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Measuring environmental stress in East Greenland polar bears, 1892–1927 and 1988–2009: what does hair cortisol tell us?

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Abstract

Hair sampled from 96 East Greenland polar bears (*Ursus maritimus*) over the periods 1892–1927 and 1988–2009 was analyzed for cortisol as a proxy to investigate temporal patterns of environmental stress. Cortisol concentration was independent of sex and age, and was found at significantly higher ($p < 0.001$) concentrations in historical hair samples (1892–1927; $n = 8$) relative to recent ones (1988–2009; $n = 88$). In addition, there was a linear time trend in cortisol concentration of the recent samples ($p < 0.01$), with an annual decrease of 2.7 %. The recent hair samples were also analyzed for major bioaccumulative, persistent organic pollutants (POPs). There were no obvious POP related time trends or correlations between hair cortisol and hair POP concentrations. Thus, polar bear hair appears to be a relatively poor indicator of the animal's general POP load in adipose tissue. However, further investigations are warranted to explore the reasons for the temporal decrease found in the bears' hair cortisol levels.

Keywords

Polar bear; hair; cortisol; EDCs; POPs; stress; temporal trend; HPA

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Introduction

Cortisol is the major glucocorticoid (GC) hormone in mammals, and as such responsible for a wide range of functions, e.g. regulation of metabolism, growth, and development, as well as responses to stress influencing the physiology and endocrinology of the reproductive and immune systems (Moberg 1991; Dobson & Smith 2000; Sjaastad et al. 2003; von Borell et al. 2007; Schmidt & Soma 2008). Cortisol (and corticosterone, another GC) have been used for assessing physical and psychological stress in a wide range of animals, in matrices such as blood, bird eggs, faeces, saliva, whale blow, urine, feathers, liver and gonad tissue, and more recently hair (Koren et al. 2002; Constable et al. 2006; Van der Staay et al. 2007; Bortolotti et al. 2008; Flores-Valverde & Hill 2008; Saco et al. 2008; Hogg et al. 2009; Lupica & Turner 2009; Okuliarová et al. 2010). Faeces, egg, and especially feather and hair samples, have the advantage that they express chronic stress rather than short-term hormonal fluctuations caused by for example circadian rhythms or the stress of hunting (Koren et al. 2002; Davenport et al. 2006; Bortolotti et al. 2008; Saco et al. 2008; Okuliarová et al. 2010). Cortisol is incorporated in the hair as it grows, meaning that hair cortisol values reflect the general hormone level in the mammalian body over this specific period of time (Bennett & Hayssen 2010; Ashley et al. 2011; Heintz et al. 2011).

Polar bears (*Ursus maritimus*), especially those of East Greenland and Svalbard, have been found to carry some of the highest persistent organic pollutant (POP) loads of any Arctic mammal species (Verreault et al. 2005; Muir et al. 2006; Letcher et al. 2010; McKinney et al. 2011). This group of contaminants include polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs) and poly- and perfluoralkyl substances (PFASs) that are all known to have endocrine disruptive and immune suppressive adverse effects in mammalian organisms including polar bears and other Arctic top predators (Letcher et al. 2010; Sonne 2010). The chronic exposure to these pollutants have in polar bears and other Arctic predators been associated with endocrine disruption (Wiig et al. 1998; Oskam et al. 2003; Braathen et al. 2004; Sonne 2010), reduced bone mineral density (Sonne 2010), and organ histopathology (Kirkegaard et al. 2005; Sonne et al. 2010). Lowered immune functions (Bernhoft et al. 2000; Lie et al. 2004; Sonne 2010), but also reduced survival, reproduction, and development (Skaare et al. 2000; Derocher et al. 2003; Sonne 2010) have been suggested. The suspected endocrine disrupting properties of many of the POPs are of growing concern (Tanabe 2002; Haave et al. 2003; Jenssen 2006; Routti et al. 2008; Scholz & Mayer 2008; Prasanth et al. 2010; Sonne 2010; Villanger et al. 2011a,b) and their ability to change basic endocrine pathways has been found to affect cortisol and other hormone levels (Oskam et al. 2004; Ropstad et al. 2006; Tintos et al. 2008; Zimmer et al. 2009; Kraugerud et al. 2011; Rosati et al. 2011; Zimmer et al. 2011).

