Study 5: Kidney cadmium concentrations in cattle from the index farm, 2003-2005 and 2009

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Abstract

Of all animal tissues, livers and kidney constitute a special dilemma in that they have a tendency to bioaccumulate toxic metals such as arsenic (As), cadmium (Cd), lead (Pb) and mercury (Hg). Maximum concentrations (ML) for Hg, Pb, Cd and tin (Sn), but not As in foodstuffs are set by European Commission Regulations. The aims of this study were 1) to determine the concentrations of As, Cd, Pb and Hg in the livers and kidneys of nine cows from the index farm and 2) to combine the kidney Cd results from these 5 cows with those reported in an earlier Department of Agriculture Fisheries and Food (DAFF) report (n = 14 animals), and describe the trend in kidney Cd concentrations on the index farm over time. Arsenic, Pb and Hg concentrations in livers and kidneys were within normal range for animal health purposes for the nine cows. Kidney Cd concentrations in six of the nine cows exceeded the normal range for animal health purposes (0.05-1.5 mg/kg) and seven of the nine exceeded the ML permitted for human consumption (1 mg/kg). When kidney Cd results from the nine cows (2009) were combined with results (n = 14) from a previous investigation (2003-2005), 8 of the 23 (37.8 %) kidneys had Cd concentrations above 1.5 mg/kg, the upper limit of the normal range for animal health. Kidney Cd concentrations appear to increase in animals with increasing time spent on the index farm. Based on current knowledge, exposure at this level is not associated with adverse effects in terms of animal health or performance.

1 Introduction

Of all animal tissues, livers and kidney constitute a special dilemma in that they have a tendency to bioaccumulate toxic metals such as arsenic (As), cadmium (Cd), lead (Pb) and mercury (Hg) (López Alonso *et al.,* 2000, 2002). Maximum concentrations (ML) for Hg, Pb, Cd and tin (Sn) in foodstuffs are set by Commission Regulation No. 1881/2006 (amended by No. 629/2008), which includes bovine muscle, livers and kidneys. Regulations are the most direct form of EU law, they have binding legal force throughout Member States as soon as they are passed, on a par with national laws. Consequently, national governments do not have to take action to implement EU regulations (http://ec.europa.eu/community_law). For As, no maximum concentration (ML) is yet established at European level but discussions are ongoing and it is anticipated that limits will be set for arsenic in the near future as the methodology for the determination of arsenic improves. The concentrations of As in food are covered at a national level through S.I. No. 44 of 1972 and its amendment S.I. No. 72 of 1992.

Cadmium, a heavy metal, has no beneficial biological role (WHO, 1992; NRC, 2005), and may be highly toxic when introduced into the body by ingestion or inhalation to both animals and humans. In some cases, however, few human health effects have been reported in countries with some of the highest naturally occurring soil Cd concentrations (Lalor *et al.,* 2008). It is believed that a better understanding of the interaction of Cd with other elements may provide the key to understanding the effects of Cd on health. Cadmium is not easily cleared by the cells and the poor efficiency of cellular export systems explains the long residence time of this element in storage tissues such as the intestine, the liver and the kidneys (EFSA, 2009), resulting in older animals having higher liver and kidney Cd concentrations (Nriagu *et al.,* 2009) even if the concentrations in their diets and water are consistently low (NRC, 2005). Perturbation of calcium (Ca), zinc (Zn) or iron (Fe) homeostasis plays a key role in Cd toxicological action that involves a general threat to basic cellular functions. A detailed review of Cd is given in Chapter 7, appendix 7. Cadmium has no known biological function in either animals or humans but mimics the actions of other divalent metals that are essential to diverse biological functions (EFSA, 2009). Cadmium bioavailability, retention and consequently toxicity are affected by several factors such as nutritional status (low body iron stores) and multiple pregnancies, pre-existing health conditions or diseases (EFSA, 2009). Cadmium can cross various biological membranes by different mechanisms (e.g. metal transporters) and when inside bind to ligands with exceptional affinity (e.g. metallothioneins). Cadmium interacts with the metabolism of essential elements such as Ca, Zn and Fe, but not only inhibits intestinal Ca transport, but may also interfere with bone calcification, decalcification and bone remodelling (WHO, 1992). In blood, 90 % of Cd is primarily found in cells, and blood concentrations are an indication of absorption over recent weeks/months (Lauwerys *et al.,* 1994; WHO, 1992; WHO, 2000). Cadmium exposure has been associated with nephrotoxicity, osteoporosis, neurotoxicity, carcinogenity and genotoxicity, teratogenicity, and endocrine and reproductive effects (EFSA, 2009).

