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Evaluation of homing pigeon feather tissue as a biomonitor of environmental metal concentrations in China

Jia Cui[1,2] · Richard S. Halbrook[3] · Shuying Zang[1,4] · Mary Ann Masdo[5] · Shuang Han[6]

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Abstract

Biomonitoring provides direct evidence of the bioavailability and accumulation of toxic elements in the environment, and homing pigeons have been proposed as a biomonitor of atmospheric pollution. We evaluated metal concentrations in homing pigeon feather tissue as a biomonitoring tool. We measured cadmium, lead, and mercury concentrations in feathers collected from 5–6-yo homing pigeons from Guangzhou, Beijing, and Harbin, China during 2011, and feathers of 1, 5, and 10-yo homing pigeons collected from Guangzhou, Beijing, and Harbin, China during 2015–16. We compared metal concentrations in feathers between sexes and among ages and evaluated spatio-temporal differences. Correlations between feather metal concentrations and previously evaluated kidney and liver metal concentrations are reported. There were no significant differences in feather metal concentrations between male and female pigeons or among 1, 5, and 10-yo pigeons. Cadmium, lead, and mercury concentrations in feathers of 1-yo pigeons were significantly correlated with concentrations in liver and kidney tissues, although the correlations were not consistent. Spatio-temporal differences in feather metal concentrations suggest the usefulness of feathers in identifying areas of concern and remedial effectiveness. Homing pigeon feather metal concentrations appear to be useful as a screening biomonitoring tool.

Keywords Homing pigeons · Heavy metals · Feather tissue · Biomonitor

Introduction

Heavy metal pollution of the atmosphere is a problem in many cities around the world that has potential impacts on wildlife and human health (Mailman 1980; Merian 1991; Swaileh and Sansur 2006; Turner et al. 2020). Heavy metal pollution of the atmosphere is caused by burning of urban and industrial waste, mining, smelting processes, gas emission from motor vehicles, and combustion of fossil fuels (Harrop et al. 1990; Mohammed et al. 2011; Clark 1992; He et al. 2020). Evaluating health effects of a contaminated atmosphere is difficult because source and volume of contaminants are dynamic and in constant flux. Because of these difficulties, use of wild species as biomonitors of exposure and effects of atmospheric contaminates has been proposed (Schulwitz et al. 2015; AL-Alam et al. 2019). Wild species are integral components of their environments and are continually breathing, eating, and sheltering within their habitats; therefore, they are exposed regardless of atmospheric changes (Furness 1993; Llabjani et al. 2012). In addition, biomonitoring provides evidence of accumulation and potential effects of exposure that is not available with mechanical air monitoring.

Our previous research has evaluated homing pigeons (*Columba livia*) as a species for monitoring atmospheric contamination. Because of their site fidelity, and known age and diet, homing pigeon are uniquely suited as a biomonitor

✉ Shuying Zang
zsy6311@163.com

1 Heilongjiang Province Key Laboratory of Geographical Environment Monitoring and Spatial Information Service in Cold Regions, Harbin Normal University, Harbin 150025 Heilongjiang, People's Republic of China

2 School of Management, Harbin Normal University, Harbin 150025 Heilongjiang, People's Republic of China

3 Cooperative Wildlife Research Laboratory and Department of Zoology (Emeritus), Southern Illinois University, Carbondale, IL 62901, USA

4 Heilongjiang Province Cold Region Ecological Safety Collaborative and Innovation Center, Harbin 150025 Heilongjiang, People's Republic of China

5 TG&G Wildlife Consulting, Carbondale, IL 62902, USA

6 Institute for Environmental and Climate Research, Jinan University, Guangzhou 511443, People's Republic of China

of atmospheric contamination. In the United States and China, homing pigeons have been used as biomonitors of Polycyclic Aromatic Hydrocarbons (PAHs), mercury (Hg), cadmium (Cd), and lead (Pb) in major urban areas (Liu et al. 2010; Cizdziel et al. 2013; Cui et al. 2013). Liu et al. (2010) reported a relationship between PAH concentrations measured in ambient air and in lung tissue of homing pigeon as well as a relationship between profiles of individual PAH congeners in lung tissue and ambient air. In addition, total PAH and mercury concentrations and incidence of lung (anthracosis/pneumoconiosis) and liver (hepatitis) lesions were greater in homing pigeons collected from Beijing, China compared to those collected from Chengdu, China (Liu et al. 2010; Cizdziel et al. 2013).

