Published in final edited form as:

Arch Womens Ment Health. 2016 April ; 19(2): 317–328. doi:10.1007/s00737-015-0563-7.

Altered stress patterns and increased risk for postpartum depression among low-income pregnant women

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Abstract

Postpartum depression (PPD) has been associated with a number of negative maternal and infant health outcomes. Despite these adverse health effects, few studies have prospectively examined patterns of pre- and postnatal stress that may increase a woman's risk for PPD. The current study examined whether the timing of altered salivary cortisol patterns and perceived stress levels during pregnancy and at 3 months postpartum was associated with PPD symptoms among 100 low-income mothers. Higher levels of PPD were found among women with a lower cortisol awakening response (first and second trimester), lower average daily cortisol (second trimester), a flatter diurnal cortisol pattern (second and third trimester and at 3 months postpartum), and a less abrupt drop in both cortisol and perceived stress from the third trimester to 3 months postpartum. These results support the need for early screening and regulation of stress levels to promote depression prevention efforts in at-risk populations.

Keywords

Postpartum depression; Cortisol; Perceived stress; Pregnancy

Recent studies have shown that up to 19 % of mothers report experiencing postpartum depressive (PPD) symptoms within the first 3 months of the postpartum period (Gavin et al. 2005). Symptoms of PPD include mothers feeling numb or disconnected from their babies and a fear of failure, within a year of having their baby, with the prevalence rate increasing to as much as 41 % for mothers with a past history of PPD (Centers for Disease Control and Prevention 2010; Hubner-Liebermann et al. 2012). Further, up to 10 % of women with PPD experience thoughts of suicide, and up to 61 % of severely depressed women are troubled by impulses to harm their child (Chandra et al. 2002).

Prior research has looked at the long-term detrimental effects that PPD may have on infant and child development. Results from these studies have shown that PPD can negatively affect infants by causing behavioral problems, delays in development, and can even increase a child's risk of developing depression (Marcus et al. 2011). For example, Hubner-Liebermann et al. (2012) found that children of depressed mothers displayed sleep and

breast-feeding problems, failure to thrive, insecure-avoidant attachment, and reduced social skills, even up to adolescence.

Due to the detrimental effects that PPD has on both mothers and infants, it is important to identify possible predictors of PPD. One factor that may be associated with PPD is stress, which can be measured by self-report and physiologically through the stress hormone cortisol. Cortisol is a stress hormone that is secreted by the adrenal gland in response to stressful situations through the hypothalamic–pituitary–adrenal (HPA) axis. During a life event that is perceived as stressful, cortisol is released through the HPA axis causing several physiological changes, including more rapid breathing and pulse, more oxygen being available to the muscles, and a rise in blood sugar levels. These short-term effects of cortisol secretion help protect an individual during an acute stressor and usually go back to baseline levels after the stressor is gone. However, chronic activation of the HPA axis, resulting from chronic stress, can lead to altered cortisol patterns which, in turn, can cause complications such as increased risk of cardiovascular disease, stroke, elevations in blood pressure, and Cushing's syndrome, characterized by hypertension and type 2 diabetes (Rosmond and Bjorntorp 2000).

Different indicators of altered cortisol patterns have been associated with certain health impairments. For example, chronically elevated levels of cortisol have been assessed by using total daily cortisol output, which is an indicator for the total amount of cortisol secreted by the HPA axis throughout the day, and have been associated with a variety of physical and psychological health outcomes such as poor sleep, obesity, diabetes, cardiovascular disease, and depression (Fiorentino et al. 2012). In addition, researchers have examined an individual's cortisol awakening response (CAR), which is normally characterized by having a sharp increase in salivary cortisol from the time of awakening to between 20 and 30 min after waking (Wilhelm et al. 2007). In a systematic review, higher levels of CAR have been associated with higher levels of general life stress (Chida and Steptoe 2009). In contrast, blunted or flat CAR patterns have been associated with higher levels of depression among Mexican-American adults (Mangold et al. 2011). Researchers have also examined diurnal cortisol patterns in relation to health outcomes. Diurnal cortisol patterns show the changes of cortisol throughout one day, with a normal diurnal cortisol pattern characterized by a peak in cortisol in the morning hours and a steady decline of cortisol throughout the day. In contrast, an altered diurnal cortisol pattern may not show this steady decline and either look flatter or show a diurnal pattern in the opposite direction (i.e., lower morning cortisol levels, with a steady increase in cortisol throughout the day). These altered diurnal cortisol patterns have been associated with higher levels of depression in middle-aged women (Knight et al. 2010, Jarcho et al. 2013). Collectively, these findings emphasize the importance of examining all three of these cortisol indices (i.e., total cortisol output, CAR, diurnal cortisol) as risk factors for depression.

To date, there has been extensive research exploring the relationship between cortisol patterns and mood and depressive disorders, with alterations in the HPA axis having been repeatedly associated with major depressive disorders (MDD) in both non-pregnant adolescent (Mangold et al. 2011) and adult populations (Adam et al. 2010; Goodyear et al. 2010; Herbert et al. 2012; Staufenbiel et al. 2013). Specifically, alterations in cortisol

patterns, such as a blunted cortisol response after awakening (i.e., CAR) and lower daily total cortisol output (i.e., area under the curve (AUC)), have been associated with increased risk for MDD (Dedovic et al. 2006). In addition, several studies have found blunted diurnal cortisol patterns (Jarcho et al. 2013; Knight et al. 2010) or a blunted cortisol response to psychological stressors (Burke et al. 2005) among women who suffer from depression.

