

**Cortisol Perturbation in the  
Pathophysiology of Septicaemia,  
Complicated Pregnancy and  
Weight Loss/Obesity**

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## Table of contents

<b>Abstract</b>	vi
<b>Statement of originality</b>	xi
<b>Acknowledgements</b>	xii
<b>Publications</b>	xiv
<b>List of tables and figures</b>	xvi
<b>Abbreviations</b>	xx

### Chapter 1

#### **Introduction**

<b>1.1</b>	<b>Historical developments</b>	1
<b>1.2</b>	<b>Physiology of the Hypothalamic-Pituitary-Adrenal axis and the Stress System</b>	4
<b>1.3</b>	<b>Glucocorticoids</b>	8
1.3.1	Biosynthesis and molecular actions	8
1.3.2	Regulation of cortisol secretion	11
1.3.3	Cortisol in circulation and the free hormone hypothesis	13
1.3.4	Factors affecting intracellular accumulation of free hormone	14
<b>1.4</b>	<b>Corticosteroid-binding globulin</b>	16
1.4.1	Physiology of CBG	16
1.4.2	CBG glycosylation	18
1.4.3	CBG in pregnancy	19
1.4.4	CBG in stress and obesity/ insulin resistance	20
<b>1.5</b>	<b>Physiologic actions of cortisol</b>	21
1.5.1	Metabolic effects	21
1.5.2	Immunological and anti-inflammatory effects	21
<b>1.6</b>	<b>Cortisol and blood pressure</b>	24
1.6.1	Salt and water homeostasis	24
1.6.2	Vascular tone	26
1.6.3	Heart	27

1.6.4	Brain	28
<b>1.7</b>	<b>Stress and the adaptive response</b>	<b>28</b>
1.7.1	Cortisol and stress	31
1.7.2	Cortisol and sepsis	35
1.7.3	Cortisol in pre-eclampsia and intrauterine growth restriction	38
1.7.4	Cortisol and obesity	41
<b>1.8</b>	<b>Summary</b>	<b>43</b>

## **Chapter 2**

### **Study design/ methods**

<b>2.1</b>	<b>Introduction</b>	<b>44</b>
<b>2.2</b>	<b>Methods</b>	<b>44</b>
2.2.1	Blood pressure measurements	44
	<ul style="list-style-type: none"> <li>• Resting blood pressure</li> <li>• 24 hour ambulatory blood pressure</li> <li>• Invasive arterial blood pressure</li> </ul>	
2.2.2	ACTH stimulation tests	45
	<ul style="list-style-type: none"> <li>• Low-dose ACTH</li> <li>• High-dose ACTH</li> </ul>	
2.2.3	Hormone assays	46
	<ul style="list-style-type: none"> <li>• Plasma total cortisol</li> <li>• Plasma free cortisol <ul style="list-style-type: none"> <li>➤ Validation of free cortisol assay</li> </ul> </li> <li>• Plasma corticosteroid-binding globulin</li> <li>• Urinary free cortisol/ cortisone</li> <li>• Plasma renin</li> <li>• Plasma aldosterone</li> <li>• Plasma nitrate/ nitrite (NOx)</li> </ul>	
2.2.4	Coolens' method	50
<b>2.3</b>	<b>Statistical analyses</b>	<b>51</b>

## **Chapter 3**

### **The hypothalamic-pituitary-adrenal axis in critical illness**

<b>3.1</b>	<b>Summary</b>	52
<b>3.2</b>	<b>Introduction</b>	53
	3.2.1 The HPA axis in stress and critical illness	54
	3.2.2 Septic shock	56
	3.2.3 Relative adrenal insufficiency	57
<b>3.3</b>	<b>Hypotheses and Aims</b>	60
<b>3.4</b>	<b>Research design and methods</b>	60
<b>3.5</b>	<b>Results</b>	63
<b>3.6</b>	<b>Discussion</b>	74
<b>3.7</b>	<b>Conclusion</b>	79
<b>3.8</b>	<b>Development of a cubic equilibrium in estimating free cortisol</b>	79

