Acupuncture blocks cold stress-induced increases in the hypothalamus–pituitary–adrenal axis in the rat

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Abstract

Electroacupuncture (EA) is used to treat chronic stress; however, its mechanism(s) of action in allaying stress remains unclear. The interplay of stress hormones of the hypothalamus–pituitary–adrenal axis (HPA) and the sympathetic nervous system (SNS) is critical in the stress response. Our objective was to determine whether EA at acupoint, stomach 36 (EA St 36) is effective in preventing chronic cold stress-induced increased hormone levels in the rat by examining four groups of animals, three of which were exposed to cold and one of which was a non-treatment control group. Before exposure to the cold, two groups were treated with either EA St36, or Sham-EA, before 10 days of cold stress. The EA St 36 animals demonstrated a significant decrease in peripheral HP hormones (ACTH and CORT) compared with stress animals (P < 0.05). These effects were specific; rats receiving Sham-EA had elevation of these hormones, similar to the stress-only animals. These effects were mirrored centrally in the brain; CRH levels were significantly (P < 0.05) reduced in EA St36 animals compared with the other animals. Finally, EA effect on peripheral and adrenal SNS hormones (norepinephrine (NE) and neuropeptide Y (NPY) respectively) was examined, with no significant difference noted in adrenal tyrosine hydroxylase or circulating NE in any of the groups. However, EA St36 was effective in preventing stress-induced elevation is adrenal Npy mRNA. These results indicate that EA St36 blocks the chronic stress-induced elevations in the HPA and the sympathetic NPY pathway, which may be a mechanism for its specific stress-allaying effects.

Key Words
► stress
► HPA
► SNS
► acupuncture

Introduction

The classic response to chronic stress consists of an elegant, concerted interplay of two important pathways, the sympathetic nervous system (SNS) and the hypothalamus–pituitary–adrenal axis (HPA). The chronic activation of these stress pathways can lead to maladaptive homeostatic conditions causing symptoms or diseases such as depression, anxiety, and obesity, which may have a direct impact on cardiovascular disorders and hypertension (Szczepanska-Sadowska et al. 2010, Tamashiro 2011, Tamashiro et al. 2011, Tran et al. 2011, McEwen 2012, McEwen et al. 2012). The initial response to stress consists of an increase in the central expression of numerous
catecholamines and peptides in the sympathetic ganglia such as norepinephrine (NE) and neuropeptide Y (NPY) (Nankova et al. 1996, Bernet et al. 1998). NPY and NE have been found to cross talk with the HPA in the CNS causing release of CRH. However, in chronic stress while NE levels return to normal, NPY levels remain elevated, thereby playing a modulating role in NE release in chronic stress (Renshaw et al. 2000, Cavadas et al. 2001, Hellig 2004). As such, NPY plays a cost-saving role for NE, so it can be reserved for more acute responses, during times of chronic stress. Concomitantly, the increase in hypothalamic CRH stimulates the release of ACTH from the pituitary gland. This leads to a subsequent release of corticosteroids as well as NE and epinephrine from the adrenal glands.

Indeed, the HPA and SNS are anatomically and functionally unified; during stress, they interact both in the periphery and in the CNS (Li et al. 2000, Jacobson 2005, Dimitrov et al. 2007, Kakui & Kitamura 2007). The hypothalamic paraventricular nucleus (PVN) is a major site for direct neuronal NPY and NE input to CRH cell bodies (Suda et al. 1993, Li et al. 2000). In several rodent models of chronic stress, such as cold stress, the increase in PVN NPY leads to stimulation of CRH synthesis and subsequent increase in serum corticosterone (CORT) levels (Jacobson 2005, Kakui & Kitamura 2007). It has also been observed that injection of NPY into the PVN increases circulating ACTH and CORT, while ACTH has been demonstrated to exert modulating influences on adrenal NPY (Suda et al. 1993, Hinson et al. 1998).