Despite the association found between alterations in cortisol patterns and MDD, there are inconsistent findings on the effect that cortisol patterns during pregnancy may have on the onset of PPD. Many of these inconsistencies are related to the abrupt hormone changes that normally occur during pregnancy and after childbirth. During pregnancy, there is a substantial increase in placental cortisol levels (particularly after the 26th week of gestation) which plays an important role in fetal organ development (Crowley 2000; Glynn et al. 2013; Kapoor et al. 2006); CAR and diurnal cortisol patterns are still observed throughout pregnancy. Immediately after childbirth, cortisol levels tend to decrease abruptly and return to pre-pregnancy levels.

It may be the gestational time point at which cortisol is measured that contributes to the inconsistencies found between cortisol and PPD, as well as the manner in which it was collected (i.e., assessing for diurnal variation in cortisol throughout the day vs. collecting cortisol at a single time point during the day). For example, one study found no significant association between blood concentrations of cortisol assessed during the third trimester of pregnancy (usually after 26 weeks of gestation) and PPD (O'Keane et al. 2011). However, recent studies by both Yim et al. (2009) and Hahn-Holbrook et al. (2013) found that women with elevated levels of placental corticotropin-releasing hormone [CRH, which stimulates the adrenocorticotrophic-releasing hormone (ACTH) that then causes the adrenal gland to release cortisol] at mid-gestation (25 weeks of gestation) were at increased risk for PPD. Interestingly, previous literature has shown that perceived stress levels decrease throughout pregnancy, contrary to patterns of cortisol. According to Glynn et al. (2001), women tend to experience events as being more stressful earlier in their pregnancy, and less stressful later in their pregnancy, with later stages of pregnancy acting as a buffer against women's perceptions of stress. There is currently no research to our knowledge that examines perceived stress at different trimesters during pregnancy and its prediction of symptoms of postpartum depression. Therefore, the effect of stressors experienced earlier in pregnancy is unclear. Given these findings, additional studies are needed to examine whether cortisol and stress patterns at different time points in pregnancy may differentially serve as predictors of PPD.

In addition to prenatal stress patterns and their role in the onset of PPD, some studies have proposed that the abrupt drop in cortisol levels observed after childbirth may serve as a possible risk factor for PPD (Bloch et al. 2005; Pedersen et al. 1993; Taylor et al. 2009). More specifically, women who do not show this drop in cortisol levels after childbirth (i.e., continue to have elevated cortisol levels at postpartum) may be at higher risk for postpartum depression. However, to date, only one study to our knowledge has examined the association between these hormonal changes in cortisol during the days following delivery and PPD. O'Keane et al. (2011) examined changes in cortisol levels from the third trimester of pregnancy (36 weeks gestation) to one to six days postpartum and their association with

postpartum blues among 70 pregnant women ages 19–49 that had no current or previous psychiatric condition and no major medical conditions. On average, results showed a significant reduction in cortisol from pregnancy to postpartum day six, with cortisol levels dropping 19 % from the third trimester of pregnancy to postpartum. However, there was no significant association found between this postpartum change in cortisol levels and postpartum blues.

Altered cortisol patterns (i.e., CAR and diurnal cortisol) during the postpartum period are also a possible factor in the etiology of postpartum depression. In addition to the postpartum drop observed after childbirth, other studies have examined the association between cortisol during the early postpartum period and PPD. For example, Taylor et al. (2009) compared the cortisol patterns of depressed and non-depressed women at 7.5 weeks postpartum and found women with PPD to have significantly higher morning cortisol levels at awakening and a blunted CAR pattern (i.e., no immediate rise in cortisol 30 min after awakening), compared to non-depressed women. These studies indicate a need for further empirical studies investigating the association between changes in cortisol levels from the third trimester of pregnancy through the postpartum period and the onset of PPD.

The purpose of the current study was to prospectively examine whether altered stress patterns (i.e., cortisol and perceived stress) during pregnancy and the early postpartum period were associated with PPD symptoms among a sample of low-income pregnant women. Based on previous studies with CRH, it was expected that altered cortisol patterns during the second trimester of pregnancy would most significantly predict higher levels of PPD symptoms, compared to the first and third trimesters of pregnancy and at 3 months postpartum. It was also expected that higher patterns of perceived stress during the earlier stages of pregnancy (first and second trimesters) would be more predictive of PPD because of the potential role of pregnancy acting as a buffer to stress during the later stages of pregnancy (Glynn et al. 2001). Finally, the current study predicted that women who experienced less of a drop in cortisol and perceived stress from the third trimester of pregnancy to the postpartum period would demonstrate higher levels of PPD symptoms.