## **Chapter 4**

### **Nitric oxide as a potential physiologically relevant measure of cortisol action in tissues**

<b>4.1</b>	<b>Summary</b>	82
<b>4.2</b>	<b>Introduction</b>	84
	4.2.1 Nitric oxide synthesis and metabolism	84
	4.2.2 The role of nitric oxide in sepsis	86
	4.2.3 Nitric oxide and cortisol	88
<b>4.3</b>	<b>Hypotheses and Aims</b>	90
<b>4.4</b>	<b>Research design and methods</b>	90
<b>4.5</b>	<b>Results</b>	92
<b>4.6</b>	<b>Discussion</b>	100
<b>4.7</b>	<b>Conclusion</b>	102

## **Chapter 5**

### **The maternal hypothalamic-pituitary-adrenal axis in pregnancy**

<b>5.1</b>	<b>Summary</b>	103
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<b>5.2</b>	<b>Introduction</b>	105
5.2.1	Maternal HPA axis	105
5.2.2	Cortisol and foetal development	110
5.2.3	Pre-eclampsia	111
5.2.4	Intra-uterine growth restriction	114
5.2.5	Assisted reproduction	116
<b>5.3</b>	<b>Hypotheses and Aims</b>	117
<b>5.4</b>	<b>Research design and methods</b>	117
<b>5.5</b>	<b>Results</b>	120
<b>5.6</b>	<b>Discussion</b>	129
<b>5.7</b>	<b>Conclusion</b>	134
<b>5.8</b>	<b>Implications and future directions</b>	134

## **Chapter 6**

### **Obesity, hypertension and the hypothalamic-pituitary-adrenal axis**

<b>6.1</b>	<b>Summary</b>	136
<b>6.2</b>	<b>Introduction</b>	137
6.2.1	Obesity and the HPA axis	139
6.2.2	Renin-aldosterone-angiotensin system	141
6.2.3	Sympathetic nervous system	143
<b>6.3</b>	<b>Hypotheses and Aims</b>	144
<b>6.4</b>	<b>Research design and methods</b>	144
<b>6.5</b>	<b>Results</b>	148
<b>6.6</b>	<b>Discussion</b>	153
<b>6.7</b>	<b>Conclusion</b>	156

## **Chapter 7**

<b>Discussion and future perspectives</b>	157
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<b>Bibliography</b>	165
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## Abstract

Cortisol, the principal glucocorticoid secreted from the adrenal glands, is essential for life. Healthy cortisol levels are maintained through negative feedback on the central nervous system (CNS) – pituitary stimulatory apparatus which regulates production of adrenocorticotropin (ACTH) and contains a light-entrained intrinsic CNS driven diurnal rhythm. Cortisol participates in a regulatory mechanism where inflammatory cytokines stimulate cortisol release and cortisol in turn suppresses cytokine release. The effects of cortisol in inflammatory states include elevating blood pressure and metabolic regulation. This thesis contains three exploratory studies examining circulating cortisolaemia using the best available methodologies (total and free cortisol and corticosteroid-binding globulin (CBG)) in clinical states characterized by immune activation/ inflammation and altered blood pressure. These clinical states include: (1) septic shock, (2) hypertensive disorders of pregnancy and (3) obesity-induced hypertension. Prior to the studies described here, little was known about cortisolaemia in these common pathological states.

Septic shock is a life threatening condition that complicates severe infection and is characterized by systemic inflammation and refractory hypotension. High plasma total cortisol levels and attenuated responses to synthetic ACTH stimulation are associated with increased mortality. The use of corticosteroids in septic shock has been highly controversial for decades, however recent trials have reported haemodynamic and survival benefits associated with the use of physiologic steroid replacement in patients with relative adrenal insufficiency (RAI) – currently defined as a total cortisol increment of 248 nmol/L or less following ACTH (250 µg) stimulation. However, CBG and albumin levels fall by around 50% with an increase in plasma free cortisol in critical illness. Hence, total cortisol may not reflect

the biologically active free (unbound) cortisol, suggesting that standard assays for plasma cortisol (which measure total plasma cortisol) underestimate HPA axis activity.