Exposure is typically a function of the concentration of Cd and the duration of the exposure, two factors that are not necessarily additive for heavy metals (Wilkinson *et al.,* 2003). A long exposure to a small dose of Cd would be unlikely to induce acute toxicity because of the ability of the liver to sequester Cd bound to metallothioneins. A short 'provocative' dose is likely to exceed the liver's ability to sequester the metal and acute toxicity arises when the metal passes through the proximal tubule of the kidney. Typically liver and kidney Cd concentrations are measured to determine exposure.

Regulatory limits of maximum Cd concentrations in muscle, liver and kidneys of cattle for human consumption set by the Commission Regulation No. 1881/2006 (amended by No. 629/2008) at 0.05, 0.5 and 1.0 mg/kg wet weight, respectively. Data from literature on the concentrations on Cd in livers and kidneys of cattle from various countries are presented in Table 1. Average concentrations (range) in mg/kg wet weight are given.

Table 1: Data from recent literature on the concentration of cadmium in livers and kidneys of cattle from various countries. Average concentrations (range) are given in mg/kg wet weight.

Country	Animal	Age	Liver Cd	Kidney Cd (*cortex only)	Reference
EU Member States					
Poland	Bison (Free ranging)	1yr	0.09±0.01 (0.07-0.10)	0.21±0.03 (0.18-0.25)*[1]	Wlostowski *et al.*, 2006
		2yr	0.22±0.1 (0.10-0.35)	0.41±0.07 (0.35-0.50) *[1]	
		4yr-6yr	0.43±0.03 (0.40-0.48)	1.24±0.38 (0.86-1.82) *[1]	
		7yr-12yr	0.45±0.08 (0.31-0.58)	2.79±0.66 (1.95-3.52)*[1]	
	Domestic cattle	8yr-12yr	0.2±0.06 (0.09-0.27)	1.30±0.47 (0.68-2.0) *[1]	
Poland	Cattle	<2yrs	0.159±0.098 (0.06-0.487)	0.425±0.195 (0.104-0.937)	Zasadowski *et al.*, 1999
		>2yrs	0.263±0.166 (0.081-0.672)	1.703±1.106 (0.59-4.275)	
Poland	Cattle		0.12	0.61	Falandysz, 1993
NW Spain	Cows	3yr-16yr	0.0547 (0.013-0.564) *[4]	0.320 (0.0298-3.393) *[4]	López-Alonso *et al.*, 2004
NW Spain	Calves	6mth-10mths	0.00756-0.00798 (ND-7.99)	0.0513-0.0579 (0.00243-1.302)	López-Alonso *et al.*, 2000
	Cows	2yr-16yr	0.0833 (0.0234-0.246)	0.388 (0.110-1.346)	
Spain	Cattle	6mths-12mths	0.0307±0.00124	0.161±0.00703	Miranda *et al.*, 2001
N Spain	Cattle	9mth-12mth	0.0229 (0.00643-0.221) Rural	0.0964 (0.0042-0.545) Rural	Miranda *et al.*, 2005
			0.0296 (0.00339-0.131) Industrial	0.161 (0.0235-0.717) Industrial	
Sweeden	Cattle		0.07	0.39	Jorhem *et al.*, 1991
Finland	Cattle		0.061	0.35	Niemi *et al.*, 1991
Finland	Cattle	Heifers	0.036		Tahvonen and Kumpulainen, 1994
		Cows	0.066		
Slovenia	Cattle		0.094	0.373	Doganoc, 1996
Netherlands	Cattle	3mths-13yr	0.16 Control area*[2]	1.61 Control area*[3]	Spierenburg *et al.*, 1988
			0.35 Polluted area*[2]	3.96 Polluted area*[3]	
Non-EU countries					
Australia	Cattle		0.04-0.21	0.1-0.66	Langlands *et al.*, 1988
Jamaica	Cattle		3.24 (ND-82.1)	7.92 (0.012-117)	Nriagu *et al.*, 2009
Kazakhatan	Cattle		0.05-0.79	0.13-1.06	Farmer and Farmer, 2000
Iran	Cattle	1yr-10yr	0.0497	0.1371	Rahimi and Rokni, 2008
Morocco	Cattle		1.45 (0.82-2.02) *[2]	4.26 (2.36-5.58) *[3]	Sedki *et al.*, 2003