Method

Participants

Sample and selection criteria—Our sample consisted of 100 low-income pregnant women who participated in a longitudinal study called the Stress Management and Relaxation Training for Moms (SMART Moms) Project, which was a prenatal stress management program designed to regulate stress in pregnant women and their infants (conducted between 2010 and 2014). Women were directly recruited for the study by approaching them while they waited for their doctor's appointment at a prenatal clinic in southern California or through referrals received by their health care provider. A total of 2,110 women were approached in the recruitment process, out of which 316 were eligible for the study and 100 were randomized (27 % were no longer interested in the study, 22 % were no longer eligible due to medical exclusions, 12 % were lost to contact, 7 % were no longer available for the stress management classes). There were no significant differences between randomized and non-randomized women on demographic variables, anxiety or

depression levels, or perceived stress. All participation was voluntary and incentives (up to \$200) were given to women who completed the entire study. Eligibility criteria were that patients: (1) be over the age of 18, (2) be able to speak either fluent English or Spanish, (3) be less than 18 weeks pregnant, (4) live in the city where the prenatal clinic was located, (5) have no prior major medical or psychiatric conditions (e.g., preeclampsia, gestational diabetes, major depression), and (6) not be taking any medications that are known to affect cortisol such as taking steroid medication (Giesbrecht et al. 2012).

Procedures—After providing informed consent, eligible women participated in health interviews administered in person or over the phone at four different time points (i.e., first, second, and third trimester of pregnancy and at 3 months postpartum). For the current study, health interview questions were used that assessed for demographic information, perceived stress levels, and postpartum depressive symptoms. After completing their health interviews, participants were instructed on how to collect salivary cortisol at home. Mothers collected salivary cortisol using a passive drool procedure where they accumulated saliva from their mouth and used a straw to place the saliva into a collection tube. Participants were then asked to put these collection tubes in a freezer bag (which was provided) and store this bag in their refrigerator until a member of the research team came to their home to collect the samples. The samples for all participants were then sent to an off-site laboratory to be analyzed. Salivary cortisol was measured at four different time points in the study: (1) baseline when the women were first recruited (first trimester of pregnancy; <16 weeks of gestation), (2) after completing their 8-week prenatal program (second trimester of pregnancy; women were randomized to either a group-based stress management program or an attention control program where women received print-based prenatal health information by mail; see Urizar et al. 2014 for more information about these prenatal programs), (3) when they reached 30–32 weeks gestational age (third trimester of pregnancy), and (4) at postpartum when their baby reached 3 months of age. At each of these study time points, salivary cortisol was collected at seven different times on one collection day (i.e., upon awakening; 30, 45, and 60 minutes after awakening; 12 pm, 4 pm, and 8 pm). Participants were also instructed to abstain from behaviors known to contaminate and interfere with salivary cortisol levels (e.g., eating, brushing their teeth, taking medications, exercising) for at least 30 minutes before collecting their saliva samples (Gröschl et al. 2001) and were asked to report times of saliva collection and adherence to these guidelines on a self-report log. The Institutional Review Board (IRB) at the California State University of Long Beach approved all study procedures.

Measures

Salivary cortisol—Salivary cortisol samples were analyzed in the laboratory with all procedures being kept constant across samples. After being thawed for biochemical analysis, the samples were centrifuged and salivary cortisol was analyzed using a time-resolved immunoassay with fluorescence detection as described in detail elsewhere (Dressendorfer et al. 1992). Intra- and interassay variability were both under 10 %. Four indices were used to identify cortisol patterns during pregnancy: average daily cortisol, AUC, CAR, and diurnal cortisol slope (Adam & Kumari 2009). Average daily cortisol was used to assess for the total cortisol output that a participant produced throughout the day. This was calculated by

summing the cortisol logarithmic transformation (base 10, cortisol values converted from $\mu\text{g/dL}$ to nmol/L) values for all seven collection times in a day and dividing that total by seven, with larger numbers representing a greater amount of daily cortisol produced. Another measurement of daily cortisol output is called AUC, which refers to total salivary cortisol output on the day of collection. The current study used an AUC variable calculated from raw values (nmol/L) that takes into account individual collection time. AUC was calculated by adding the awakening collection and the 12 pm collection, divided by 2 and multiplied by the time between awakening and 12 pm plus the addition of the 12 pm and 4 pm collection divided by 2 and multiplied by the time between 12 pm and 4 pm plus the addition of the 4 pm collection and the 8 pm collection divided by 2 and multiplied by the time between 4 and 8 pm. Larger numbers represent a greater amount of cortisol produced throughout the day. CAR was used to measure the acute rise in cortisol typically seen after waking in the morning. The current study used residual cortisol as a measurement of CAR that takes into account potential differences in each individual participant's cortisol awakening times. CAR (from nmol/L) values were calculated by a regression equation where the first morning cortisol sample (awakening) served as a predictor for the second morning cortisol sample (30 minutes after awakening), producing a residual cortisol value that removes the variance associated with cortisol awakening values and thereby reducing potential differences in participant's cortisol awakening times. Larger numbers represent a greater CAR. Diurnal cortisol slope measures the rate of decline in levels of cortisol across the day. Diurnal slope was measured by calculating the change in raw cortisol (nmol/L) from 30 minutes after awakening (i.e., cortisol peak) to 8 pm (i.e., 8 pm cortisol–30 min post-awakening cortisol) with larger numbers representing a flatter diurnal slope. Lastly, the postpartum drop in cortisol was calculated by subtracting the average daily cortisol (log scores) during the third trimester from the average daily cortisol at 3 months postpartum (i.e., third trimester cortisol–postpartum cortisol), with higher numbers representing a greater drop in cortisol levels after childbirth.