The polar bear is a protected species, although strictly regulated hunting is legal in some places, often limited by quotas to native hunters (IUCN PBSG 2005). Thus non-invasive methods for assessing contaminant load and stress in general are valuable tools when examining the health of the entire circumpolar polar bear population. Jaspers et al. (2010) recently showed that POPs could be measured in polar bear hair samples. Shortly after, Bechshøft et al. (2011) measured the stress hormone cortisol in the same matrix. The present study attempts to link these two findings, by applying both methods to hair from the same individual bears. The results were combined with POP analyses of subcutaneous adipose tissue samples also obtained through the unique ongoing Danish program of polar bear sampling in cooperation with the local indigenous hunters of Scoresby Sound/Ittoqqortoormiit in central East Greenland. The main aim of the present study was to assess the usefulness of polar bear hair cortisol as a measure of temporal environmental stress and as a biomonitoring tool for POP exposure. In doing so, the temporal trends in hair cortisol

and POPs, as well as their relationship with each other and with the POP values measured in the adipose tissue samples, were investigated.

Materials & methods

Samples

Hair from 96 East Greenland polar bears (42 female, 47 male, and 7 of unknown sex) was included in the present study. Age estimation was conducted by counting the cementum growth layer groups (GLGs) of the lower right incisor (I3) after decalcification, thin sectioning (14 μ m) and staining (Toluidine Blue), using the method described by Dietz et al. (1991). Male bears were categorized as adults at age ≥ 6 years ($n = 31$), and female bears at age ≥ 5 years ($n = 29$), with the remaining bears categorized as subadults ($n = 21$) (Rosing-Asvid et al. 2002). Female mean age was 10.5 years (range 3–26) and male mean age was 8.0 years (range 3–19). All samples were collected in East Greenland (app. 61°–82°N, 10°–42°W). Historical hair samples ($n = 8$; year of kill: 1892–1927) were collected from polar bear furs held at the Zoological Museum (the Natural History Museum of Denmark, ZMUC, Copenhagen, Denmark). The recent hair samples ($n = 88$; year of kill: 1988–2009) were collected routinely for NERI (National Environmental Research Institute, Aarhus University, Denmark) by the subsistence hunters living in Scoresby Sound during their annual catch of polar bears in East Greenland. Samples were collected over the course of the whole year, though with more than 2/3 sampled during the first half of the year (January – June). During sampling, hair may become contaminated with polar bear subcutaneous adipose tissue (fat) and/or blood. However, this partial cross-contamination has been shown to be of little concern with regards to cortisol measurement (Bechshøft et al. 2011). All hair samples were taken from the chest area of the polar bears. The cortisol levels of the recent hair samples have also been included in the studies presented in Bechshøft et al. (2011, Submitted).

Cortisol analysis of hair

Hair samples were analyzed for cortisol according to the procedure described by Bechshøft et al. (2011). Briefly, the samples were washed with isopropanol, dried down, and then powdered using a ball mill. Approximately 50 mg of powdered hair from each sample was extracted overnight with methanol. Extracts were evaporated, reconstituted in assay buffer, and then analyzed for cortisol using the Salimetrics (State College, PA) high sensitivity salivary cortisol enzyme immunoassay kit (cat. # 1-3002). According to the manufacturer, the antiserum has the following percentage cross-reactivity with other endogenous steroids: cortisone - 0.130, 11-deoxycortisol - 0.156, 21-deoxycortisol - 0.041, corticosterone - 0.214, aldosterone - ND (not detected), 17 β -estradiol - ND, testosterone - 0.006, dehydroepiandrosterone - ND, progesterone - 0.015, and 17 α -hydroxy-progesterone - ND. Intra- and inter-assay coefficients of variation of the assay in the present study averaged less than 10 %. All cortisol analyses were done at the Dept. of Psychology, University of Amherst, Massachusetts.

