females</td>
<td>17</td>
<td>53</td>
<td>9–189</td>
</tr>
<tr>
<td>Maternal testosterone (nmol/l)</td>
<td>34</td>
<td>1.7</td>
<td>0.93–2.7</td>
</tr>
<tr>
<td>Maternal cortisol (nmol/l)</td>
<td>32</td>
<td>644</td>
<td>499–950</td>
</tr>
</tbody>
</table>

Male fetuses had significantly higher testosterone concentrations than females p < 0.001) (fig 1). The gestational age range was similar in the two sexes: males, geometric mean 27 weeks, range 17–38 weeks; females, geometric mean 27 weeks, range, 20–36 weeks. Testosterone increased significantly in females with gestational age (r = 0.63, p < 0.01) but not in the males. Fetal cortisol was not significantly related to gestational age in either the males or females. With maternal cortisol and maternal testosterone, there was no significant relation with gestational age or difference with fetal sex.

There was no acute change in testosterone concentration after transfusion through either the IHV (mean pre- and post-transfusion, both 1.8 nmol/l, n = 14) or through the PCI (mean pre-transfusion 1.8 nmol/l, mean post-transfusion 1.7 nmol/l, n = 9). This was also found after a regression analysis adjusting for baseline fetal testosterone.

Table 2 shows the correlations between testosterone and cortisol in both fetus and mother.

The correlation between cortisol and testosterone in fetal plasma was positive (r = 0.407, p = 0.008). In contrast, maternal testosterone was not significantly correlated with maternal cortisol –0.032. Fetal plasma testosterone correlated positively with maternal concentrations (r = 0.414, p = 0.015) and maternal and fetal cortisol were also positively correlated (r = 0.526, p = 0.002). Similar patterns were observed for the male and female subgroups (all correlations greater than 0.4), but due to the smaller numbers not all were significant.

Multiple regression analysis was next used and showed that fetal sex, fetal cortisol, and maternal testosterone were all significantly and independently related to fetal plasma testosterone concentrations. In this analysis there was no contribution from maternal cortisol (table 3).

DISCUSSION
The main finding of this study is that, unlike the norm in the adult, there was a positive correlation between fetal cortisol and testosterone concentrations. Thus the mechanism of inter-related control of the HPA axis and testosterone production is different in the fetus compared with the adult.

As expected, we found that testosterone concentrations are higher in the male than the female fetus, although the differences were not large. This confirms previous results in amniotic fluid and cord blood. We also found that there was a positive relation with gestational age in female but not male fetuses. This also confirms previous findings. Beck-Peccoz and colleagues have reported, as we show here (fig 1), that by term, concentrations are similar in the two sexes.
we necessarily needed to include samples from non-normal fetuses. Six of the group had an anomalous karyotype and 10 had some non-hydropic structural anomaly. However this made no difference to any of the parameters studied here. When we studied the normal fetuses alone, similar, although non-significant correlations emerged. We have also found a similar significant positive correlation between cortisol and testosterone concentrations in amniotic fluid in a large sample from normal fetuses (unpublished observations).

Although the testosterone did not show an acute rise in response to stress, the positive correlation between fetal cortisol and testosterone concentrations suggests that some of the factors that cause raised fetal cortisol concentration may also cause an increase in testosterone concentration. This in turn may influence fetal development in ways associated with a more masculine profile.

**Table 2** Pearson correlations between maternal and fetal cortisol and testosterone concentrations (all analyses were carried out with the ln transformed values).

<table>
<thead>
<tr>
<th></th>
<th>Fetal cortisol</th>
<th>Maternal testosterone</th>
<th>Maternal cortisol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fetal testosterone</td>
<td>0.407 (0.008)</td>
<td>0.414 (0.015)</td>
<td>0.416 (0.018)</td>
</tr>
<tr>
<td>Maternal testosterone (males)</td>
<td>0.530 (0.011)</td>
<td>0.618 (0.005)</td>
<td>0.462 (0.032)</td>
</tr>
<tr>
<td>Fetal testosterone (females)</td>
<td>0.44 (0.078)</td>
<td>0.443 (0.150)</td>
<td>0.61 (0.018)</td>
</tr>
<tr>
<td>Fetal cortisol</td>
<td>–</td>
<td>0.123 (0.511)</td>
<td>0.526 (0.002)</td>
</tr>
<tr>
<td>Maternal testosterone</td>
<td>–</td>
<td>–</td>
<td>0.032 (0.866)</td>
</tr>
</tbody>
</table>

**Table 3** Multiple regression analysis for fetal testosterone (ln) as dependent variable.

<table>
<thead>
<tr>
<th></th>
<th>beta</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fetal cortisol (ln)</td>
<td>0.54</td>
<td>5.8</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Maternal testosterone (ln)</td>
<td>0.39</td>
<td>4.2</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Sex</td>
<td>-0.50</td>
<td>5.4</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

**REFERENCES**

A baby boy born to non-consanguineous parents showed skin lesions of generalised persistent cutis marmorata, dilated superficial veins, and telangiectasia involving the limbs, trunk, and scalp (fig 1). The lesions spared the palms and soles, and systemic examination was normal. An ultrasoundogram of the head and abdomen and systemic examination was normal. An ultrasoundgram of the head and abdomen was normal. An ultrasoundgram of the head and abdomen was normal.

Cutis marmorata telangiectatica congenita is a rare benign sporadic congenital vascular anomaly characterised by persistent cutis marmorata, telangiectasia, and phlebectasia and often associated with skin atrophy and ulceration. The cutaneous lesions commonly occur on the legs, arms, and trunk and rarely involve the face and scalp. Associated abnormalities such as body asymmetry, vascular and neurological anomalies, glaucoma, macrocephaly, and psychomotor retardation occur in many patients. The diagnosis is mainly clinical, and prognosis is generally good, with cutaneous lesions improving during infancy. There is no specific treatment, and long term follow up is indicated with associated abnormalities.

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Consent for figure 1 was obtained from the patient’s parents.

REFERENCES

www.archdischild.com