Perceived stress—The 14-item Perceived Stress Scale (PSS; Cohen et al. 1983) was used to assess perceptions of stress during the first, second, and third trimesters of pregnancy and during the postpartum period. The PSS measures the degree to which situations in one's life are appraised as unpredictable, uncontrollable, and overloading during the past month. Each item on the PSS is on a five-point Likert scale ranging from 0 to 4 ("0 = never" to "4 = very often"). A total perceived stress score is derived by summing all 14 items. Higher scores on the PSS indicate higher perceived stress (possible total range of scores = 0 to 56). The PSS has been shown to have good test–retest reliability and internal consistency (Cohen et al. 1983). Cronbach's alpha for the current study was .75 (first trimester), .74 (second trimester), .74 (third trimester), and .74 (3 months postpartum), respectively.

Postpartum depression—The ten-item Edinburgh Postnatal Depression Scale (EPDS; Cox et al. 1987) was used to assess symptoms of postpartum blues and depression at 3 months postpartum. The total possible score ranges from 0 to 30 and indicates the possible degree of postpartum depression experienced during the past week. Higher scores indicate a more severe form of postpartum depression. A cutoff score of 10 was used for reporting high postpartum depressive symptoms. The EPDS has been used with a variety of sample

populations and has shown good psychometric properties (Dayan et al. 2006; Karacam and Kitis 2008). The Cronbach's alpha for the EPDS in the current study at 3 months postpartum was .81.

Data analyses

Hierarchical regression analyses were performed to determine whether altered stress patterns (i.e., cortisol and perceived stress) at different trimesters of pregnancy (first, second, and/or third trimesters) and at 3 months postpartum were associated with PPD, adjusting for family income level (annual combined family income) and randomization group (0 = attention control group, 1 = stress management group). For each regression model, family income was entered in the model first, followed by randomization group (i.e., stress management vs. attention control group), and the stress variable being tested (cortisol or perceived stress) entered last. Separate models were tested for altered stress patterns during each trimester of pregnancy and at 3 months postpartum to determine which were most significantly associated with PPD. Lastly, a hierarchical regression analysis was conducted to determine whether the level of postpartum drop in average daily cortisol output (log scores) and perceived stress scores from the third trimester of pregnancy to 3 months postpartum would be associated with higher PPD symptoms, adjusting for family income level and randomization group.

From our original sample of 100 women, 88 % completed their salivary cortisol collection during the second and third trimesters of pregnancy, and 81 % collected salivary cortisol at 3 months postpartum. For participants that were missing a cortisol value during a collection day due to providing an insufficient amount of saliva or not collecting saliva at that time of day (e.g., missing 4 pm cortisol value), data was imputed based on the slope of the other cortisol values that the participant had provided for that collection day. Cortisol outliers were defined as being three standard deviations from the mean for each cortisol index. Seven participants were identified as being cortisol outliers across the four study time points. Thus, all multiple regression analyses were conducted with and without these participant cases. No significant differences were found in the results presented when the outliers were taken out of the analyses or included; therefore, the results below represent data from our full study sample.

Results

Sample characteristics

On average, participants were 27 years old ($SD=6.3$) and in their tenth week of pregnancy ($SD=4.72$). About 70 % of participants were of Latino decent and 70 % spoke Spanish. The majority of our sample had a high school education or less (71 %), was unemployed (68 %), and had an annual family income level of less than \$10,000 a year (40 %). Forty-nine percent of the sample was married, and 37 % were first time mothers. In addition, 22 % of our sample displayed high postpartum depressive symptoms at 3 months postpartum (i.e., score of 10 or higher on the EPDS).

Association among study variables

Perceived stress and salivary cortisol—A repeated measures analysis was used to identify the pattern of perceived stress during pregnancy and found that perceived stress levels decreased throughout pregnancy and continued to decrease at 3 months postpartum [$F(1, 82)=7.70, p<.01$; see Table 1]. A repeated measures analysis was also used to identify the pattern of cortisol during pregnancy. The results of this repeated measures test found that average cortisol output increased steadily throughout pregnancy and significantly decreased at 3 months postpartum [$F(1, 77)=26.93, p<.001$; see Table 1]; similarly, AUC increased significantly from the first trimester to second trimester and gradually increased from the second trimester to third trimester [$F(1, 77)=17.78, p<.001$; see Table 1]. The repeated measures analysis also showed that diurnal cortisol patterns decreased or became flatter throughout pregnancy and at 3 months postpartum [$F(1, 77)=.82, p>.05$; see Table 1]. Finally, a repeated measures test showed that cortisol awakening response decreased, or became flatter, from the first trimester to the second trimester of pregnancy and then steadily increased (i.e., became steeper) from the second trimester of pregnancy to 3 months postpartum [$F(1, 77)=.05, p=n.s.$]. Pearson correlation analyses showed different cortisol indices and perceived stress to be significantly correlated at various time points during pregnancy, but not all. Perceived stress during all three trimesters of pregnancy and at 3 months postpartum was significantly associated with diurnal patterns of cortisol during the third trimester ($r=.26$ to $.37, p<.05$), with higher levels of perceived stress being associated with flatter diurnal cortisol patterns during the third trimester of pregnancy. Perceived stress was not significantly associated with average cortisol output, AUC, or CAR at any time point during pregnancy or postpartum.