Given the negative physiological impact of chronic stress, blocking the stress-induced effects of the SNS and HPA may provide a much needed protection against stress-related disorders. Acupuncture has been widely used for over 2500 years across Asia and has most recently gained popularity in Western cultures. Traditional Chinese Medicine (TCM) practitioners have traditionally used electroacupuncture (EA) in the treatment of stress-related disorders; however, there has been little evidence to support its efficacy as an anxiolytic. Two studies have shown that acupuncture can block acute stress-induced increases in the HPA axis (Han et al. 1999, Yang et al. 2002). Although there is limited information on chronic stress, we have recently reported that EA at acupoint Zusanli, stomach 36 (ST36) can ameliorate chronic cold stress-induced increases in central (PVN) and peripheral (plasma) NPY in rats, providing one potential mechanism of action of acupuncture on reducing stress (Eshkevari et al. 2012).

The objective of the current study was to determine whether application of EA at ST36 (EA ST36) during chronic cold stress blocks the stress-induced increases in the major hormones of the HPA and how changes may be related to the adrenal SNS response. This model of chronic stress has been well established by others in our department; Kuo et al. (2007) used this model to study the role of NPY in the relationship between stress and obesity (Kuo et al. 2007). We therefore used this chronic stress/pain paradigm to examine PVN CRH, adrenal NE and NPY, and circulating CORT and ACTH in sham and EA ST36 rats after 10 days of cold stress. We chose ST36 because it is a potent point on the human meridian point system according to TCM. It is used in many instances in TCM, including stress.

Materials and methods

Animals

The animal experiments in this study were approved by the Georgetown University Animal Care and Use Committee (GUACUC), in compliance with National Institute of Health guidelines. A total of 34 adult male Sprague Dawley rats weighing 290–420 g, with indwelling jugular catheters, were received from Harlan Laboratories, Inc. (Dublin, VA, USA). The rats were randomly assigned to four groups. Groups 1 and 2 were controls (n = 7 per group): group 1 received no treatments (Control group), while group 2 was the stress-only (Stress) group in which the animals were exposed to 10 days of cold stress. The two experimental groups (n = 10 per group) consisted of a sham EA group (Sham-EA), which received 4 days of pretreatment with EA at a sham point 5 mm away from the rat tail, bilaterally with no stress, followed by Sham-EA for the next 10 days immediately preceding exposure to the cold stress; the fourth group was the experimental EA group, which was pre-treated with EA ST36 for 4 days before the cold stress and continued to receive EA ST36 immediately before exposure to the cold stress for 10 additional days. EA ST36 was specifically used, not only because of its efficacy to manage stress according to TCM but also due to its location (Fig. 1). ST36 is located 0.5 cm below fibular head of the hind leg in rat bilaterally and is easily acupunctured while the rat remains conscious. It was important to conduct the acupuncture on non-anesthetized animals in our study, given the confounding known effects of anesthetics on stress hormones.

The rats were housed one per cage, to protect the jugular catheters, and the room was kept at a constant temperature of 23 °C. The jugular catheters were checked on the day of arrival. Catheter care that consisted of ensuring patency with a 1 cc sterile syringe and a 23 G blunt tip sterile stainless steel needle (Small Parts, Inc.,
Seattle, WA, USA), followed by injection of 0.1 ml of the Harlan recommended lock solution: 5 ml 100% sterile glycerin (Fisher Scientific, Pittsburg, PA, USA) with 5 ml 1000 U/ml heparin sodium, was performed on days 1 and 7 of the experiment. The animals were maintained in a 12 h light:12 h darkness cycle with free access to food and water. All animals were familiarized with the experiment personnel for 4 days before the onset of the experiments by petting the animals and allowing them to crawl into a cotton sock, which was later used in the protocol to momentarily hold the animal in place while inserting acupuncture needles. The control animals (Control) received no further treatments once the experiment was begun, while the stress control group received only cold stress.

Acupuncture

The acupuncture protocol consisted of placing the animal; head first, into the cotton sock previously used in the acclimation period. Once the animals were comfortably secured in the sock, sterile, stainless steel, single-use acupuncture needles measuring 34 G (0.22 mm) and 1 inch (25 mm) (Millennia, Shanghai, China) were quickly inserted either in the Sham point or the EA St36 point, bilaterally. The electrodes were wrapped quickly around the needle and were taped in place to the needle and then to the rat. The electrodes were subsequently attached to an EA machine (Model AWQ-104L, UPC Medical Supplies, San Gabriel, CA, USA). The animals were placed in a single cage on bedding material and did not receive food or water for the duration of the treatment, which lasted for 20 min. The points were stimulated at a frequency of 10 Hz with 2 mA output, and a pulse width of 0.1 s, based on other rat models of acupuncture treatment (Lao et al. 2004, Zhang et al. 2005). The uniformity of the electrical output was achieved using an oscilloscope that measured the EA machine’s outputs on all rats and adjusted to achieve the desired output. All acupuncture treatments occurred in the morning between 0900 and 1100 h and were administered 30 min before the initiation of the cold stress treatments, and animals were observed closely to ensure that needles were not displaced.