POP analysis of hair

Chemical analysis of polar bear hair was performed at the Toxicological Centre (University of Antwerp) for a wide range of legacy POPs following the analytical protocol described by Jaspers et al. (2010). The chemical analysis targeted the detection of 37 polychlorinated biphenyl congeners (PCBs: CB 138, 146, 149, 153, 156, 158, 170, 171, 172, 174, 177, 180, 183, 187, 194, 195, 196, 199, 203, 205, 206 and 209), 8 polybrominated diphenyl ethers congeners (PBDEs: BDE 28, 47, 49, 99, 100, 153, 154 and 183), hexachlorobenzene (HCB) dichlorodiphenyltrichloroethane (*p,p'*-DDT, *o,p'*-DDT) and metabolites (*p,p'*-DDE, *o,p'*-DDE, *p,p'*-DDD, and *o,p'*-DDD), hexachlorocyclohexanes (HCHs; α -, β - and γ -HCH), and

chlordane like-compounds (CHLs), such as cis-chlordane (CC), trans-chlordane (TC), cis-nonachlor (CN), trans-nonachlor (TN), and oxychlordane (OxC). In this study, we report only on compounds detected above LOQ in 50 % of the individuals. Missing data were substituted per compound according to $C_{\text{sub}} = \text{LOQ} \times f$, where f equals the proportion of samples with detection above LOQ. As such, we report on concentrations of Σ PCBs (CB 138, 153, 156, 170, 180, 183 and 187), p,p' -DDE, Σ CHLs (OxC and TN), and BDE 47. Individual CB congeners were highly correlated with Σ PCBs ($r = 0.80$; $p < 0.01$), as were OxC and TN with Σ CHLs ($r = 0.97$; $p < 0.01$).

Briefly, the hair samples were thoroughly washed with distilled water and dried at ambient temperature. After being cut in small pieces, internal standards (CB 143 + ϵ -HCH + BDE 77) were added and 0.068 to 0.319 g of hair was incubated overnight at 40 °C with 5 mL of HCl (4 M) and 5 mL of hexane:dichloromethane (4:1, v:v). After liquid-liquid extraction, the organic phase was cleaned-up on acid silica (Covaci & Schepens 2001) using hexane:dichloromethane (4:1, v:v). Quantification was performed on a mass spectrometer (Agilent MS 5973, Palo Alto, CA, USA) coupled to a gas chromatograph (Agilent GC 6890, Palo Alto, CA, USA). A procedural blank and a certified reference material (CRM 397: human hair – IRMM, Belgium) were analysed every 10th sample to support quality control. Concentrations of analytes were corrected by subtracting the average blank value. LOQs were fixed at 3*S.D. of the procedural blanks and ranged for all analytes between 0.10 and 0.40 ng g⁻¹ dry wt. For analytes not detected in blanks, LOQs were calculated from a signal to noise ratio of 10. Basic information on the measured POP concentrations can be found in Table 1, and further details are reported in Jaspers et al. (2010) and Eulaers et al. (In prep).

POP analyses of adipose tissue

Subcutaneous adipose tissue from the recent polar bears analyzed for hair cortisol and hair POPs in this study had previously been analyzed for PCBs, PBDEs, as well as DDT and CHL compounds according to and as reported in Dietz et al. (2004, 2007, Submitted). In the present study, only the concentrations of the compounds that were also measured in the hair samples were used (see above). All values were normalized to lipid weight. All adipose tissue contaminant analyses were done by Letcher Research Lab in Ottawa.

Statistical analyses

Cortisol and POP concentrations were log-transformed prior to all analyses, except when examining the time trend and the collinearity between the four POP groups in hair. This was done in order to meet the assumption of normality and homogeneity of the variance in the analyses. A one-way ANOVA was used to test for differences in mean cortisol concentrations between the hair of the three types of external contamination (blood, fat, and clean). A one-way ANOVA was applied to test the relationship between cortisol and sex and age, respectively. A Pearson's correlation test was also executed, in order to assess the variation of hair cortisol for the bears' full age range. Jaspers et al. (2010) recommended using only clean hair samples for POP analysis. However, the results in the present paper were similar whether only clean, fat-contaminated or all samples were used. Hence we decided to use all samples in order to obtain more robust statistics. Confidence levels were set to $p = 0.05$ and all statistical analyses were conducted using R (version 2.12.1; R Development Core Team 2008).

