

Cattle tissues as a source of cadmium for consumers

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Abstract

The aim of this study was to re-evaluate the analytical results and time trends of the content of cadmium in muscle, liver, and kidney samples of young bovine animals and cows slaughtered in the Czech Republic during the years 1993–2010, and to estimate the total dietary exposure for the entire population aged 4–90 years and specifically, for children at the age of four to six years. Analyses showed that the arithmetic means of cadmium concentration in cow kidney and liver are higher than in young bovine ($P < 0.0001$), but not in muscle ($P = 0.227$). The mean cadmium concentration in cow kidney ($0.595 \text{ mg} \cdot \text{kg}^{-1}$) was twice as high as in young bovine kidney ($0.285 \text{ mg} \cdot \text{kg}^{-1}$) for the entire studied period. The mean concentration of cadmium in cow liver ($0.113 \text{ mg} \cdot \text{kg}^{-1}$) was higher compared to young bovine liver ($0.078 \text{ mg} \cdot \text{kg}^{-1}$). The mean concentration of cadmium in cow muscle ($0.008 \text{ mg} \cdot \text{kg}^{-1}$) was comparable with young bovine muscle ($0.006 \text{ mg} \cdot \text{kg}^{-1}$). The evaluation of time trends showed increasing concentrations of cadmium for cow (increasing slaughtering age) and young bovine kidney and decreasing concentrations for cow and young bovine muscle, but no significant change for liver. The estimated Cd burden of the entire population is worthy of attention (10% were over the tolerable dose of $2.5 \mu\text{g} \cdot \text{kg}^{-1}$ body weight and week). For more than 50% of four to six-year-old children the burden exceeded the tolerable weekly intake. The contribution of food belonging to the group of meat and meat products, including cattle tissues, to usual cadmium exposure is only 5%. Nevertheless, the food safety recommendation is not to consume cow kidney as food.

Food, kidney, contamination, heavy metals, trend, exposure

Cadmium (Cd) is a toxic metal occurring in the environment from natural sources and also as a consequence of anthropogenic activities related to industry and agriculture. Many legislative control measures have been taken to decrease the contamination of foodstuff in Europe since the 1970s and this regulatory effort continues until the present time when new emerging toxicological data were collected (EFSA 2011). For a non-smoking person who is not occupationally exposed to Cd, foodstuffs represent the source of up to 90% of his or her total intake of Cd (EFSA 2009). Smokers have $\times 4$ – 5 higher Cd concentrations in the blood and $\times 2$ – 3 higher Cd contents in the kidneys (Dallongewille et al. 1998). The absorption of Cd through the human digestive tract is relatively low (3–5%). Cadmium accumulated in the kidneys and liver has a very long half-time of excretion from the human body, in the range of 10–30 years (Kjellström and Nordberg 1978; EFSA 2009). Cadmium is primarily toxic for the kidneys. Exposure to Cd is associated with many other effects such as nephrotoxic, neurotoxic, carcinogenic, genotoxic, and teratogenic effects, the development of osteoporosis or osteomalacia, damage to the endocrine system and reproductive functions (EFSA 2009). It is also classified as a group 1 human carcinogen (IARC 2015). In 2009, EFSA re-evaluated the existing Tolerable Weekly Intake (TWI) of Cd and set it to $2.5 \mu\text{g} \cdot \text{kg}^{-1}$ body weight (EFSA 2009, 2011). Regulation (EC) No. 1881/2006 establishes the maximum limit (ML) for Cd content in meat (excluding offal) of

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bovine animals, sheep, porcine animals and poultry as follows: 0.050 mg·kg⁻¹ wet weight; for liver: 0.50 mg·kg⁻¹ wet weight; and for kidney: 1.0 mg·kg⁻¹ wet weight.

The aim of this study was to re-evaluate the recent analytical results and time trends of the content of Cd in muscle, liver and kidney samples of young bovine animals and cows slaughtered in the Czech Republic during the years of 1993–2010, and to estimate consequences for the total dietary exposure of the whole population of consumers and specifically, for younger children.

Materials and Methods

Sampling of cattle tissues and market food samples

Samples of bovine meat and offal were collected by the Czech State Veterinary Administration (SVA), within the implementation of the national plan for the monitoring of residues and contaminants in accordance with the Council Directive 96/23/EC (1996) and Commission Decision 97/747/EC (1997) in the years 1993–2010. The sampling methodology was previously described by Drápal et al. (2012).