New Zealand	Cattle	Heifers	n/a*[2]	<0.04-0.82*[3]	Roberts *et al.*, 1994
		Beef cows	n/a*[2]	<0.04-2.06*[3]	
		Dairy cows	n/a*[2]	<0.04-1.65*[3]	
China	Cattle	2yr - 4yr	<0.5, 1.31, 2.47	2.15, 6.64, 38.3	Cai *et al.*, 2009

*[1] Kidney cortex only
*[2] Results converted from dry weight to wet weight by dividing by 3.52, based on the assumption that the water content of a liver is 77.9 %
*[3] Results converted from dry weight to wet weight by dividing by 3.52, based on the assumption that the water content of a kidney is 70.2 %
*[4] Geometric means are presented

The aims of this study were;

1. To determine the concentrations arsenic (As), cadmium (Cd), lead (Pb) and mercury (Hg) in the livers and kidneys of nine cows from the index farm.
2. To combine the kidney Cd results with those reported in an earlier Department of Agriculture Fisheries and Food (DAFF) report (n = 14 animals) and describe the trend on kidney Cd concentrations on the index farm over time.

2 Material and methods

2.1 Animals and sampling

Cows, that had spent between 5.1 and 13.2 years on the index farm (n = 9; Cow 1 to Cow 9) were slaughtered, either on the index farm (n = 1; 09/04/2009 and n=1; 21/08/2009) or at a local slaughterhouse (n = 4; 14/04/2009 and n=3; 21/08/2009). Blood samples were collected, by jugular venipuncture into plain and ETDA blood tubes (BD Vacutainer Systems, Plymouth, UK) before animals were slaughtered. Sera was obtained after centrifugation of blood samples at 1,600 X *g* for 20 min, following storage at room temperature for approximately 5 h (to facilitate transport to the laboratory) and at 4˚C for 24 h; serum samples were submitted to the Clinical Pathology Laboratory, University Veterinary Hospital (UVH; University College Dublin, Ireland) for routine biochemistry panel; or frozen at -20˚C and stored. Whole blood (EDTA) samples were also submitted for complete blood counts (CBC) within 8 h of collection.

2.2 Biochemistry

Biochemistry panel included: creatine kinase (CK), total protein (TP), albumin (Alb), urea, asparate aminotransferase (AST), L-γ-glutamyltransferase (GGT), globulin, non esterified fatty acids (NEFA) and beta-hydroxybutarate (BHB). All biochemical parameters were determined using the Randox RX imola™ assay kits (Randox Laboratories Ltd., Co. Antrim, N. Ireland) and were run in-house. Daily quality control (QC) samples were run for each assay on the Randox RX imola™, and results for QC were only accepted if they fell within one standard deviation of their expected value. Only if QC samples met their criteria could assays then be run.

2.3 Complete blood counts (CBC)

Samples were analysed using the Abbott CELL-DYN® 3500R (Abbott Laboratories Ireland Ltd., Citywest Business Campus, Dublin 24, Ireland) veterinary package. The CELL-DYN®

3500R uses flow cytometry to count and identify blood cells. Daily QC samples were run on the analyser to determine the performance of the machine and only if QC fell within expected parameters could the machine be used.

2.4 Tissue collection and analysis

The entire liver and both kidneys were collected from each animal. Livers and right and left kidneys (including cortex and medulla) were sectioned and the samples were packed in polyethylene bags and kept on ice for transport to the laboratory. At the laboratory, samples were trimmed of fat and divided into sub-samples for either analysis or storage. All samples were frozen and stored at -20 ^{o}C until sent on ice to the Agri-Food and Applied Biosciences Institute, Food Chemistry Analytical unit (AFBI, Newforge Lane, Belfast; United Kingdom Accreditation Service (UKAS) for heavy metals analysis) for analysis of As, Cd, Pb and Hg.