EA St36 EA needling  The rats in the EA St36 group received EA treatments as described earlier. The location of the needles for EA St36 is on bilateral hind legs of the animal. These points were identified using rat mapping for TCM acupuncture. We chose St36 as the TCM acupoint of interest as it is considered one of the most potent and commonly used points in TCM practice. Additionally, previous rodent stress studies have successfully demonstrated that St36 can modulate stress pathways (Lim et al. 2003, Sun et al. 2005, Eshkevari et al. 2012).

Sham-EA needling  EA treatment for the sham group was the same as described earlier, except the points selected were non-acupuncture map points on the back of the animal, 2 cm lateral to the tail region. This point was used as the sham point as there are no known acupuncture points near them and they were out of reach of the animals.

Stress

On day 4 of the experiment, cold stress, which entailed placing the animal in 1 cm deep crushed ice (2–5 °C) for 1 h daily, was carried out as described previously (Zukowska-Grojec 1995). The stress, Sham-EA and EA St36 animals received this daily 1-h cold exposure for 10 days. The animals in the Sham-EA and EA St36 were placed in the cold stress cages 30 min after they had received their acupuncture treatments. Following the cold stress, animals were returned to their home cages and allowed to rest.

Blood sampling

Blood samples were collected on day 1 (before initiation of any treatments), day 7, and day 14 of the experiment via the indwelling jugular catheters using a 1 cc sterile syringe. Following blood collection, the sterile heparin lock solution was replaced and animals were returned to their cages. On days 7 and 14 of the protocol, the animals were exposed to the acupuncture and cold stress treatments and allowed to acclimate to room temperature (RT) for 1 h before bloods were drawn between 1100 and 1300 h. The blood sampling occurred between these times taking into account the diurnal nature and circadian fluctuations of ACTH and CORT. Plasma was collected in 1.5 ml EDTA tubes, centrifuged at 4 °C at 6708 g for 2 min, and the supernatant plasma was stored at −80 °C. Serum was collected in 1.5 ml low retention tubes, placed on a rack at RT for 15 min, and centrifuged at RT for 5 min at 5000 r.p.m. The supernatant serum samples were collected and stored at −80 °C.

Analysis of ACTH, CORT, and NE by ELISA

Each ELISA was performed in accordance with the manufacturer’s recommended protocols. ACTH ELISA was performed using an ELISA kit (Cat #S-1185; Bachem,
San Carlos, CA, USA – specificity of 100% for rat ACTH with a typical sensitivity of 0.26 ng/ml). This kit required an initial extraction step that consisted of equilibrating a 200 mg C-18 sep-column with 1 ml 100% acetonitrile, followed by 1% trifluoroacetic acid (HPLC grade) 3 ml, three times, and centrifuged with a cold vacuum centrifuge once it was buffered. The collected residue was rehydrated with equal volume (150 μl) of assay buffer, and used in the assay. CORT was determined using an ELISA kit (Cat #DSL-10-81100 with a specificity of 100% for rat CORT and a typical sensitivity of 1.6 ng/ml) from Diagnostic Systems Laboratories (Webster, TX, USA). NE ELISA kit (Cat #BA E-5200; Rocky Mountain Diagnostics, Colorado Springs, CO, USA – specificity of 100% for rat NE with a typical sensitivity of 0.2 ng/ml) was used to measure NE.

The optical density from each assay was read on a standard ELISA plate reader set at 450 nm.

Immunohistochemistry

Immunohistochemical staining for CRH was performed on formalin-fixed paraffin-embedded 5 μm sections of rat brain PVN. As previously published, by Eshkevari et al. (2012), the PVN was located from dorsa-ventral coordinate of 8.0 mm from Bregma and medio-lateral coordinate of 0.7 mm. The sections were deparaffinized with xylene and rehydrated through a graded alcohol series, starting with 100% EtOH and ending with 70% EtOH, followed by rinsing in water and TBS with 0.05% Tween. For antigen retrieval, slides were immersed in 10 mM citrate buffer (pH 6.0) with 0.05% Tween at 98 °C for 20 min and allowed to cool for 20 min at RT. After blocking with 3% hydrogen peroxidase and 10% normal goat serum, slides were incubated with a primary antibody, CRH.