Our previous studies have demonstrated exposure and effects of atmospheric heavy metal contaminants in homing pigeon lung tissue and heavy metal exposure in liver and kidney tissues; and we have reported the usefulness of biomonitoring in evaluating spatio-temporal changes in environmental contamination (Cui et al. 2016 and 2018). However, we have not evaluated feather tissue of homing pigeons as a means for monitoring metal exposure and contamination. Metals that normally enter circulating blood via ingestion or respiratory routes may be deposited in feathers during feather growth (Burger and Gochfeld 1999; Bortolotti 2010); therefore, evaluating environmental contaminants in feather tissue may provide a non-invasive and non-destructive method for assessing exposure in avian species (Burger 1993; Kim and Koo 2007; Frantz et al. 2012; Cherel et al. 2018; Peterson et al. 2019).

In previous studies, it was possible to measure contaminants in feather tissue and to evaluate exposure or to compare contaminant concentrations between different locations; however, specific ingested sources of the contaminants could not be identified. For example, exposure to heavy metal concentrations in feathers of seabirds were used to monitor contamination in marine environments influenced by the oil industry, and a variety of other polluting sources (Burger and Gochfeld 1995; Burger et al. 2008; Thébault et al. 2020). Similarly, Beyer et al. (1997) reported that concentrations of mercury in breast feathers of *Mycteria americana* from Costa Rica were lower than those from Florida, USA reflecting differences in mercury concentrations between the two environments, although the specific ingestion sources of mercury exposure could not be identified.

In our current study, we measured concentrations of Cd, Pb, and Hg in feathers of different aged homing pigeons collected from Beijing, Guangzhou, and Harbin, China and evaluated correlations with concentrations previously measured in liver and kidney tissues of these same pigeons. Our objectives were: (1) to evaluate age and sex differences in feather Cd, Pb, and Hg concentrations among 1, 5, and 10-yo homing pigeons, (2) to evaluate correlations of Cd, Pb, and Hg concentrations between feather tissue, and liver and kidney tissues, (3) to evaluate temporal changes in Cd, Pb, and Hg concentrations measured in feather tissues of 5–6-yo homing pigeons collected during 2011 and 2015, and (4) to evaluate spatial differences in Cd, Pb, and Hg concentrations in feathers of 1-yo pigeons collected from Beijing and Harbin, China during 2016.

Methods

Individual collection and processing

Collection and processing of homing pigeons has previously been reported (Cui et al. 2013, 2016, 2018). Briefly, different age homing pigeons were collected from cooperating homing pigeon hobbyists in Beijing, Guangzhou, and Harbin, China during 2011 and 2015–16. Liver, kidney and feather tissues were removed from collected pigeons and analyzed for heavy metals. We have previously reported data evaluating liver and kidney metal concentrations, here we describe processing and evaluating metals in feather tissue.

Breast feathers plucked from individual pigeons, placed in envelopes, and stored at room temperature. Prior to analysis, feathers were washed three times with acetone to remove oil and lipids, rinsed three times using tap water, deionized water, and ultrapure water, and then air dried. Dried feathers were analyzed for Cd and Pb, and Hg following EPA Method 3050B (USEPA 1996) and EPA Method 200.8 (USEPA 1994), respectively. This research was approved by Harbin Normal University following the guidelines of the American Veterinary Medical Association (AVMA 2013). Detailed methods and quality control have previously been described, (Cui et al. 2013).

Data analysis

Descriptive and inferential statistical analyses were performed using SPSS 16.0 (SPSS Inc., Chicago, USA). An ANOVA was used to evaluate differences in feather metal concentration among different age groups collected from Guangzhou during 2015, and to evaluate differences in metal concentration among the same age pigeons collected from Beijing, Guangzhou and Harbin during 2011. An Independent-sample T test was used to evaluate differences in metal concentration among same age pigeons collected from Beijing and Harbin during 2016 and between male and female pigeons collected from Guangzhou, Beijing and Harbin during 2011 and 2016. A Pearson correlation was used to evaluate correlations in metal concentrations between feather, liver, and kidney tissues of same aged pigeons collected from Beijing, Guangzhou, and Harbin. A p value $<$ 0.05 was considered statistically significant.