In this study, we have showed that plasma free cortisol is a better guide to circulating glucocorticoid activity in systemic infection than total cortisol. We have also validated the use of Coolens' method in estimating free cortisol in systemic infection, using plasma total cortisol and CBG measurements as plasma free cortisol is not performed in clinical laboratories. Free cortisol measurement allows better categorization of RAI and non-RAI groups with a free cortisol increment of 110 nmol/L as cut-off. Moreover, we have shown that survivors of RAI have normal adrenocortical function on follow-up testing suggesting a lack of functional adrenal reserve rather than adrenal damage during critical illness. Larger randomized controlled trials will be required to redefine RAI using free cortisol measurements and relate that to clinical outcomes and responses to corticosteroid therapy.

Nitric oxide (NO) is normally produced in the endothelium by the constitutive form of the NO synthase and this physiologic production is important for blood pressure regulation and blood flow distribution. Studies have shown that an overproduction of NO by the inducible form of NO synthase (iNOS) may contribute to the hypotension, cardiodepression and vascular hyporeactivity in septic shock. Clinical studies of non-selective inhibitors of the L-arginine nitric oxide pathway showed increased mortality from cardiovascular complications. However, glucocorticoids, which improve vasopressor sensitivity, may act by partially suppressing NO synthesis through selective direct inhibition of iNOS, and suppression of inflammatory cytokine synthesis. Hence, plasma nitrate/ nitrite (NO<sub>x</sub>) levels may provide a titratable end point to individualize glucocorticoid therapy in sepsis.

The NOx study in this thesis showed that cortisol (total and free), CBG and NOx correlated to illness severity. Free cortisol, and to a lesser extent total cortisol, but not NOx levels, predicted septic shock. NOx levels were characteristically stable within individuals but inter-individual differences were only partly accounted for by illness severity or renal dysfunction. NOx levels correlated weakly with cortisol, did not relate to the need for vasopressors and were not suppressed by hydrocortisone treatment. Thus, NOx is not a suitable target for glucocorticoid therapy in septic shock.

Pregnancy is the only sustained physiologic state of hypercortisolism in humans. A large body of data suggests that excessive foetal and prenatal glucocorticoid exposure leads to reduced birth weight and adverse health in offspring such as elevated blood pressure and insulin resistance. Pre-eclampsia and gamete donor pregnancies are associated with immune activation, elevated inflammatory cytokines as well as elevated blood pressure. Prior to the study described in this thesis however, there was no prospective data on maternal cortisolaemia in these complicated pregnancies.

My study has demonstrated for the first time that there was a substantial fall in plasma CBG levels in the last few weeks of gestation with a corresponding rise in free cortisol in normal pregnancy, a finding obscured for methodological reasons in past studies. This free cortisol elevation in late pregnancy may facilitate organ maturation in the foetus and perhaps prepare the mother for the metabolic demands of labour. In pre-eclampsia and gestational hypertension, plasma CBG, total and free cortisol levels were lower in late third trimester; and in IUGR, plasma CBG levels were suppressed from 28 weeks gestation until delivery but with no significant difference in plasma total and free cortisol. Women with assisted reproduction using donor gametes/ embryos had significantly lower plasma CBG, total and free cortisol levels even in those with normal pregnancy outcomes. Low CBG may be due to reduced



synthesis or enhanced inflammation-driven degradation. Low maternal cortisol may be due to a lack of placental corticotropin-releasing hormone, or reduced maternal ACTH, driving cortisol production. This unanticipated maternal hypocortisolism in complicated pregnancies may trigger precocious activation of the foetal HPA axis and could have implications for postnatal and adult health. Speculatively, since excess prenatal GCs increase HPA axis activity, we proposed that maternal hypocortisolism may predispose to the hypocortisolaemic state characterized by fatigue, pain and stress sensitivity, in offspring.