Figure 1

(A and B) Effect of EA given before and concomitantly with chronic cold stress on HPA hormones. (A) Plasma ACTH levels: on day 7, all three experimental groups had significantly higher ACTH levels than the control group (*P < 0.05). However, by day 14, plasma ACTH levels in the stress-only and the stress + Sham-EA animals were significantly higher than the control animals (*P < 0.05). In sharp contrast, EA St36 prevented this increase when compared with the stress-only animals (*P < 0.05). Furthermore, there was no significant difference between the ACTH plasma levels of the St36 animal compared with the controls. (B) Serum CORT levels: the serum CORT levels in the stress-only and Sham-EA animals were again significantly elevated when compared with control animals (*P < 0.05). EA St36 prevented this elevation when compared with the stress-only and stress + Sham-EA serum CORT levels (*P < 0.05). EA St36 had effectively prevented the stress-induced increases in serum CORT to levels similar to the control animals. (C) Plasma NE levels: there were no significant differences noted in the plasma NE levels of the four study groups.
Results

Effect of EA St36 on plasma ACTH and serum CORT in chronically stressed rats

There were no significant variances in any parameters after 7 days of cold stress among the experimental groups, with ACTH and CORT being elevated similarly in all three cold stress-exposed groups (Fig. 1A). However, after 10 days of cold stress, ACTH and CORT levels in stress-only and Sham-EA animals were significantly \( P<0.05 \) increased compared with the control group (Fig. 1A and B). In marked contrast, 4 days of pretreatment with EA at acupuncture point St36 (which continued for 10 days with concomitant exposure to cold stress), ameliorated the effects of cold stress: ACTH and CORT levels in stressed EA St36 rats were not different from those seen in control animals and were also significantly lower than those of the stress-only and Sham-EA groups \( P<0.05 \) (Fig. 1A and B).

Effect of EA St36 on plasma NE in chronically stressed rats

After 10 days of chronic cold stress, there were no significant differences in the plasma NE levels between any groups (Fig. 1C), which was not unexpected, considering changes in circulating NE may be related to more acute stress situations.

Effects of EA St36 on PVN CRH

Figure 2 illustrates PVN \( C rh \) mRNA expression. Chronic exposure to cold stress resulted in significant increases in CRH message in stress-only rats and Sham-EA rats when compared with control animals \( P<0.05 \). Although there was no significant difference between EA St36 and control CRH expression, PVN CRH in the EA St36 group was also not significantly lower than the other two stress groups. (Fig. 2). A representative immunohistochemistry (IHC) identifying CRH protein in the different groups is shown in Fig. 3A. Figure 3B shows the average number of CRH-positive cells from each group. Stress significantly elevated CRH protein in the PVN compared with control animals \( P<0.01 \). Sham-EA did not prevent the increase; by contrast, CRH protein in EA St36 rats was not

Statistical analysis

Data were analyzed using GraphPad Prism v4 (GraphPad Software, La Jolla, CA, USA) and are presented as mean ± S.E.M. We used one-way ANOVA with Tukey multiple \( t \)-test or Kruskal–Wallis post-test depending on the sample size to compare between treatment groups. \( P<0.05 \) was considered statistically significant for the indicated sample size per group.
significantly different from unstressed controls, consistent with its effects on Crh mRNA, but was significantly \( (P<0.05) \) lower than the stress-only and Sham-EA animals.

**Effects of EA St36 on adrenal NPY and TH**

To start identifying how chronic stress-related changes in NE and NPY might relate to the HPA response, we studied the effects of cold stress on the adrenal medullary NPY and TH message (an important enzyme in the synthesis pathway of the catecholamines). We found that chronic cold stress had a significant impact on adrenal Npy mRNA expression in raising transcription activity when compared with the non-stressed control group \( (P<0.05) \); Fig. 4A). EA St36 prevented this significant \( (P<0.05) \) increase in message, and levels were similar to that of the control animals. Again, the Sham-EA had failed to prevent the stress-induced increase in NPY (Fig. 4A).