Salivary cortisol and postpartum depression—Hierarchical regression analyses were conducted to examine if cortisol indices during the first, second, and third trimesters of pregnancy predicted PPD, controlling for income and randomization group. Results showed that the CAR during the first [$F(3, 77)=3.17, p<.05, R^2=.11$] and second [$F(3, 74)=4.58, p<.05, R^2=.15$] trimesters of pregnancy were significantly associated with PPD, such that lower levels of CAR, or a blunted CAR response, were associated with higher PPD symptoms. This association was not significant for CAR during the third trimester or at 3 months postpartum and PPD (see Table 2).

Second, results showed that average daily cortisol during the second trimester of pregnancy was significantly associated with PPD [$F(3, 74)=3.24, p<.05, R^2=.11$], such that lower levels of average daily cortisol during the second trimester were associated with higher PPD symptoms. We also examined this relationship with AUC and found no significant relationships between AUC and PPD at any of the time points during pregnancy and postpartum. This association was not significant for average daily cortisol during the first and third trimesters of pregnancy or at 3 months postpartum and PPD (see Table 3).

Third, results showed that cortisol diurnal slope during the second and third trimesters of pregnancy [$F(3, 74)=3.92, p<.05, R^2=.14$; and $F(3, 74)=3.73, p<.05, R^2=.13$, respectively], as well as at 3 months postpartum [$F(3, 74)=2.99, p<.05, R^2=.11$], were significantly associated with PPD such that having a flatter diurnal cortisol slope was associated with

higher PPD symptoms. This association was not significant for cortisol diurnal slope during the first trimester of pregnancy and PPD (see Table 4).

Finally, results showed that the postpartum drop in average daily cortisol from the third trimester of pregnancy to 3 months postpartum was significantly associated with PPD [$F(3, 73) = 3.08, p < .05, R^2 = .11$], such that having a smaller or flatter drop in cortisol between the third trimester of pregnancy to the postpartum period was associated with higher PPD symptoms (see Table 5). Figure 1 shows that the postpartum drop is a function of women with low PPD symptoms having higher levels of cortisol during pregnancy and thereby showing a bigger drop in cortisol between the third trimester of pregnancy to the postpartum period, compared to women with high PPD symptoms.

Perceived stress and postpartum depression—Hierarchical regression analyses were also conducted to examine if perceived stress during each trimester of pregnancy predicted postpartum depression, controlling for income and randomization group. Results showed that higher levels of perceived stress during all three trimesters of pregnancy and at 3 months postpartum were significantly associated with higher levels of PPD, respectively ($F = 7.31, 6.81, 10.09, \text{ and } 22.42; p < .01$; see Table 6). Finally, results showed that a smaller decrease in perceived stress from the third trimester of pregnancy to 3 months postpartum (i.e., elevated stress levels during this time period) was associated with higher levels of PPD [$F(3, 74) = 3.56, p < .05, R^2 = .12$; see Table 6].

Discussion

The purpose of the current study was to examine whether altered stress patterns during pregnancy and the early postpartum period predicted the onset of PPD among a sample of low-income pregnant women. We predicted that altered cortisol patterns during the second trimester of pregnancy would most significantly predict higher levels of PPD symptoms compared to the first and third trimester of pregnancy and at 3 months postpartum. Our hypothesis was in part supported for CAR and average daily cortisol, with these indices during the second trimester of pregnancy being more associated with PPD. More specifically, flatter CAR patterns during the first and second trimesters of pregnancy (but not the third trimester or 3 months postpartum) and flatter diurnal patterns during the second and third trimesters of pregnancy, as well as lower average daily cortisol levels during the second trimester, were found to be important risk factors for PPD. These results provide support for previous human and animal studies that have found CRH (that stimulates ACTH which in turn causes the adrenal gland to release cortisol) during the second trimester of pregnancy to be associated with increased PPD symptomatology (Glynn et al. 2013; Hahn-Holbrook et al. 2013; Yim et al. 2009). Additionally, previous studies have shown flatter, more blunted CAR patterns and overall higher average daily cortisol levels to be predictors of MDD and depressive symptomatology in non-pregnant populations (Chida and Steptoe 2009; Fiorentino et al. 2012; Stetler et al. 2004; Taylor et al. 2009). As noted by Wilhelm et al. (2007), CAR is associated with the large-scale activation of the body's arousal systems, as part of the process of waking up in the morning, which involves activation of the brain stem, HPA axis, and the subsequent release of cortisol. It is speculated that this global activation of arousal systems may not only affect the area of biological rhythms and waking