2.5 Meta-analysis

Fourteen cattle (A to N), aged between 0.6 and 10.7 years, were submitted for post mortem between 09/04/03 and 14/06/05 to the Department of Agriculture, Fisheries and Food (DAF) Regional Veterinary Laboratory (RVL), Kilkenny from the index farm, and kidney Cd concentrations were measured in these animals.

Results from these fourteen animals (A to N) were combined with kidney Cd results from the nine cows (mean kidney Cd concentrations of the left and right kidney; Cow 1 to Cow 9) and the combined results reviewed together to examine the trend in kidney Cd concentrations relative to the age of the animal.

3 Results

3.1 Biochemistry and CBC

Biochemistry and CBC results for the nine cows are presented in Table 2.

3.2 Heavy metals

Arsenic, Cd, Pb and Hg results for the nine cows are presented in Table 3. Normal, high and toxic As, Cd, Pb and Hg concentrations in relation to animal health are presented in Table 4. Arsenic, Pb and Hg concentrations in livers and kidneys were within normal range for animal health purposes. Kidney Cd concentrations in six of the nine cows exceeded the normal range for animal health purposes (0.05-1.5 mg/kg), but were less than the high range.

Maximum concentrations of Pb in bovine offal for human consumption are 0.5 mg/kg, (EC No. 1881/2006). Lead concentrations exceed 0.5 mg/kg in the right kidney of cow 9. To date, maximum concentrations have not been set for As or Hg in bovine muscle or offal (FSAI, 2009). Maximum concentrations of Cd in bovine liver and kidney for human consumption are 0.5 and 1 mg/kg wet weight, respectively (EC No. 629/2008). Seven of the nine cows had kidney Cd concentrations exceeding 1.0 mg/kg. No livers of the nine cows exceeded 0.5 mg/kg Cd.

Table 2: Biochemistry and hematology results from nine cows, who spent between 5.1 to 13.2 years on the index farm, which were slaughtered in either April or August 2009 in order to collect their livers and kidneys for heavy metal analysis. Normal reference ranges and units of measurement are also presented.

Biochemistry	Cow 1	Cow 2	Cow 3	Cow 4	Cow 5	Cow 6	Cow 7	Cow 8	Cow 9	Reference range & units
Total protein (TP)	72.7	67	68.9	68.7	78.8	85.7	87.4	76.1	66.4	67-85 g/L
Urea	25.2	2	2.7	2.4	1.8	7	6.8	6.2	6.5	1.5-7.5 mmol/L
Creatine kinase (CK)	1521	61	45	40	18	118	130	94	11	0-200 U/L
Beta hydroxyl butrate (BHB)	0.25	0.24	0.616	0.23	0.19	0.44	0.35	0.53	1.94	0.1-1 mmol/L
Globulin	43.5	39.5	39.5	40.4	52	53.9	51.8	45.3	37.7	31-55 g/L
Albumin	29.2	27.5	29.4	28.3	26.8	31.8	35.6	30.8	28.7	29-39 g/L
L-γ-glutamyltransferase (GGT)	37	11	14	13	19	11	17	10	8	0-20 U/L
Asparate aminotransferase (AST)	296	31	42	42	29	51	44	46	15	0-65 U/L
Non esterified fatty acids (NEFA)	0.42	0.11	0.72	0.23	0.09	0.22	0.12	0.16	1.2	0-0.7 mmol/L
Complete blood count (CBC)										
White cell count (WBC)	1.84	7.51	8.41	6.9	6.97	9.59	12.39	16.08	3.33	5.6-14.31 $x10^9/L$
Red cell count (RBC)	6.87	5.56	5.78	6.48	5.75	6.19	6.23	6.69	5.43	5.37-10.63 $x10^{12}/L$
Whole blood heamoglobin (Hgb)	130	96	101	113	104	121	120	127	104	90-146 g/L
Packed cell volume (PCV)	0.34	0.24	0.26	0.29	0.26	0.33	0.32	0.34	0.27	0.21-0.37 l/L
Mean cell volume (MCV)	49.2	42.8	44.7	44.3	46.1	53.3	51.2	50.4	50.4	28-52 fl
Mean cell haemoglobin (MCH)	19	17.3	17.4	17.4	18	19.5	19.3	19	19.2	11.1-15.3 pg/ml
Mean cell haemoglobin concentration (MCHC)	386	405	390	392	390	366	377	377	380	330-420 g/l
Platelets (Plt)	113	372	334	581	330	321	178	299	408	100-800 $x10^9/L$
Mean platelet volume (MPV)	8.6	6.4	7.4	6.3	7.4	9.8	12.6	9.9	9.7	5-8 fl

Table 3: Liver and kidney arsenic (As), cadmium (Cd), mercury (Hg) and lead (Pb) concentrations (mg/kg wet weight) from nine cows, who spent between 5.1 to 13.2 years on the index farm, which were slaughtered in either April or August 2009 in order to collect their livers and kidneys for heavy metal analysis.