Historical samples ($n = 8$) were used in the time trend analysis only. We compared hair samples from two main time periods; historical samples ($n = 8$, collected 1892–1927) and recent samples ($n = 88$, collected 1988–2009). The cortisol concentration of the two periods was compared using a one-way ANOVA. The temporal trend was then analyzed in the recent samples, using continuous time stochastic modeling (ctsm) as described in Vorkamp

et al. (2011), though using annual mean cortisol value and years with two or more values only ($n = 11$). Briefly, the method represents a robust regression-based analysis to detect temporal trends (Nicholson et al. 1998) using the median (or mean) as yearly index value. The total variation over time was divided into a linear and a nonlinear component. Log-linear regression analysis was applied to describe the linear component and a locally weighted regression smoother (loess) with a window width of 7 years was applied to describe the nonlinear component (Fryer & Nicholson 1999, 2002). The linear and nonlinear components were then tested by one-way ANOVA. All four POP groups analyzed in hair were likewise examined for time trends using ctsm. In addition, the highly persistent PCB congeners CB 153 and 180 were also analyzed separately.

One-way Pearson's correlation tests between hair cortisol and hair POP levels were conducted on those hair samples that had values for all four of the analyzed POP groups ($n = 55$). A stepwise multiple regression analysis (using backward elimination) was conducted on the same individuals in order to determine which of the hair POP groups (Σ PCB, p,p' -DDE, Σ CHL, BDE 47) were of greater importance for the hair cortisol value. Correlation between the hair cortisol values and the POP group compound values measured in adipose tissue was investigated using Pearson's correlation tests ($71 \leq n \leq 72$). In addition, the same test was run separately for bears that had been harvested in the fall ($n = 8$), the season that the hair is grown (Pedersen 1945). Collinearity between the individual hair POP groups was tested using one-way Pearson's correlation tests on those hair samples that had values for all of the four analyzed groups ($n = 55$). The correlation between hair and adipose tissue POP compounds (PCB 138, 153, 170, 180; p,p' -DDE; OxC; TN; BDE 47) was analyzed using one-way Pearson's correlation tests ($50 \leq n \leq 52$).

Results

Temporal trends in hair cortisol and hair POP concentrations

The preliminary ANOVAs showed that there was no significant difference in hair cortisol concentration between the three contamination groups (blood, fat, clean; $p = 0.13$) nor between the age groups (adult, subadult; $p = 0.24$), the sexes (male, female; $p = 0.23$) or the sex/age interaction ($p = 0.36$). Please also see Fig. 1 for an illustration of hair cortisol vs. exact age ($p = 0.86$, $r = -0.02$). Hence, no age or sex classification of the data was necessary. Hair cortisol concentrations were significantly higher in the historical period (1892–1927; mean $\pm$ S.D.: 23.8 ± 4.7 pg mg⁻¹, range: 14.19–29.44, $n = 8$) compared to the recent period (1988–2009; mean $\pm$ S.D.: 12.8 ± 4.2 pg mg⁻¹, range: 3.98–24.42, $n = 88$) (Fig. 2; $p < 0.001$; $F = 24.77$). There was a log-linear time trend in the median cortisol concentration of the recent hair samples showing an annual decrease of 2.7 % over the period 1988–2009 ($p < 0.01$; $F = 15.48$) (Fig. 3). There was no significant temporal trend for any of the POP groups analyzed in the recent hair samples ($0.32 < p < 0.88$; $0.02 < F < 1.09$), which was also true for the two major PCB congeners 153 ($p = 0.96$; $F < 0.01$) and 180 ($p = 0.79$; $F = 0.08$).

Hair cortisol vs. hair POP concentrations

There were no significant correlations between hair cortisol and hair POP concentrations ($0.41 < p < 0.93$; $-0.08 < r < 0.11$). However, multiple regression analysis indicated that hair Σ PCB was of least importance to the cortisol concentration, as it was the only parameter to be taken out of the most explanatory model: $\log(\text{cortisol}) = \log(\Sigma\text{CHL}) + \log(\text{BDE47}) + \log(p,p'\text{-DDE})$. The associated p -values were $\log(\Sigma\text{CHL})$: $p < 0.01$; $\log(\text{BDE47})$: $p = 0.01$, and $\log(p,p'\text{-DDE})$: $p = 0.09$ (for the model as a whole: $p = 0.01$; $F = 4.00$; multiple $r^2 = 0.19$). The four hair POP groups were highly significantly correlated (all; $p < 0.01$; $0.77 < r < 0.89$).