Unlike the stress-induced changes observed in Npy mRNA, there was no change in TH mRNA levels in any of the experimental groups (Fig. 4B). This may again relate to the fact that NE plays a more important role in the acute response to stress while NPY exerts a more chronic effect on modulating NE and maintaining homeostasis in the face of chronic stress.

**Discussion**

Our findings indicate that EA St36, beginning 4 days before induction of cold stress, can prevent the chronic stress-induced increases in the HPA, as well as SNS-related adrenal NPY. This effect was specific to St36, as Sham-EA was not different to responses in stress-only animals. These findings indicate that the mechanism of action of EA St36 involves blocking the HPA at (or before) the level of
PVN CRH. This supports our initial report of the efficacy of EA St36 in preventing chronic cold stress-induced increases in central and peripheral NPY (Eshkevari et al. 2012) and extends the information by reporting for the first time that EA ameliorates the effects of chronic stress on the HPA. These findings support targeted EA as therapeutic intervention in chronic stress conditions.

The phenomenon that EA could prevent elevations in ACTH levels in chronic cold stress was demonstrated in the late 1970s and early 1980s in rat and human models of chronic stress such as opioid withdrawal (Wen et al. 1978, Fung et al. 1980). Our results support and extend these earlier findings in human models of stress. Indeed, pretreatment with EA at TCM point St36 (Fig. 5) maintained ACTH at control animal levels, while those of the stress animals were significantly higher. In our model of pretreating animals, before exposure to chronic cold stress, with EA stimulation at St36, we were able to ameliorate the cold stress effects. Furthermore, the pretreatment with EA St36 maintained CORT at control levels, indicating that EA, specifically at St36, was again effective at preventing the stress-induced increases in both HPA-related hormones in our model of chronic stress. Plasma ACTH levels are under tight negative-feedback control from the glucocorticoids, which are released in response to ACTH secretion. However, during chronic stress, CORT levels remain elevated engendering catabolic consequences that lead to breakdown of vital functions (Sapolsky et al. 2000). As EA St36 (but not Sham-EA), prevented these stress-induced increases, it is possible that the deleterious effects of chronically high corticosteroids might be prevented in TCM EA-treated animals.

These findings are novel; there are currently no published data on the effects of acupuncture on peripheral ACTH and CORT levels in a chronic stress model such as the one we used. There have, however, been a few studies demonstrating the effects of EA on the HPA in acute stress, but the EA points used were not always specified. Han et al. (1999) discovered that in their rat acute stress model of tooth pulp stimulation, acupuncture had similar effects to those we found on the adrenocortical system. They also found that ACTH and CORT levels were decreased with EA at the large intestine meridian point 4 (LI4, a point commonly used in TCM for facial and dental pain) treatments after tooth pulp stimulation was begun (Han et al. 1999). Their animals had a similar rise in ACTH and CORT with the stressor, which was significantly lower by EA treatments. Interestingly, in another more recent study of the effects of EA on a painful, acute inflammation rat model, the investigators had contradictory findings: CORT levels were elevated by acupuncture treatments, which lead to better outcomes in reduction of inflammation and paw-withdrawal latency (Li et al. 2007). We believe the difference in our model and the aforementioned models may be due to varying pathways that are stimulated during EA procedures, such as to the arcuate nucleus and the periventricular hypothalamic nucleus, depending on the type and duration of stress, as well as the EA point used. Indeed, it is well established that there are various pain/stress ascending pathways, as well as various modulating descending pathways that could have played
stress such as cold and pain, such as the one in our model, into four varying categories, which include i) physical stressors such as hemorrhage or exercise, ii) psychological stress, iii) social stress, and finally iv) homeostatic stressors such as hemorrhage or exercise (Kvetnansky et al. 2009). Stressor-specific responses have been linked to numerous stressors that have been divided into four varying categories, which include i) physical stress such as cold and pain, such as the one in our model, ii) psychological stress, iii) social stress, and finally iv) homeostatic stressors such as hemorrhage or exercise (Kvetnansky et al. 2009). Stress can be further classified as chronic, as in our model, or acute, and again this may provide an explanation for the difference between our findings and those of the aforementioned study, which had used acute pain/inflammation as their model of stress.