Animal	Slaughter date	Sample Type	As	Cd	Hg	Pb	Years on Index farm
Cow 1	09/04/2009	Liver	<0.007	0.136	<0.005	<0.07	13.1
		Left kidney	0.016	3.602	0.012	<0.07	
		Right kidney	0.02	4.279	0.014	<0.07	
Cow 2	15/04/2009	Liver	0.01	0.091	<0.005	<0.07	7.9
		Left kidney	0.014	2.092	<0.005	<0.07	
		Right kidney	0.024	2.136	<0.005	0.07	
Cow 3	15/04/2009	Liver	<0.007	0.21	<0.005	<0.07	5.1
		Left kidney	0.28	0.633	0.014	<0.07	
		Right kidney	0.28	0.699	0.016	0.08	
Cow 4	15/04/2009	Liver	<0.007	0.275	<0.005	0.09	12.9
		Left kidney	0.011	3.143	<0.005	0.11	
		Right kidney	0.011	3.107	<0.005	0.11	
Cow 5	15/04/2009	Liver	<0.007	0.14	0.005	<0.07	13.2
		Left kidney	0.23	2.776	0.008	0.09	
		Right kidney	0.019	3.042	0.008	0.09	
Cow 6	21/08/2009	Liver	0.012	0.242	<0.005	<0.07	9.9
		Left kidney	0.015	3.416	0.009	0.07	
		Right kidney	0.016	3.297	0.009	0.07	
Cow 7	21/08/2009	Liver	0.005	0.057	<0.005	<0.07	5.3
		Left kidney	0.031	0.478	0.014	0.17	
		Right kidney	0.035	0.48	0.014	0.16	
Cow 8	21/08/2009	Liver	0.011	0.121	<0.005	0.08	13.0
		Left kidney	0.021	2.993	0.024	0.1	
		Right kidney	0.023	2.856	0.026	0.13	
Cow 9	21/08/2009	Liver	0.023	0.09	<0.005	0.12	5.4
		Left kidney	0.02	1.074	0.013	0.1	
		Right kidney	0.024	0.95	0.013	0.9	

Table 4: Normal, high and toxic (chronic) concentrations on arsenic, cadmium, mercury and lead in bovine livers and kidneys in ppm (mg/kg) wet weight for animal health purposes. Table adapted from Puls, 1994.

	Normal	High	Toxic
Arsenic (As)			
Liver	0.004-0.4	1.0-50	7.0-100
Kidney	0.018-0.4	1.5-5.0	5.0-53
Cadmium (Cd)			
Liver	0.02-1.0	1.4-9	50-160
Kidney	0.05-1.5	5.0-36	100-250
Mercury (Hg)			
Liver	0.0007-0.06	2.0-40	2.0-40
Kidney	0.008-0.09	14-146	43-200
Lead (Pb)			
Liver	0.1-1.0	2.0-10	5.0-300
Kidney	0.2-2.0	3.0-20	5.0-700

3.3 Meta-analysis

Fourteen cattle (A to N), aged between 0.6 and 10.7 years, were submitted for post mortem between 09/04/03 and 14/06/05 to the Department of Agriculture, Fisheries and Food (DAF) Regional Veterinary Laboratory (RVL), Kilkenny and kidney Cd concentrations were measured in these animals. Two of the fourteen (14.3 %) and three of the fourteen (21.4 %) animals had kidney Cd concentrations above 1.5 and 1.0 mg/kg, respectively.

Results from these fourteen animals (A to N) were combined with kidney Cd results from the nine cows (mean kidney Cd concentrations of the left and right kidney; Cow 1 to Cow 9). Actual Cd results for all animals (n=23; A to N, and Cow 1 to Cow 9) are presented in Table 5 and a scatter plot with a fitted line in Figure 1.