The third state of immune/ inflammatory activation associated with blood pressure dysregulation studied in this thesis is obesity. The epidemiologic relationship between obesity and hypertension is widely recognised. Central obesity in particular has been associated with exaggerated HPA responses to stimuli. Studies of severe dieting and starvation resulted in hypercortisolism and a significant decrease in CBG. The HPA axis and the renin-angiotensin-aldosterone system (RAAS) have been implicated in the pathophysiology of obesity-induced hypertension. However, there is little data on the effect of moderate weight loss (30% caloric restriction) on adrenocortical function, and the relation of adrenal hormones to altered blood pressure with weight loss.

In this study, measures of HPA axis and RAAS and blood pressure monitoring were performed in twenty-five obese subjects before and after a 12-week diet program (6000kJ/day). Short-term, moderate weight loss (mean 8.5 kg) was associated with a small reduction in blood pressure (mean arterial pressure 6 mmHg) and significantly reduced levels of aldosterone and renin but not cortisol levels. These findings suggest that aldosterone may have an important role in the blood pressure reduction with weight loss via a renin mediated mechanism, perhaps involving renal sympathetic tone. In contrast to severe caloric restriction, HPA axis activation does not occur with moderate weight loss. This suggests a threshold

effect of weight loss on the HPA axis where greater caloric restriction is required for HPA stimulation, or a counterbalancing of central and direct adrenal effects on HPA axis function.

Overall, these three exploratory studies have provided novel data on HPA axis function in systemic infection, pregnancy and in diet-induced weight loss. Each study offers a basis for further studies of HPA axis function in these disorders.

## **Statement of originality**

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university, and to the best of my knowledge and belief contains no material previously published or written by another person, except where due reference is made in the text.

I give consent to this copy of my thesis being made available in the University Library.

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Jui Ting Ho

April 2007

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## Publications

Publications related to work presented in this thesis:

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**Ho JT**, Lewis JG, O'Loughlin P, Bagley CJ, Romero R, Dekker GA, Torpy DJ. Reduced Maternal Corticosteroid-binding Globulin and Cortisol Levels in Pre-eclampsia and Gamete Recipient Pregnancies. *Clinical Endocrinology (Oxf)* 2007 Jun; 66(6):869-77

**Ho JT**, Keogh JB, Lewis JG, Clifton PM, Torpy DJ. Moderate weight loss reduces renin and aldosterone but does not influence basal or stimulated pituitary-adrenal axis function. *Hormone and Metabolic Research* 2007 (In Press)

Torpy DJ, **Ho JT**. Value of Free Cortisol Measurement in Systemic Infection. *Hormone and Metabolic Research* 2007 Jun; 39(6):439-44

Torpy DJ, **Ho JT**. Corticosteroid binding globulin gene polymorphisms: clinical implications and links to idiopathic chronic fatigue disorders. *Clinical Endocrinology (Oxf)* 2007 Aug; 67(2):161-7

Torpy DJ, **Ho JT**. Evaluation of adrenocortical function in adults. *Australian Prescriber* 2007

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**Ho JT**, Lam S, Chapman MJ, O'Connor S, Edwards J, Ludbrook G, Lewis JG, Torpy DJ.

Nitric oxide activity increases with sepsis severity but does not predict shock.

Dorin RI, Qualls CR, Pai HK, **Ho JT**, Lewis JG, Torpy DJ, Urban FK. Comparison of equilibrium estimates of free cortisol: Reversible changes in cortisol affinity for albumin in septic shock and relative adrenal insufficiency.

## List of tables and figures

### Tables

Table 1.1	Human and animal data that link prenatal glucocorticoid excess and stress to postnatal development of metabolic syndrome and psychiatric disorders.	38
Table 3.1	Clinical characteristics of patients with septic shock, sepsis and the healthy controls.	62
Table 3.2	The effect of varying concentrations of purified human serum albumin in a solution containing 600nmol/L cortisol on free cortisol fraction obtained by equilibrium dialysis, and on N the ratio of albumin bound: free cortisol.	72
Table 4.1	Clinical characteristics of patients with sepsis and septic shock.	91
Table 4.2	Plasma concentrations of cortisol, NOx, albumin, and creatinine (CBG) on admission in septic shock and sepsis groups.	93
Table 4.3	Ordinary least-products regression analysis between plasma NOx and cortisol measurements (total and free cortisol, corticosteroid-binding globulin) and renal function	96
Table 5.1	Mechanisms and hypotheses implicated in the pathogenesis of pre-eclampsia	109
Table 5.2	Characteristics of pre-eclampsia (PE), gestational hypertension (GH), intrauterine growth restriction (IUGR), assisted reproduction by gamete donation (GR) and control groups.	119
Table 6.1	Baseline characteristics of study subjects	142
Table 6.2	Hormones of the renin-angiotensin-aldosterone system and hypothalamic-pituitary-adrenal axis pre- and post-weight loss.	148