the body up but is also responsible for activating parts of the brain that organize emotion, memory, personality, and identity. Therefore, according to theories proposed by Chida and Steptoe (2009), if the biological systems and mechanisms associated with CAR are flattened or blunted, it may predispose certain women to be more vulnerable to psychological conditions such as depression. Although previous studies have shown higher average daily cortisol levels to be associated with MDD in non-pregnant populations, women who have a lower cortisol output may have suffered from early life stress that may cause this blunting of cortisol response in adult life and may even extend to pregnancy. To support this theory, a study conducted by Willner et al. (2014) found that greater cumulative risk exposure to stress in a sample of youth was significantly associated with lower overall cortisol output, which was driven by having a low CAR. These findings support our current results of a low CAR and low average daily cortisol both being significantly related to a higher risk of PPD during the first (CAR and average daily cortisol) and second trimesters of pregnancy (CAR). Future studies should examine this phenomenon further in order to determine if these blunted cortisol patterns exist pre-pregnancy. In the case of pregnancy, lower than normal levels of CAR and average cortisol output during the first and second trimesters may be associated with having a higher risk of PPD because cortisol levels during this time period still resemble those found in non-pregnant women. As cortisol levels begin to spike during the third trimester, CAR and average daily cortisol may no longer be reliable markers of stress, particularly given that substantial increases in placental cortisol levels during the third trimester play an important role in fetal organ development, particularly brain and lung development (Crowley 2000; Glynn et al. 2013).

Results from the current study also demonstrated that women who had flatter diurnal cortisol patterns during the second and third trimesters and at 3 months postpartum showed higher levels of PPD. Typically studies have found diurnal cortisol patterns to maintain a peak throughout gestation, staying relatively high even into the third trimester, with flatter cortisol patterns being associated with higher levels of trait anxiety (Meinlschmidt et al., 2010; Kivlighan et al. 2008). Our results are one of the first to our knowledge to report an association between diurnal cortisol and PPD. One study, by O'Connor et al. (2014), found flatter diurnal cortisol patterns during later pregnancy to be associated with higher prenatal depression levels (between 20 and 32 weeks gestation; 50 % African American women), while another study found flatter diurnal cortisol patterns among women who experienced anxiety and high stress during late pregnancy (Kivlighan et al. 2008). Taylor et al. (2009) examined a similar phenomenon between cortisol and PPD during the early postpartum period (i.e., 4, 6, and 8 weeks postpartum) and found significantly flatter diurnal cortisol patterns in depressed mothers compared to non-depressed mothers. The connection between the timing of flatter diurnal cortisol patterns (second and third trimesters of pregnancy and postpartum) and the risk of PPD in the current study may be due to the substantial changes that occur in hormonal activity during the third trimester of pregnancy and after child birth, as well as the effect that these changes have on the body. More specifically, the increasing amount of physical and emotional stress that is placed on a woman's body during late pregnancy, as well as the continuation of stress during the postpartum period (e.g., having a new baby to take care of, dealing with stressors associated with being a new mother, having different levels of social support), may lend insight into why these diurnal patterns of

cortisol are so similar to ones found in patients experiencing chronic fatigue (Taylor et al. 2009). Consequently, elevated stress levels experienced during the second and third trimesters of pregnancy may cause the body to show signs of chronic fatigue that result in flattened diurnal cortisol patterns during this time period and continues into the postpartum period, when cortisol levels should drop to pre-pregnancy levels.

We also hypothesized that higher levels of stress (cortisol and perceived stress) from the third trimester of pregnancy to 3 months postpartum would be associated with higher levels of PPD. Consistent with our hypothesis, we found that women who experienced less of an abrupt drop in both cortisol and perceived stress from the third trimester of pregnancy to the postpartum period were at a higher risk for PPD. These results provide empirical support for theories proposed by previous studies about the possible effect of the postpartum drop in hormones and chronic stress on increased risk for PPD and suggest that women whose postpartum stress remains at similar levels as those observed during the third trimester of pregnancy (when cortisol levels are at their highest) are at a greater risk of experiencing symptoms of postpartum depression than women whose stress levels decrease after childbirth (Bloch et al., 2005; Pedersen et al. 1993; Taylor et al. 2009). Similar findings have been found in one previous study where women who showed less of a postpartum drop in cortisol demonstrated higher levels of fatigue, poor sleep, poor appetite, and PPD (Corwin and Pajer 2008). In particular, Corwin and Pajer theorized that stress levels may remain chronically high after childbirth for women who experience a prolonged or difficult labor or a negative emotional delivery and suggest that future studies examine women's experience with childbirth and changes in cortisol levels during this time period. One study by Glynn et al. (2013) proposes that the natural drop in cortisol from the third trimester to postpartum is a result of diminished activity of the HPA axis during the early postpartum and may be associated with an increased risk for PPD. This rationale led to the current study's investigation of whether or not sustained levels of cortisol from the third trimester to the postpartum and a lack of a decline in cortisol during this period may serve as a possible risk factor for PPD. Research has proposed that this diminished activity of the HPA axis during the postpartum period may serve an adaptive role for the mother such as conserving energy for lactation, enhancing immune function, and resulting in overall lower levels of stress in mothers (Slattery and Neumann 2008). Furthermore, these data also support hypotheses related to the dysregulation of the HPA axis that is consistent with the atypical subtype of postpartum depression. Atypical depression, a distinct clinical subtype of depressive disorders, is characterized by mood reactivity, reduced appetite, and/or substantial weight loss and has been associated in previous research with a hyporesponsive, or diminished, HPA axis regulation (Glynn et al. 2013, Kammerer et al. 2006). Atypical depression has also been associated with flatter levels of cortisol at awakening as well as flatter diurnal patterns (Lamers et al. 2012).