Hair cortisol vs. adipose tissue POP concentrations

When comparing hair cortisol values and the POP compound values measured in adipose tissue, only OxC presented a significant correlation ($p = 0.02$, $r = 0.28$; for all other compounds $0.11 < p < 0.98$; $-0.06 < p < 0.19$). When examining only the bears that had been sampled in the fall months when the hair is grown (Pedersen 1945), there were still no significant correlations between hair cortisol and adipose POP group concentrations ($0.27 < p < 1.00$; $-0.44 < r < 0.22$). Likewise, there were no significant correlations between hair and adipose tissue POP group compounds ($0.44 < p < 0.96$; $-0.09 < r < 0.11$).

Discussion

In a previous study (Bechshøft et al. 2011) we reported polar bear hair cortisol values as depending on sex. In the present study, however, with a five-fold sample size, hair cortisol seems to be neither sex nor age dependent. This is in accordance with the hair studies by Bennet & Hayssen (2010; domestic dog) and Macbeth et al. (2010; grizzly bear), whereas studies on cortisol in other matrices in different species seemed more inconclusive in this regard (Handa et al. 1994; Dobson and Smith 2000; Tryland et al. 2002; Oskam et al. 2004; Chow et al. 2010, 2011).

Temporal trends in hair cortisol concentrations

The finding that the historical samples were significantly higher in cortisol levels than the recent samples seems to confirm the previously reported stability of stress hormones in keratinous matrices such as hair and feathers (Bortolotti et al. 2009; Webb et al. 2010). Additionally, the historical samples provided a baseline hair cortisol concentration. There was a significant decrease in hair cortisol concentration over time as a whole (1892–2009), but also when looking only at the recent samples (1988–2009). Among possible reasons for this recent temporal decrease are perhaps the endocrine disrupting qualities of the polar bear contaminant load in combination with other stressors (Sonne 2010; Kovacs 2011), even if the present study found only few indications of this in relation to the hair cortisol (please also see further discussion of this below). Notably, the decrease found here is in accordance with the findings of Bortolotti et al. (2009), who examined corticosterone trends in recent vs. 50 year old museum feather samples of great horned owl (*Bubo virginianus*). The authors ascribed this to either the birds of today being “different than they were 50 years ago” or to sampling bias caused by the recent samples to be from more marginal members of the population (Bortolotti et al. 2009). Webb et al. (2010) found a similar trend in that hair cortisol levels of Medieval Peruvian mummies were higher on average than levels measured for today’s individuals, although here the authors speculated that this could be in part because the archaeological hair samples analyzed came from individuals of whom some at least were chronically ill and approaching death. Whichever of these hypotheses holds true, it would indeed be of much interest to investigate whether the trend also holds for a wider range of species. If cortisol levels are indeed artificially depressed by environmental pollutants, this would severely impair the bears’ physiological ability to respond to and cope with the multitude of stressors they are subjected to, including climate changes, in addition to factors affecting their regulation of metabolism, growth, and development, as well as reproductive and immune systems. Another possible explanation is that the seeming downregulation of adrenocortical activity over time could be explained by the concept of allostasis (McEwen & Wingfield 2003), where the allostatic load brought on by various environmental stressors results in changed physiological setpoints for e.g. cortisol. This hypothesis is supported by the results presented in Bechshøft (2011). A third reason for the decrease in cortisol levels over time could be related to polar bear population density; fewer bears would mean less competition for the available prey and vice versa. Unfortunately, the status of the East Greenland polar bear population is unknown, as no population inventory

has been conducted to date (IUCN PBSG 2010). However, the closely related Svalbard (Barents Sea) polar bear population which was subject to extensive harvest from 1870 until all hunting in the area was banned in 1973 (Lønø 1970; Larsen 1986) may now be showing signs of recovery (Derocher 2005; Aars et al. 2009). In order to answer the question of potential correlation between population density and hair cortisol, it would be of great interest to examine the temporal development in cortisol in Svalbard polar bear hair samples, or, if possible, to obtain hair samples from East Greenland animals harvested during the period 1927 to 1988, thus covering the temporal “blind spot” in the present study. Overall, this time gap and the small number of historic samples are acknowledged as a potential drawback to the present paper, and further investigations are consequently encouraged.