### Figures

Figure 1.1	The hypothalamic-pituitary-adrenal axis, illustrating negative feedback by cortisol at the hypothalamic and pituitary levels.	5
Figure 1.2	Major components of the central and peripheral stress system.	7
Figure 1.3	Shuttling of glucocorticoid receptor $\alpha$ (GR $\alpha$ ) between the cytoplasm and the nucleus and its transactivating or transrepressive	10



	activities.	
Figure 1.4	A graphic depiction of circadian rhythm of cortisol over a 24-h period.	12
Figure 1.5	A schematic diagram of protein glycosylation of corticosteroid binding globulin	18
Figure 1.6	The change in pregCBG during gestation and in the postpartum period.	19
Figure 1.7	Interactions between NF- $\kappa$ B and activated GR	23
Figure 1.8	Homeostatic regulation curves	29
Figure 1.9	Schematic diagrams showing three states of altered cortisol secretion associated with blood pressure dysregulation	32
Figure 1.10	Acquired glucocorticoid resistance	35
Figure 2.1	Validation of free cortisol assay (ligand binding/ultrafiltration method) against equilibrium dialysis.	45
Figure 2.2	Unbound (free) cortisol, calculated from total cortisol and CBG, as a function of unbound cortisol, measured by ultrafiltration in plasma samples of normal subjects.	49
Figure 3.1	Basal total and free plasma cortisol, and cortisol increments after tetracosactrin (ACTH 1-24), CBG and albumin levels in patients with patients with septic shock (n=45), sepsis (n=19) and in healthy controls (n=10).	64
Figure 3.2	Basal and tetracosactrin-stimulated total and free cortisol levels in septic shock patients with RAI ( $\Delta$ cortisol $\leq$ 248 nmol/L, n=15) and without RAI ( $\Delta$ cortisol $>$ 248 nmol/L, n=30).	66
Figure 3.3	Cortisol (total and free), CBG and albumin levels from serial tetracosactrin stimulation tests in septic shock patients.	69
Figure 3.4	Comparisons between measured free cortisol by ultrafiltration method and (A) calculated free cortisol by Coolens' equation (the substitute for N is 1.74) and (B) calculated free cortisol using experimentally derived N to take account of varying plasma albumin concentrations, as shown in Table 2.	71
Figure 3.5	Correlation between measured free cortisol (ultrafiltration/ligand binding method) and free cortisol estimated using either (A) Coolens equation or (B) cubic equilibrium equation. Free cortisol estimates by the cubic equation are obtained using group-specific	79