When data was combined with results from the previous DAF investigation (DAFF, 2006), eight of the twenty three (37.8 %) and ten out of twenty three (or 43.5 %) of kidneys had Cd concentrations above 1.5 and 1 mg/kg, respectively.

Table 5: Kidney cadmium concentrations (mg/kg wet weight) of the 9 cows (Cows 1 to 9) from the index farm, who spent between 5.1 to 13.2 years on the index farm, which were slaughtered in either April or August 2009, and from 14 other animals (A-N), aged between 0.6 and 10.7 years, who were submitted for post mortem between 09/04/03 and 14/06/05 to the Regional Veterinary Laboratory (RVL), Kilkenny from the index farm.

Animal ID	Breed	Sex	DOB	Date Died	Time on index farm (years)	Cd, mg/kg
A	CH	M	22/03/04	02/06/05	0.46	0.196
B	CH	M	20/03/04	14/06/05	0.49	0.139
C	FR	F	01/07/04	20/02/05	0.64	0.472
D	FR	M	01/05/04	18/05/05	1.05	0.315
E	FR	M	20/02/04	05/05/05	1.14	0.694
F	CHx	M	22/02/02	04/05/03	1.19	0.103
G	CHX	F	07/06/00	09/04/03	2.84	0.664
H	CHX	F	27/05/00	09/04/03	2.87	0.623
I	CHX	F	20/05/00	09/04/03	2.89	0.391
J	CHx	F	03/04/00	09/04/03	3.01	0.264
K	FR	F	26/02/99	12/07/05	3.51	0.926
Cow 3	FR	F	17/03/04	15/04/09	5.08	0.666
Cow 7	FR	F	19/12/02	21/08/09	5.35	0.479
Cow 9	FR	F	11/03/04	21/08/09	5.45	1.012
Cow 2	FR	F	21/05/01	15/04/09	7.90	2.114
L	FR	F	01/01/95	15/07/03	8.53	1.91
Cow 6	Ch	F	15/05/95	21/08/09	9.92	3.356
M	CH	F	04/04/95	08/04/05	10.01	4.872
O	FR	F	04/05/94	11/01/05	10.69	1.314
Cow 4	AA	F	30/05/96	15/04/09	12.88	3.125
Cow 8	FR	F	15/03/96	21/08/09	12.99	2.925
Cow 1	FR	F	15/03/96	07/04/09	13.06	3.941
Cow 5	FR	F	02/02/96	15/04/09	13.20	2.909