Result

Gender and age-related differences

There were no statistical differences in feather Cd, Hg and Pb concentrations between male and female pigeons; therefore, male and female data were combined for other statistical evaluations (Table 1). There also was no significant different in feather concentrations of Cd, Pb, and Hg among 1-yo, 5-yo, and 10-yo pigeons collected from Guangzhou during 2015 (Table 2).

Correlations, 1-yo pigeons

There was a significant ($p < 0.05$) positive correlation in Cd concentrations between feather tissue, and liver and kidney tissues in 1-yo pigeons collected from Beijing, Guangzhou, and Harbin ($n = 28$) during 2016 (Table 3). In contrast, feather Pb concentrations were negatively correlated with liver and kidney tissue concentrations (Table 3). Feather Hg concentrations were positively correlated with kidney tissue concentrations, however, there was no significant correlation between feather and liver tissues concentrations (Table 3).

There was a significant ($p < 0.01$) positive correlation in Hg concentrations between feather tissue, and liver and kidney tissues in 5–6-yo pigeons collected from Beijing, Guangzhou, and Harbin ($n = 31$) during 2011 (Table 4). However, there was no significant correlation of Pb and Cd concentrations between feather tissue, and liver and kidney tissues concentrations (Table 4).

Table 1 Gender-based concentrations (mean ± SE ng/g) of heavy metals in feather tissues of homing pigeon collected from Guangzhou, Beijing and Harbin during 2011 and 2016

Year		Female	Male	*P*
2016		$n = 25$	$n = 23$	
	Cd	10.8 ± 2.0	9.9 ± 2.3	0.773
		(3.0–40.1)	(2.4–53.9)	
	Pb	310.2 ± 37.1	291.2 ± 22.8	0.672
		(93.1–799.5)	(130.7–524.7)	
	Hg	17.9 ± 2.5	15.5 ± 2.0	0.475
		(3.4–42.7)	(2.7–35.6)	
2011		$n = 8$	$n = 23$	
	Cd	14.4 ± 5.1	8.0 ± 0.9	0.254
		(2.09–38.3)	(2.37–19.3)	
	Pb	729.3 ± 165.4	516.0 ± 39.9	0.246
		(354.7–1587.0)	(190.1–908.3)	
	Hg	40.3 ± 6.9	33.4 ± 5.2	0.434
		(11.7–70.2)	(3.7–81.1)	

Temporal differences in feather metal concentrations

Lead concentrations in feathers of 5 - 6-yo pigeons collected from Guangzhou were significantly greater ($p = 0.009$) in pigeons collected during 2011 compared to concentrations measured in pigeons collected during 2015 (Table 5). In contrast, Hg concentrations in feathers of pigeon collected during 2011 were significantly less ($p = 0.011$) than concentrations in feathers of pigeons collected during 2015 (Table 5). There were no significant differences in Cd concentrations measured in feathers of 5–6-yo pigeons from Guangzhou during 2011 and 2015 ($p = 0.703$).

Location differences in feather metal concentrations

Lead and Cd concentrations were significantly greater ($p < 0.001$ for Pb; $p = 0.025$ for Cd) in feathers of 1-yo pigeons collected from Harbin compared to concentrations measured in feathers of same aged pigeons collected from Beijing during 2016; however, Hg concentrations were not significantly different (Table 6).

Discussion

Our objective was to measure metal concentrations in feathers of homing pigeons and evaluate whether feather tissue could be used as a biomonitor of environmental metal contaminations. We compared metal concentrations

Table 2 Age-based concentrations (mean ± SE ng/g, $n = 29$) of heavy metals in feather tissues of homing pigeon collected from Guangzhou during October 2015