In order to begin examining where in the HPA pathway EA may work, we investigated the central effects of EA St36. Our finding that stimulation at acupoint EA St36 prevents stress-induced increases in Crh mRNA (Fig. 2) mirrored the efficacy of stimulation on ACTH levels and was consistent with previous work that increased CRH is associated with a variety of stressors (Slawecki et al. 2005, Santibanez et al. 2006, Yanagita et al. 2007). However, currently, there are no reports on the effects of EA on stress-induced elevations of PVN CRH. We believe that as CRH plays an important role in initiation and integration of the stress response, the central effects of EA St36 on CRH PVN may explain the downstream effects we have observed in HPA hormone levels.

In addition to stimulating ACTH, CRH neurons from the PVN project to medullary and spinal cord autonomic neurons (49). Here, they regulate the adrenal and peripheral sympathoneural response to stress (Sawchenko & Swanson 1982, Swanson et al. 1986). Therefore, we also examined the effects of EA St36 on plasma NE and adrenal NPY and TH activity, which are downstream of HP activation. Regulation of TH expression is a major mechanism by which NE and the adrenergic system respond to stress, and TH plays an integral role in adaptation to various stressors (Stone & McCarty 1983). In our model of chronic stress, we found no significant differences in plasma NE (Fig. 1C) or adrenal TH activity (Fig. 4B) between the groups. This finding is actually consistent with the fact that the NE response is primarily an acute effect to help regulate blood pressure and blood flow (Nankova & Sabban 1999, Nankova et al. 1999). The lack of change in plasma NE and adrenal TH levels in our groups is consistent with other investigators who have found that NE levels, although elevated at first, do indeed stabilize over time with exposure to the same stressor (Glavin 1985a, Glavin 1985b).

Acupuncture has also been used, with some success, in human acute stress models including acute mental stress (Middlekauff et al. 2002). However, there have been no recent studies on the effects of EA on the chronic stress-induced activation of the SNS. As part of the SNS response, stress is also a major activator of adrenal NPY, and various stressors including cold stress have been associated with increases in adrenal Npy mRNA (Renshaw & Hinson 2001). Our findings support and extend these previous studies, by demonstrating that adrenal Npy mRNA was significantly elevated after 14 days of stress, and EA St36 prevented this increase in NPY expression. This suggests that NPY may modulate the chronic stress response in concert with the hormones of the HPA. Indeed, the stress-induced increase in adrenal NPY may result from central signals from either CRH or NPY, which we have previously shown to be elevated in the PVN of stressed rats (Eshekevari et al. 2012). In either case, the ability of EA St36 to block the increase in adrenal NPY could be via EA actions at the PVN.

We have demonstrated that treatment with EA at the specific point, St36 starting 4 days before, and continuing through 10 days of chronic cold stress, can prevent increases in the central PVN hormone CRH expression, thereby preventing the stress-induced elevations in circulating ACTH and CORT levels. Furthermore, we have shown that peripherally, EA St36 can influence
adrenal NPY levels, which may also contribute to its stress-ameliorating effects. An important area of future work would be to see if EA is effective when given after stresses have begun, which would have important implications for therapeutic intervention. Further studies will also need to be conducted to identify the potential effects of EA St36 on the pain pathways activated in this model of chronic cold stress. Additionally, to further confirm our findings, it would be useful to block the pathways elucidated. We have demonstrated that EA St36 is useful at reducing stress. Additionally, to further confirm our findings, it would be useful to block the pathways elucidated. We have demonstrated that EA St36 is useful at reducing stress-induced elevations in HPA hormones. This may be of use therapeutically in stress-related disorders but warrants further investigation, perhaps in a human chronic stress model.

Declaration of interest
The authors declare that there is no conflict of interest that could be perceived as prejudicing the impartiality of the research reported.

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Author contribution statement
L E, a nurse anesthetist, physiologist, and licensed acupuncturist was the main contributing author. The study was conducted based on her experience in treating chronic pain and stress patients; the idea to develop the study was thus generated. She wrote the bulk of the manuscript, with input from contributing authors below. E P, contributed to the set up of the IHC protocols and assisted with the Materials and methods section in the manuscript pertaining to IHC. S E M, provided guidance on study protocols and assisted with manuscript revisions and preparation.

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