Market food samples representing a common Czech diet were collected in all country regions as part of the national Total Diet Study during the years 2004–2011. The sampling methodology was described by Ruprich (2014).

Analytical methods

Samples of cattle tissues were analysed by SVA laboratories. Homogenized samples of biological material were mineralized in a microwave device (Ethos plus, Milestone) after the addition of concentrated nitric acid and hydrogen peroxide. Determination of cadmium was carried out using graphite furnace atomic absorption spectrometry with Zeeman correction (GF-AAS) (Varian 1985, 1988), and in some cases by using inductively coupled plasma mass spectrometry (ICP-MS) (Varian 2004). The levels of quantification (LOQ) were 0.01 mg·kg⁻¹ for liver and kidney, and 0.005 mg·kg⁻¹ for muscle. The results were provided in the Standard sample description for food and feed format developed by EFSA (2010).

Analyses of market food at the laboratories of the National Institute of Public Health used the microwave wet digestion in a closed system (Ethos plus, Milestone) using nitric acid and hydrogen peroxide. Then, evaporation (Start D, Milestone) was used too, for mineralization of food samples and GF-AAS with Zeeman correction for determination of Cd (Perkin-Elmer 1991, 1999). The range of LOQs was 0.0001–0.002 mg·kg⁻¹ of various food samples. All methods employed were accredited according to the European Standard EN ISO/IEC 17025.

Statistical analyses

Statistical evaluation of trends was performed using the linear regression analysis. *T*-test for independent samples was used to analyse the difference between observed concentrations of Cd for both cattle categories. A probability lower than 0.05 ($P < 0.05$) was considered as significant. Regression analyses and *t*-test were performed using the STATISTICA 12 software (StatSoft 2013).

Exposure assessment

Exposure assessment was done by the Monte Carlo Risk Assessment modelling software (MCRA), version 8.0 (RIVM, NL). Food consumption datasets, used from the Individual Food Consumption national study SISP04 (Ruprich et al. 2006), were reorganized into 20 Level 1 food groups, according to the FoodEx1 EFSA hierarchic classification system. Food concentration data (3520 analytical results) for Cd came from the national Total Diet Study (Ruprich 2014). The data represent dietary sources from analyses performed during the time period of 2004–2011. For evaluation of total exposure doses of Cd the following MCRA calculation parameters were used: Logistic-Normal Normal (LNN) exposure model, uncertainty analysis based on 10000 MC simulations, 100 resampling cycles, replacement of values < LOQ by 50% of LOQ (middle bound).

Results

The analytical results from SVA (9729 individual samples) were organized according to tissue, year of collection, and category of slaughtered animals. The means and range of cadmium content in bovine tissues (mg·kg⁻¹ wet weight) in the Czech Republic during the years 1993–2010 are summarized in Table 1. Statistical testing (*t*-test) showed significant differences between the observed mean concentrations for both studied cattle categories for samples of kidney ($P = 0.000004$) and liver ($P < 0.000001$), but not for muscle ($P = 0.2265$). Evaluation of trends showed increasing concentrations of Cd in cow and young bovine kidney. The result of the analysis is presented in Fig. 1. The model for cow

Table 1. The cadmium content in bovine tissues in the Czech Republic in the years 1993–2010 (mg·kg⁻¹ wet weight) (for calculation of mean and range values < LOQ were replaced by 50% of LOQ value = middle bound values)