No baseline blood cortisol data exists for polar bears. The levels reported in the polar bear literature so far are all supposedly affected by the acute stress inflicted on the bears during capture or hunting, which can lead to artificially high baseline cortisol levels in blood plasma samples obtained in this way (Tryland et al. 2002; Haave et al. 2003; Oskam et al. 2004). For example, polar bear plasma cortisol levels measured in samples from tagged bears (Oskam et al. 2004) were 16 times higher than the basal cortisol levels we have found in hair from the same species. Hence, no other relevant “normal” polar bear cortisol data exists with which to compare our results and discuss the results with regards to normal cortisol fluctuations within and between individuals. However, it is clear that the historical samples are significantly higher than the more recent ones, in mean as well as range. How important the decrease historically as well as over the recent years is from a physiological perspective is hard to say without further studies. However, a study on domestic dogs have found hair cortisol values close to the ones found in polar bears; a mean of 10.88–12.63 pg mg⁻¹ hair (Bennett & Hayssen 2010). The variation in the dog study was similar to the one found in the recent polar bear samples, but extrapolation between species should be done with extreme caution (Verreault et al. 2008; Letcher et al. 2010).

Temporal trends in hair POP concentrations

Temporal trends were not observed for any of the POPs analyzed in the hair samples and no correlation between hair cortisol and hair POP group compound levels. Reports on the temporal trends of POPs in the Arctic show a decline in several of these toxic substances over the last decades, but constant or increasing trends in others (Derocher et al. 2003; Dietz et al. 2004; Braune et al. 2005; Verreault et al. 2005; McKinney et al. 2010, 2011). At the same time, other pollutants such as short-chained chlorinated paraffins (SCCPs) (AMAP 2004; Braune et al. 2005), polychlorinated naphthalenes (PCNs) (Corsolini et al. 2002; AMAP 2004; Braune et al. 2005), perfluorinated carboxylic acids (PFCAs) (Dietz 2008) and perfluorooctanesulfonate (PFOS) (Bossi et al. 2005; Smithwick et al. 2006) were recently discovered in the Arctic. In other words, the occurrence of POP time trends in the Arctic, and in the polar bear is an established scientific reality. The absence of POP related time trends or correlations in the present study could be due to the unique nature of polar bear hair strands, which are pigment-free with a hollow core (Born 2008). A number of studies on drug incorporation in pigmented and non-pigmented hair have shown that darker hair binds larger quantities than lighter or non-pigmented hair even when blood plasma levels were the same in the original subjects (Uematsu et al. 1992; Gygi et al. 1997; Wilkins et al. 1998; Stout & Ruth 1999; Kempson & Lombi 2011), proving that melanin has a high binding affinity for xenobiotics (Harrison et al. 1974; Shimada et al. 1976; Cone 1996; Stout & Ruth 1999). The fact that we also found no correlations between POPs in hair and adipose tissue POP compounds serves to support this hypothesis. Similar results were presented in the polar bear hair contaminant pilot study by Jaspers et al. (2010) and in the hedgehog (*Erinaceus europaeus*) hair study by D’Have et al. (2005). An alternative explanation could

be related to the time of year that polar bears grow their fur; by the time fall comes around and it is time for the new fur to be formed, the animals are likely to be experiencing a certain amount of energetic stress, leading to massive amounts of POPs being released into the blood stream as the bear's energy reserves of adipose tissue stores are metabolized (Polischuk et al 2002 and references there-in). As the POPs are once more available to the body, they become incorporated in the different tissues, including hair. However, one could imagine that there would only be room for a certain amount of the pollutant compounds in each hair, so that it at a given time simply reaches a point of saturation. Bennett & Hayssen (2010) also discussed hair as having a maximum storage limit, although in relation to pigment and cortisol.