Finally, we predicted that higher levels of perceived stress during the earlier stages of pregnancy (first and second trimesters) would be more predictive of PPD, given that perceived stress levels have been shown to be highest during this time period (Glynn et al. 2001). Contrary to our hypothesis, our results showed that high perceived stress during all three trimesters of pregnancy and at 3 months postpartum was significantly associated with an increased risk in PPD among our sample of low-income pregnant women. The

discrepancy in these results may be due to our study sample being predominately Latina women that come from low-income backgrounds compared to that of previous studies (i.e., predominantly middle to upper middle class, non-Hispanic White women; Glynn et al. 2001). Therefore, our specific sample of women may experience unique stressors that may be difficult to cope with, may be more chronic in nature (e.g., lack of steady income, long work hours during pregnancy, lack of social and financial support during pregnancy), may be of a much larger scale, and may be internalized as a more significant stressor than those observed in previous studies (Glynn et al. 2001).

Study limitations

The findings presented should be interpreted with some degree of caution due to several study limitations. The majority of the study sample consisted of low-income Latina women (71 % Latino descent); therefore, the study findings may not be generalizable to pregnant women from other demographic backgrounds or other women of Latina descent outside of the southern California area. However, to date, this study is one of the few that have examined prenatal and postnatal stress and risk for postpartum depression in this important population, which is the largest and most rapidly growing ethnic group in the USA both among adults and children. In California alone, Latinos account for approximately 40 % of the overall population and is growing in increasingly larger numbers every year (Chapa and De La Rosa 2004). Second, our sample was recruited from a local prenatal health clinic and was a voluntary recruitment process. Therefore, study participants may have been more willing and able to participate in the study than non-participants due to several factors, such as not having a job, not having other children to care for, or having less stressors in their life in general. Finally, because adherence to the cortisol collection protocols of the study were largely based on self-report, it is difficult to ensure that adherence to these protocols was followed. In the current study, 88 to 93 % of women adhered to the instructions and protocols of cortisol collection.

Implications

In summary, our study findings indicate that women with altered cortisol patterns earlier on in pregnancy (i.e., lower CAR and average daily cortisol) are at greater risk for PPD and that these patterns are detectable and possibly preventable. Additionally, results showed that women with flatter diurnal cortisol patterns during the third trimester and at 3 months postpartum are at greater risk for PPD. Finally, our study findings demonstrated that woman whose cortisol and perceived stress levels stay at an abnormally high level after childbirth are at greater risk for PPD. Contextual factors such as dealing with the stress and responsibilities of having a newborn infant, experiencing fears of parenthood, and not having adequate social support may explain why some women experience altered stress patterns during pregnancy and the postpartum period which, in turn, lead to postpartum depression. By recognizing these altered stress patterns as risk factors in the etiology of postpartum depression and being able to pinpoint a time during pregnancy in which altered stress patterns are most predictive of PPD, gynecologists, pediatricians, and general health practitioners may be able to better identify women who are at a high risk of developing PPD after pregnancy. Furthermore, in screening women for altered cortisol and perceived stress patterns during pregnancy, doctors may be better able to suggest preventative measures such

as behavioral stress management and relaxation programs, which have been shown to reduce stress and help regulate cortisol patterns during pregnancy and the postpartum period (Urizar et al. 2014; Urizar & Muñoz 2011). Collectively, these results support the need for prenatal prevention interventions that educate and train expecting mothers in stress management and relaxation that target stress risk factors in order to minimize the adverse effects of PPD for low-income mothers and their infants.

Acknowledgments

Kathryn Scheyer and Guido G. Urizar Jr. are in the Department of Psychology, California State University, Long Beach. This study was conducted as part of a collaboration between the Partners in Research and Outreach for Health (PRO-Health) Research Lab (Guido G. Urizar Jr., Director), St. Mary Medical Center (Miguel Gutierrez, Director), and the African American Infant Health Program at the Long Beach Department of Health and Human Services (Pamela Shaw, Director). Research reported in this publication was supported by the Eunice Kennedy Shriver National Institute of Child Health & Human Development of the National Institutes of Health under Award Number SC2HD068878 (Guido G. Urizar Jr., PI). The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health. The authors gratefully acknowledge the contributions of Yasmin Kofman, Janessa Cuomo, Crystal Tandler, and the other members of the PRO-Health Research Lab for their instrumental support in data collection. The authors would also like to thank Chi-Ah Chun, Ph.D. and Ilona Yim, Ph.D. for reviewing a previous version of this manuscript, as well as Nicolas Rohleder, Ph.D. for conducting the cortisol assays. This publication is based on the first author's undergraduate honors thesis at California State University, Long Beach.