Tissue	Year	Cows (> 2 years) mg·kg ⁻¹ wet weight			Young bovine (> 6 months < 2 years) mg·kg ⁻¹ wet weight				
		n	Mean	Range (min)	Range (max)	n	Mean	Range (min)	Range (max)
Muscle	1993-1994	367	0.008	0.003	0.070	606	0.008	0.003	0.102
	1995-1996	222	0.008	0.003	0.275	280	0.008	0.003	0.392
	1997-1998	152	0.007	0.003	0.050	143	0.008	0.003	0.060
	1999-2000	186	0.008	0.003	0.080	167	0.008	0.003	0.394
	2001-2002	228	0.007	0.003	0.039	235	0.006	0.003	0.028
	2003-2004	180	0.010	0.003	0.640	197	0.005	0.003	0.049
	2005-2006	77	0.016	0.003	0.781	74	0.004	0.003	0.021
	2007-2008	55	0.003	0.002	0.010	23	0.002	0.002	0.007
	2009-2010	49	0.002	0.003	0.005	31	0.002	0.003	0.003
Total	1516		0.003	0.781	1756		0.003	0.394	
Liver	1993-1994	384	0.111	0.005	0.930	593	0.085	0.005	2.000
	1995-1996	225	0.111	0.005	0.920	275	0.071	0.005	0.690
	1997-1998	138	0.109	0.005	0.420	139	0.081	0.013	0.390
	1999-2000	185	0.127	0.020	3.348	159	0.079	0.020	0.420
	2001-2002	229	0.099	0.020	0.504	237	0.074	0.008	0.330
	2003-2004	165	0.099	0.018	0.547	194	0.074	0.003	0.436
	2005-2006	75	0.122	0.005	0.400	75	0.079	0.015	0.280
	2007-2008	53	0.116	0.012	0.300	27	0.081	0.027	0.232
	2009-2010	50	0.119	0.026	0.510	31	0.079	0.017	0.220
Total	1504		0.005	3.348	1730		0.005	2.000	
Kidney	1993-1994	388	0.454	0.005	2.980	593	0.264	0.005	1.559
	1995-1996	215	0.471	0.005	2.400	272	0.257	0.005	1.670
	1997-1998	135	0.513	0.020	1.910	137	0.306	0.055	1.340
	1999-2000	183	0.584	0.020	5.500	157	0.270	0.005	1.160
	2001-2002	227	0.521	0.048	2.895	235	0.271	0.020	1.760
	2003-2004	169	0.557	0.087	2.895	203	0.277	0.040	1.110
	2005-2006	79	0.636	0.050	3.500	73	0.319	0.050	1.880
	2007-2008	52	0.816	0.199	2.020	24	0.289	0.012	1.000
	2009-2010	50	0.799	0.111	2.240	31	0.308	0.042	1.200
Total	1498		0.005	5.500	1725		0.005	1.880	

kidney ($y = -3.3274 + 0.022 \cdot x$) explains 81% of the data variability. The models for young bovine kidney ($y = -4.8013 + 0.0025 \cdot x$) explain 40% of the data variability. Evaluation of trends for cow and young bovine muscle is presented in Fig. 2. The model for cow muscle ($y = 0.687 - 0.0003 \cdot x$) accounts for 49% of the data variability. The models for young bovine muscle ($y = 0.8935 - 0.0004 \cdot x$) explain 89% of the data variability. The data point for cows and year 2007/2008 was considered as an outlier. Linear regression showed that mean concentrations of Cd in cow and young bovine liver are not dependent on time.

The distribution of total Cd dietary exposure doses were studied for the entire Czech population (aged 4–90) and specifically, for younger children (four to six years of age). Table 2 presents mean exposure doses of Cd estimated for the Czech population aged 4–90 and for four to six-year-old children and uncertainty bounds (2.5–97.5 percent) of exposure estimates.

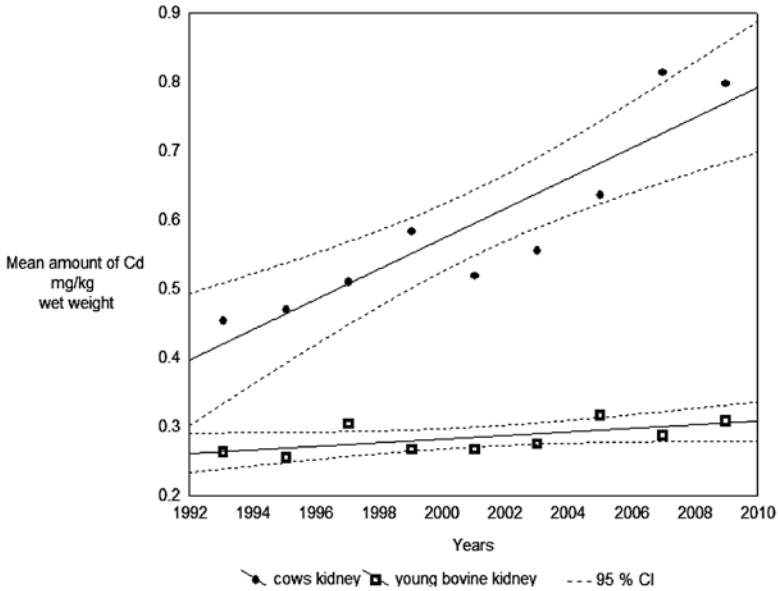


Fig. 1. Trends in the observed mean Cd concentrations in $\text{mg}\cdot\text{kg}^{-1}$ wet weight in cow and young bovine kidney during the time period of 1993–2010. The figure shows regression lines with 95% confidence interval (CI) of estimated models.