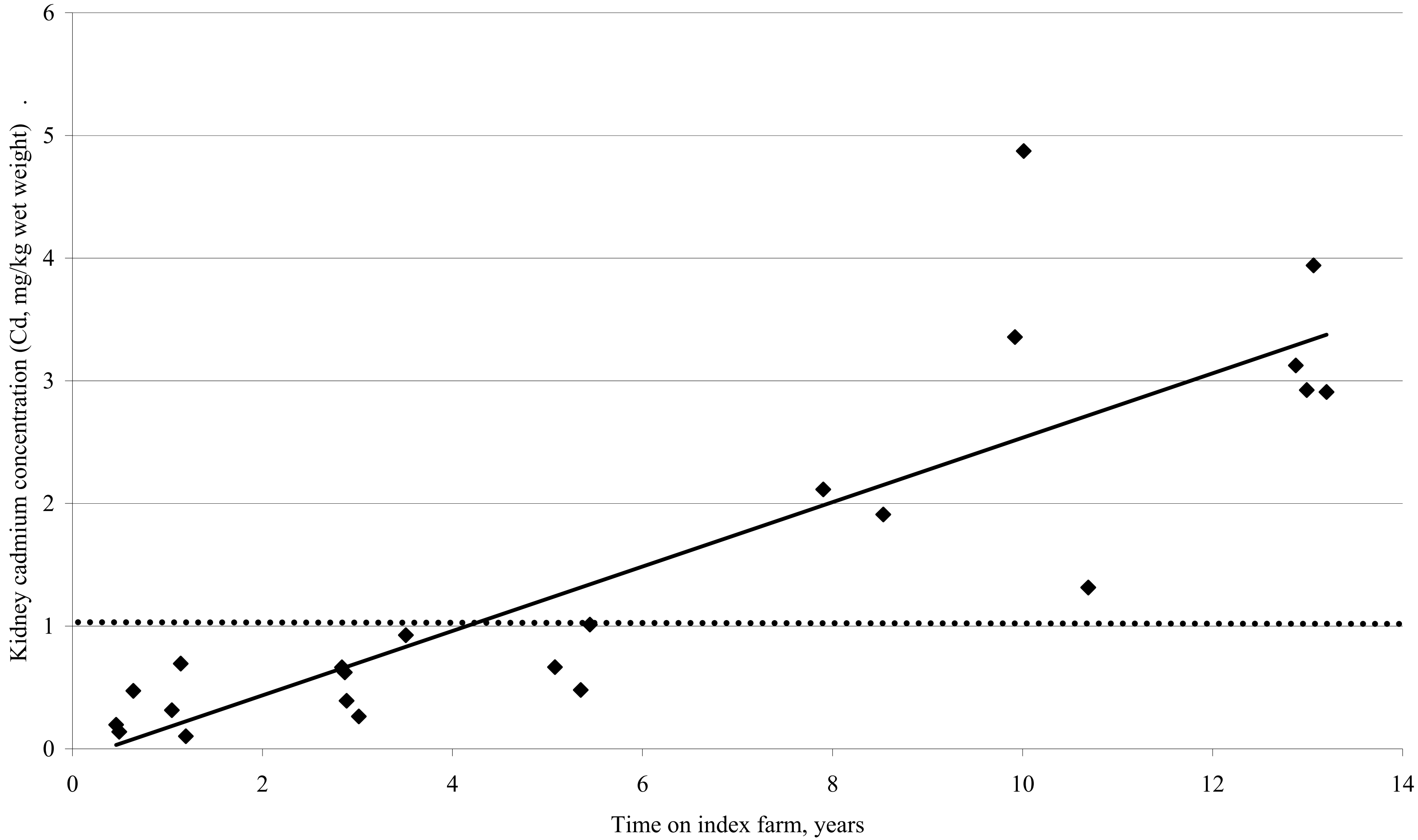

Figure 1: Scatter plot (with fitted line) of kidney cadmium concentrations (mg/kg fresh weight) of the 9 cows (Cows 1 to 9) from the index farm, who spent between 5.1 to 13.2 years on the index farm, which were slaughtered in either April or August 2009, and from 14 other animals (A-N), aged between 0.6 and 10.7 years, who were submitted for post mortem between 09/04/03 and 14/06/05 to the Regional Veterinary Laboratory (RVL), Kilkenny from the index farm.. Maximum permissible cadmium concentration in bovine kidneys for human consumption is 1 mg/kg fresh weight (EC No 629/2008).

4 Discussion

The kidney of food animals is a major source of Cd in the human diet (FSAI, 2009), and ML of Cd allowed in bovine muscle, livers and kidneys for human consumption are set at 0.05, 0.5 and 1.0 mg/kg fresh weight, respectively. Results from the current study revealed a range of kidney Cd concentrations between 0.103 and 4.872 mg/kg fresh weight (Table 3; Figure 1), with ten of the twenty three (43.5 %) kidney results above the ML for human consumption. These ten animals were cows that had spent between 5.5 and 13.2 years on the index farm. The poor efficiency of cellular export systems explains the long residence time of Cd the kidneys (EFSA, 2009), resulting in older animals having higher kidney Cd concentrations (Nriagu *et al.,* 2009) even if the concentrations in their diets and water are consistently low (NRC, 2005). Little or no time series studies, however, have examined the specific accumulation of Cd in bovine kidneys overtime so the normal rate of Cd accumulation in cattle is poorly understood, with the majority of data on Cd concentrations in cattle derived from samples from animals submitted for slaughter. Cattle from north eastern Poland aged between 8 and 12 years had kidney cortex Cd concentrations between 0.68 and 2.0 mg/kg wet weight. Free ranging Bison from the same area, aged 7 to 12 years, had kidney cortex concentrations between 1.95 and 3.52 mg/kg wet weight (Wlostowski *et al.,* 2006). Similarly in NW Spain, cows between 3 and 16 years had kidney Cd concentrations between 0.0298 and 3.393 mg/kg wet weight (López Alonso *et al.,* 2004). Jamaica, where soil Cd concentrations are high, cattle kidney Cd concentrations between 0.012 and 117 mg/kg have been reported (Nriagu *et al.,* 2009). From an animal health perspective, kidney Cd concentrations between 0.05-1.5 ppm wet weight are described as normal, 5.0-36 ppm wet weight as high and 100-250 ppm as toxic chronic (Puls, 1994). The gap in the description between 'normal' and 'high' kidney Cd concentrations, i.e. values that lie between 1.5 and 5.0 ppm wet weight, leave some difficulty in determining the significance, if any, of the kidney Cd concentrations reported here on animal health. Fisk *et al.,* (2005) describes the threshold concentration for the potential to cause renal dysfunction as between >50-400 mg/kg, concentrations well above those reported here.