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Fig. 1. Average pre- and postpartum cortisol (log scores) of women with low and high levels of postpartum depressive symptoms

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Descriptive statistics for cortisol indices and perceived stress during pregnancy (first, second, and third trimesters) and at 3 months postpartum

Table 1

Variables	First trimester		Second trimester		Third trimester		Three months PPM	
	M	SD	M	SD	M	SD	M	SD
Residual CAR (nmol/L)	.17	10.89	.01	12.78	-.27	9.20	.14	11.27
Average daily cortisol (nmol/L)	17.44	8.69	19.88	8.35	20.34	8.24	14.08	7.73
Area under the curve (AUC) (nmol/L)	148.93	63.06	192.07	93.62	202.19	103.15	133.55	87.35
Diurnal cortisol (nmol/L)	-17.76	16.57	-18.23	17.29	-16.20	15.60	-12.65	14.34
Perceived stress	24.37	7.19	23.14	6.75	23.10	6.63	22.37	7.51

Note: Regression analyses for average daily cortisol used log scores; however, the numbers presented in the table are in nanomoles per liter *PPM* = postpartum

Hierarchical regression analysis for prenatal and postnatal cortisol awakening response and postpartum depression

Table 2

Variables	First trimester			Second trimester			Third trimester			Three months PPM		
	R ²	Standard error	Standard β	R ²	Standard error	Standard β	R ²	Standard error	Standard β	R ²	Standard error	Standard β
Income Randomization group	.11*			.15*			.07			.05		
	.01	.34	-.07	.01	.32	-1.18	.01	.34	-.13	.01	.34	-.14
	.05	1.14	-.23*	.05	1.15	-2.43*	.04	1.18	-.22	.04	1.20	-.20
Residual CAR	.05	.05	-.23*	.09	.04	-2.92**	.01	.06	-1.19	.00	.05	-.04

Note: Randomization group was coded as 0 = attention control group and 1 = stress management group

* $p < .05$,

** $p < .01$

Table 3
Hierarchical regression analysis for prenatal and postnatal average daily cortisol output and postpartum depression

Variables	First trimester			Second trimester			Third trimester			Three months PPM		
	R ²	Standard error	Standard β	R ²	Standard error	Standard β	R ²	Standard error	Standard β	R ²	Standard error	Standard β
	.06			.11*			.09			.07		
Income Randomization group	.01	.34	-1.15	.01	-.36	-.12	.01	.34	-.88	.01	.34	-.16
	.05	1.16	-.22	.04	-2.38	-.22*	.04	1.17	-1.96	.04	1.18	-.21
Average cortisol output	.01	3.62	-.08	.05	-6.04	-.23*	.03	2.55	-1.78	.02	2.18	.14

Note: Randomization group was coded as 0 = attention control group and 1 = stress management group

* $p < .05$,

** $p < .01$

Table 4
Hierarchical regression analysis for prenatal and postnatal diurnal cortisol slope and postpartum depression

Variables	First trimester			Second trimester			Third trimester			Three months PPM		
	R ²	Standard error	Standard β	R ²	Standard error	Standard β	R ²	Standard error	Standard β	R ²	Standard error	Standard β
Income Randomization group	.09			.14			.13			.11		
	.01	.34	-.08	.01	.33	-1.10	.01	.34	-.09	.02	.34	-.12
	.05	1.15	-.22	.05	1.17	-.27*	.05	1.16	-.24*	.04	1.17	-.19
Diurnal cortisol slope	.03	.04	.17	.08	.03	.28*	.07	.04	.27*	.05	.04	.23*

Note: Randomization group was coded as 0 = attention control group and 1 = stress management group

* $p < .05$,

** $p < .01$

Hierarchical regression analysis for postpartum drop in cortisol and perceived stress and postpartum depression

Table 5

Variables	Cortisol		Perceived stress			
	R ²	Standard error	Standard β	R ²	Standard error	Standard β
	.11*			.12*		
Income	.01	.33	-.13	.01	.33	-.09
Randomization group	.04	1.17	-.21	.05	1.17	-.19
Postpartum drop in cortisol	.05	1.56	-.23*	.06	.09	-.25*

Note: Randomization group was coded as 0 = attention control group and 1 = stress management group

* $p<.05$,
** $p<.01$

Hierarchical regression analysis for prenatal and postnatal perceived stress and postpartum depression

Table 6

Variables	First trimester			Second trimester			Third trimester			Three months PPM		
	R ²	Standard error	Standard β	R ²	Standard error	Standard β	R ²	Standard error	Standard β	R ²	Standard error	Standard β
Income	.22*	.30	-.09	.21*	.31	-.13	.28*	.29	-.09	.46*	.25	-.01
Randomization group	.05	1.06	-.21*	.05	1.07	-.20*	.04	1.04	-.16	.05	.90	-.07
Perceived stress	.16	.07	.40**	.15	.08	.38**	.22	.07	.48**	.40	.06	.66**

Note: Randomization group was coded as 0 = attention control group and 1 = stress management group

* $p < .05$,

** $p < .01$