	$K_A$ values derived using the non-linear least squares solution.	
Figure 4.1	Dichotomous effects of endothelial nitric oxide synthase (eNOS)-derived and inflammatory nitric oxide synthase (iNOS)-derived nitric oxide (NO).	84
Figure 4.2	NOx concentrations and hydrocortisone infusion	87
Figure 4.3	Illness severity represented by APACHE II scores correlated positively with plasma total and free cortisol and NOx concentrations on admission.	94
Figure 4.4	Serial plasma total and free cortisol, and NOx concentrations in hydrocortisone treated ( $n = 18$ ) and untreated ( $n = 17$ ) septic shock patients.	97
Figure 5.1	Mean plasma CRH concentrations in seven women throughout pregnancy. Sequential samples were obtained at 1- to 2-week intervals beginning at 12 weeks gestation.	103
Figure 5.2	A schematic representation of the HPA axis in the (A) non-pregnant and (B) pregnant states. In the latter, cortisol participates in a positive feedback loop by stimulating placental CRH secretion, whereas inhibiting hypothalamic CRH release.	104
Figure 5.3	Mean ( $\pm$ SE) total plasma concentrations of cortisol and ACTH during normal pregnancy. Blood samples were obtained weekly at 0800 to 0900 hours, during labour and on the second postpartum day.	105
Figure 5.4	Plasma total and free cortisol, and corticosteroid-binding globulin (CBG) concentrations in control subjects ( $n=33$ ).	122
Figure 5.5	Comparing subjects with pre-eclampsia (PE, $n=11$ ), gestational hypertension (GH, $n=16$ ) and controls ( $n=33$ ).	123
Figure 5.6	Plasma total and free cortisol and CBG concentrations in women who had intrauterine growth restricted neonates ( $n=12$ ) & controls	124
Figure 5.7	Plasma total and free cortisol and CBG concentrations in women with assisted fertilization using donor oocytes/ embryos ( $n=22$ ).	125
Figure 5.8	Comparing measured free cortisol by ultrafiltration/ ligand binding method to calculated free cortisol by Coolens' method using Bland-Altman plot.	126
Figure 6.1	A schematic outline of factors that contribute to the pathogenesis of obesity-induced hypertension	135

Figure 6.2	Study Protocol	143
Figure 6.3	Mean arterial pressures (B) fell significantly after 7.7 kg weight loss (A). Blood pressure response to salt loading was not altered by weight loss.	146
Figure 6.4	Plasma aldosterone and renin levels pre- and post weight loss.	149
Figure 6.5	Cortisol measures including total and free cortisol responses to Cosyntropin, CBG levels and 11 beta hydroxysteroid dehydrogenase 1 (11 $\beta$ -HSD1) activity as represented by the ratio of urinary free cortisol to cortisone.	149
Figure 7.1	Schematic diagrams showing three states of altered cortisol secretion associated with blood pressure dysregulation	155

## Abbreviations

ACTH	Adrenocorticotrophic hormone
AngII	Angiotensin II
APACHE II	Acute Physiology and Chronic Health Evaluation
AVP	Arginine Vasopressin
BMI	Body mass index
BW	Body Weight
CBG	Corticosteroid-binding globulin
CNS	Central Nervous System
CRH	Corticotropin-releasing hormone
DHEA	Dehydroepiandrosterone
DHEAS	Dehydroepiandrosterone sulphate
ELISA	Enzyme-linked immunosorbent assay
eNOS	Endothelial nitric oxide synthase
GC	Glucocorticoids
GH	Gestational hypertension
GR	Glucocorticoid receptor
GRE	Glucocorticoid-response element
HC	Healthy control
hGR $\alpha$ / $\beta$	human Glucocorticoid receptor alpha/ beta
HPA	Hypothalamic-pituitary-Adrenal
HPLC	High performance liquid chromatography
ICU	Intensive care unit
ICV	Intracerebroventricular
IGF	Insulin like growth factor
IL	Interleukin
iNOS	inducible nitric oxide synthase
IUGR	Intrauterine growth restriction
MAP	Mean arterial pressure
MODS	Multiple organ dysfunction syndrome
MR	Mineralocorticoid receptor
MW	Molecular weight
NO	Nitric oxide

NO <sub>x</sub>	Nitrate/ nitrite
NOS	Nitric oxide synthase
POMC	Pro-opiomelanocortin
PRA	Plasma renin activity
RAAS	Renin-angiotensin-aldosterone system
RAI	Relative adrenal insufficiency
RM-ANOVA	Repeated measures analysis of variance
SEM	Standard error of the meas
SIRS	Systemic inflammatory response syndrome
S	Sepsis
SGA	Small for gestational age
SNS	Sympathetic nervous system
SS	Septic shock
Th1/Th2	T helper cell 1 and 2
TNF- $\alpha$	Tumour necrosis factor–alpha
11 $\beta$ -HSD <sub>1</sub> & <sub>2</sub>	11 beta hydroxysteroid dehydrogenase type 1 and 2