	Tissue	Age (1–2)	Age (5–6)	Age (9–10+)	F	*p* value
		($n = 9$)	($n = 10$)	($n = 10$)		
Cd	feather	12.9 ± 3.9	11.4 ± 4.8	5.5 ± 0.5	1.217	0.312
		(2.4–40.1)	(3.0–53.9)	(3.4–8.0)		
Pb	feather	341.1 ± 67.2	310.9 ± 36.9	213.5 ± 17.7	2.348	0.116
		(152.6–799.5)	(182.1–497.3)	(154.1–295.8)		
Hg	feather	25.1 ± 3.3	24.9 ± 1.9	21.7 ± 3.6	0.406	0.670
		(10.7–39.6)	(20.1–38.4)	(10.6–42.7)		

One-way ANOVA, $p < 0.05$

Table 3 Pearson correlation in heavy metal concentrations between feather, liver and kidney tissues in 1-yo pigeons collected from Beijing, Guangzhou, and Harbin ($n = 28$) during 2016

	Feather	Kidney	Liver
Cd			
Feather	1	0.395*	0.475*
Kidney	0.395*	1	0.872**
Liver	0.475*	0.872**	1
Hg			
Feather	1	0.633**	0.057
Kidney	0.633**	1	0.242
Liver	0.057	0.242	1
Pb			
Feather	1	−0.779**	−0.808**
Kidney	−0.779**	1	0.783**
Liver	−0.808**	0.783**	1

*Indicate significant correlation at 0.05 level

**Indicate significant correlation at 0.01 level

Table 4 Pearson correlation in heavy metal concentrations between feather, liver and kidney tissues 5–6-yo pigeons collected from Beijing, Guangzhou, and Harbin ($n = 31$) during 2011

	Feather	Kidney	Liver
Cd			
Feather	1	−0.036	0.027
Kidney	−0.036	1	0.644**
Liver	0.027	0.644**	1
Hg			
Feather	1	0.624**	0.719**
Kidney	0.624**	1	0.873**
Liver	0.719**	0.873**	1
Pb			
Feather	1	−0.097	−0.024
Kidney	−0.097	1	0.579**
Liver	−0.024	0.579**	1

*Indicate significant correlation at 0.05 level

**Indicate significant correlation at 0.01 level

Table 5 Temportal-based concentrations (ng/g, dry wt, $n = 20$) of Cd, Hg, and Pb in feathers of 5-6 year old pigeon collected from Guangzhou during May 2011and October 2015

	Tissue	2011	2015	F	p value
		($n = 10$)	($n = 10$)		
Cd	Feather	13.9 ± 4.2	11.4 ± 4.8	0.15	0.703
		(2.4–38.3)	(3.0–53.9)		
Pb	Feather	685.9 ± 121.6	310.9 ± 36.9	8.711	0.009
		(190.1–1587.0)	(182.1–497.3)		
Hg	Feather	17.6 ± 1.8	24.9 ± 1.9	7.919	0.011
		(7.7–28.7)	(20.1–38.4)		

Table 6 Spatial-based concentration (± SEM, ng/g) of heavy metals in the feathers of 1-yo homing pigeon collected from Beijing and Harbin during August 2016

		Beijing	Harbin	p value
		($n = 10$)	($n = 9$)	
Cd	Feather	6.3 ± 1.5	16.9 ± 3.8	0.025
		(3.1–19.0)	(4.8–36.14)	
Hg	Feather	5.9 ± 0.6	6.1 ± 0.8	0.822
		(4.0–9.6)	(2.7–9.1)	
Pb	Feather	207.6 ± 37.9	451.8 ± 38.9	<0.001
		(93.1–510.8)	(259.6–628.6)	

P value indicate significant difference between Beijing and Harbin (Independent T Test p values)

measured in feathers to metal concentrations previously measured in liver and kidney tissue and evaluated spatio-temporal changes. We measured no significant differences in feather metal concentrations between male and female pigeons, which is similar to our previous reported results for metals in live and kidney tissues (Cui et al. 2013 and 2016). Our results also indicated no significant difference in feather metal concentrations among 1–2, 5–6, and 9–10-yo pigeons (Table 2). This result is contrary to our previously reported results for metal concentrations in liver and kidney tissues where we observed age related differences in metal concentrations (Cui et al. 2013). This difference is not unexpected because feathers are replaced periodically in avian species; therefore, would reflect metal exposure during times when feathers were growing (Malik and Zeb 2009; Abdullah et al. 2015). In contrast, metal concentrations in liver and kidney tissues would reflect metal accumulation over the life of the pigeon depending on metal exposure, concentrations in circulating blood, and elimination rates from these organs.