Hair cortisol vs. hair and adipose tissue POP concentrations

When comparing hair cortisol values and the POP values measured in adipose tissue from the same individuals, only OxC (a chlordan metabolite) came out with a significant and positive, albeit weak, correlation. OxC has previously been linked with a range of chemically induced stress responses in a selection of species (Bondy et al. 2004; Kunisue et al. 2007; Murvoll et al. 2007). Kunisue et al. (2007) and Bondy et al. (2004) pointed out the high persistency of oxychlordan. Polar bears accumulate high levels of chlordanes and hence oxychlordan (McKinney et al. 2011) and Sonne et al. (2009) stated that despite risk quotients being low for oxychlordan, the compound should still be considered a problem for polar bear reproduction, as it has been associated with reduced size of sexual organs in East Greenland male and female polar bears (Sonne et al. 2006c). Still, one has to wonder why only oxychlordan and not also for example the major PCB compound concentration measured in the adipose tissue would be associated with cortisol values found in polar bear hair. The lack of correlation could also simply be a matter of choice of statistical methods and number of variables included, as described and discussed in the upcoming follow-up article by Bechshøft et al. (Submitted). In any case, as pointed out by Kempson & Lombi (2011), we still know only little of the processes that determine how and which compounds become part of the hair strand.

Conclusions

The main aim of the present study was to assess the usefulness of polar bear hair cortisol as a measure of temporal environmental stress and as a biomonitoring tool for POP exposure. Based on the current results, polar bear hair appears to be a relatively poor indicator of the animal's general POP load in adipose tissue. However, further investigations are warranted to explore the reasons for the temporal decrease found in the bears' hair cortisol levels. A wider study of hair cortisol, preferably involving several of the circumpolar polar bear subpopulations is recommended.

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Highlights

We analyzed cortisol in hair from 96 Greenland polar bears (1892–1927 and 1988–2009).

Cortisol concentration was independent of sex and age.

Significantly higher cortisol concentration was found in historical samples.

A linear time trend was found in the recent samples (cortisol decrease of 2.7% p.a.).

No time trends or correlations in cortisol vs. hair or adipose tissue pollutants.

Fig. 1. Scatter plot of cortisol concentration in East Greenland polar bear hair samples (pg mg^{-1} hair) vs. age of the individual bears. ($p = 0.86$, $r = -0.02$, $n = 96$).

Fig. 2.

Box-and-whisker plot of hair cortisol concentration (pg mg^{-1} hair) in East Greenland polar bears. Cortisol concentrations were significantly higher in the historical period (1892–1927; mean $\pm$ S.D.: $23.8 \pm 4.7 \text{ pg mg}^{-1}$, range: 14.2–29.4, $n = 8$) compared to the recent period (1988–2009; mean $\pm$ S.D.: $12.8 \pm 4.2 \text{ pg mg}^{-1}$, range: 4.0–24.4, $n = 88$) ($p < 0.001$; $F = 24.77$).

Fig. 3.

Scatter plot of cortisol concentration in East Greenland polar bear hair samples (pg mg^{-1} hair) over time, showing a negative log-linear temporal trend over the period 1988–2009 ($p < 0.01$, $F = 15.48$, $n = 84$). Only years with two or more values are plotted ($n = 11$). Year: Year of kill. The filled dots are median values.

Table 1

Sample size, mean concentrations $\pm$ S.D., and range of pollutant compounds measured in hair of East Greenland polar bears (ng g⁻¹ hair, dry weight). Further details can be found in Jaspers et al (2010) and Eulaers et al. (In prep.).

	PCB							DDE	CHL		PBDE
	138	153	156	170	180	183	187		Oxy-chlordane	Trans-nonachlor	
n	68	69	65	69	69	65	66	67	69	69	47
Mean $\pm$ S.D.	7.9 $\pm$ 19.0	29.4 $\pm$ 78.6	1.0 $\pm$ 1.9	13.9 $\pm$ 29.1	25.8 $\pm$ 59.2	0.8 $\pm$ 1.8	0.6 $\pm$ 1.3	2.2 $\pm$ 5.0	5.8 $\pm$ 20.8	2.2 $\pm$ 5.6	0.5 $\pm$ 0.8
Min.-Max.	0.2 – 143.6	0.4 – 616.2	0.2 – 13.9	0.2 – 206.6	0.2 – 435.7	0.1 – 13.7	0.1 – 9.5	0.1 – 36.0	0.2 – 171.3	0.2 – 44.3	0.1 – 5.8