In Ireland, DAFF Central Meat Control Laboratory currently measure Cd in muscle samples from animals (http://www.agriculture.gov.ie/), and the Public Analyst Laboratories (PALs) do not carry out any routine testing for Cd in beef meat or offal. With this in mind, it was not possible to compare the results of this study with national average kidney Cd concentrations in Ireland, however, comparison is possible with results complied following meta-analysis by the European Food Safety Authority (EFSA).

The European Food Safety Authority Cd working group carried out a meta-analysis of reported results from different food groups from 18 EU member states (including Ireland), Iceland, Australia and three commercial organisations for the years 2003-2007. The initial data set included 187,143 results, however, prior to analysis clusters of very high values were noted that suggested local high contamination issues or more likely errors in data transmission. Thus, to better reflect the situation in the general population, data below the 1st percentile and above the 99th percentile for each category were censored; of the 187,143 total results received, 2,250 (1.2 %) were excluded as statistical outliers, while 47,691 were excluded for a other reasons. The final data set included 137,202 results. Of the twenty eight different groups examined, category 10B1 provided a statistical description of Cd concentrations in bovine, sheep, pig, poultry and horse livers (n = 10,534); median, mean, 95 % percentile and maximum liver Cd concentrations were 0.0430, 0.1160±0.306, 0.36 and 3.6 mg/kg. Category 10B2 provided a statistical description of Cd concentrations in bovine, sheep, pig, poultry and horse kidneys (n = 4586): median, mean, 95 % percentile and maximum kidney Cd concentrations were 0.152, 0.2009, 0.5743 and 1.73 mg/kg. Of these liver and kidney samples, 3.7 % of livers and 0.96 % of kidneys exceeded ML (0.50 and 1.0 mg/kg for livers and kidneys, respectively). In the current study, the combined kidney data resulted in mean, median, 95 percentile and maximum kidney Cd concentrations of 1.35, 1.0, 4.03 and 4.87 mg/kg, all results were much higher than those reported by EFSA. Although the ages of animals cannot be established from the EFSA results, it would be expected that our results should in someway reflect the European norm. Similarly, a review of liver and kidney Cd concentration from published literature is presented in Table 5. While this list is not exhaustive, it was arranged to give an overview of naturally occurring Cd concentrations in livers and kidneys of cattle in various parts of the world and with a few exception kidney Cd concentrations are lower than those reported here.

Until recently, the tolerable weekly intake (TWI) of Cd for humans was set at 7 µg/kg bodyweight (set by the Joint FAO/WHO Expert Committee on Food Additives), however, in March 2009 this level was revised downwards by the EFSA Panel on contaminants in the food chain to a TWI of 2.5 µg/kg bodyweight, based on the analysis of national and EU wide dietary consumption surveys where average and high level Cd exposure was defined at 2.3 and 3.0 µg/kg bodyweight. In light of the current revisions in relation to Cd and human health, it will be of interest to see if Cd levels are also revised downwards with respect to animal health in the future.

Conclusion

Kidney Cd concentrations were associated with both increasing age and time spent on the index farm, suggesting that animals were most likely exposed to a low concentration of Cd either continuously or intermittently over a long period of time. Neither the source nor route of Cd exposure has been determined. As yet, a national monitoring programme for Cd in bovine livers and kidneys in Ireland has not been established. Therefore, we cannot determine if the concentrations reported in cattle from the index farm are similar to elsewhere in Ireland. Based on current knowledge, exposure at this level is not associated with adverse effects in terms of animal health or performance.

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