In 1-yo homing pigeons, Cd, Pb, and Hg concentrations in feathers were significantly correlated with concentrations in liver and kidney tissues although the correlations were not consistent (Table 3). Cadmium concentrations in feathers of 1-yo pigeons were positively correlated while Pb concentrations were negatively correlated with concentrations in both liver and kidney tissues. Mercury concentrations in feathers of 1-yo pigeons were positively correlated with concentrations in kidney tissue but not significantly correlated with concentrations in liver tissue. However, Hg concentrations also were not significantly correlated between kidney and liver tissues in 1-yo pigeons. In contrast, Cd, Pb, and Hg concentrations were all significantly correlated ($p > 0.01$) in liver and kidney tissues of 5–6-yo pigeons, while only Hg concentrations in feather tissue was correlated with concentrations in liver and kidney tissues (Table 4). These correlation differences between ages are not unexpected because feather metal concentrations reflect exposure during feather growth while liver and kidney metal concentrations reflect exposure and accumulation over the life of the individual. These data suggest that feather metal concentrations may be useful in assessing metal concentrations in liver and kidney tissues of 1-yo pigeons, while additional studies are necessary in order to better understand relationships between feather tissue metal concentrations and internal organ metal concentrations in older pigeons.

We observe temporal differences in feather Pb and Hg concentrations in 5–6-yo pigeons collected from Guangzhou during 2011 and 2015 (Table 5). This difference indicates a potential change in Pb and Hg exposure between the two time periods evaluated and suggest decrease in environmental Pb exposure and increase in environmental Hg exposure. Although we have previously reported changes in pigeon tissue metal concentrations that were correlated with changes in atmospheric metal concentrations (Cui et al. 2016; Cui et al. 2018), additional study is needed to evaluate correlations between metal concentrations in feathers and atmospheric metal concentrations that existed during the time of feather growth. However, because metals accumulate in feathers only during feather growth, we postulate that feather tissue metal concentrations would more accurately reflect temporal changes in environmental metal concentrations compared to concentrations measured in other tissues.

Comparison of metal concentrations in feathers of 1-yo pigeons collected from Beijing and Harbin (Table 6), suggest that measuring metal concentrations in feathers may be useful in evaluating spatial differences in environmental metal concentrations. Feathers that grow in different locations would accumulate metals based on exposure during the growth period; therefore, it is reasonable to expect feather metal concentrations to be a reasonable biomonitor of spatial differences.

Conclusions

Our data suggest that measuring feather metal concentrations may be useful in evaluating temporal and/or spatial differences in metal exposure, and pigeon age and sex does not appear to influence results. An important caveat in using pigeon feathers as a biomonitoring tool is that metals accumulate in feathers during the period of feather growth; therefore, results relate only to that time period. In addition, metal concentrations in feather tissue do not prove adverse effects; however, depending on specific metal concentrations, it may warrant additional research of internal tissues or conditions that may indicate adverse effects. Therefore, because homing pigeon feathers can be collected without having to sacrifice the pigeon, measuring metal concentrations in feather tissue may serve as a useful initial evaluation to assess if further evaluations of effects are warranted.

Evaluating temporal changes in feather metal concentrations may provide evidence of effectiveness of remedial actions and comparing spatial differences in feather metal concentrations may serve as a screening tool identifying individuals or populations where additional study may be warranted. Homing pigeon feathers are easy to collect, store, and analyze for metals, and our research suggest that they may be very useful as a screening tool in biomonitoring.

Data availability

All data included in this study are available upon request by contact with the corresponding author.

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Author contributions SYZ, RSH, and JC developed research concepts and methods; JC conducted data analyses and wrote original draft; RSH supervised research and edited paper; JC and SH conducted chemical analyses; JC, RSH and MAM conducted necropsies and sample collections.

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Compliance with ethical standards

Conflict of interest The authors declare no competing interests.

Animal research All applicable international, national, and/or institutional guidelines for the care and use of animals were followed.

Consent to participate This article does not contain any studies with human participants performed by any of the authors.

Consent to publish All of the authors gave final approval for publication.

Plant reproducibility Plant reproducibility was not involved in this article.

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