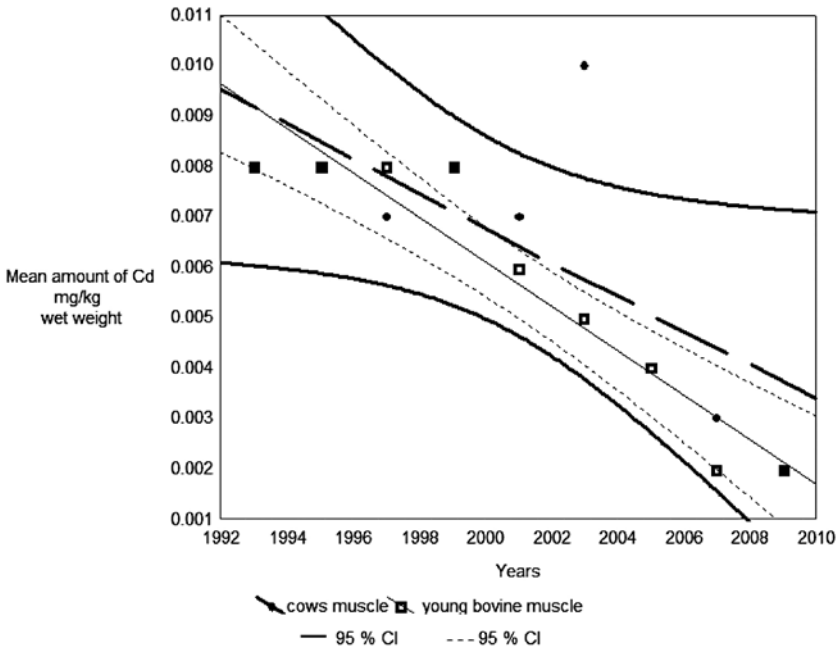


Fig. 2. Trends in the observed mean Cd concentrations in $\text{mg}\cdot\text{kg}^{-1}$ wet weight in cow and young bovine muscle during the time period of 1993–2010. The figure shows regression lines with 95% confidence interval (CI) of estimated models. The point from year 2007/2008 in dataset for cows can be considered as an outlier.

Table 2. Exposure doses of Cd estimated for the Czech population 4–90 years old and young children four to six years old, and uncertainty bounds (2.5–97.5 percent). TWI EFSA (2011) is 2.5 $\mu\text{g}\cdot\text{kg}^{-1}$ of body weight and week.

Percentage of population	Exposure dose (mg/kg b.w./week)	Lower bound (p2.5)	Upper bound (p97.5) dose	Percentage of reference (approx.)
Population 4–90 years				
50	1.40	1.32	1.48	60
90	2.49	2.35	2.64	100
95	2.96	2.76	3.13	120
99	3.98	3.72	4.25	160
Young children 4–6 years				
50	3.06	2.79	3.27	120
90	4.29	3.83	4.76	170
95	4.74	4.14	5.35	190
99	5.63	4.79	6.48	230

Discussion

The results included in Table 1 and Figs 1 and 2 support the hypothesis that arithmetic means of Cd concentration in muscle and kidney of both groups of bovine animals were changing during the studied period of time. It was not proven that the Cd content in cow and young bovine liver had changed in time. The mean concentration of Cd in cow kidney ($0.595\text{ mg}\cdot\text{kg}^{-1}$) was twice as high as the mean concentration of Cd in young bovine kidney ($0.285\text{ mg}\cdot\text{kg}^{-1}$) for the entire studied period. This fact was already described and logically explained by the tendency of Cd to cumulate in the kidneys (Drápal et al. 2012). The increase in Cd concentration in cow kidney is most probably connected with the age of animals as documented e.g. by Pechová et al. (1998) who confirmed the highly significant relation between the age of cows and Cd content in kidney. Unfortunately, data describing the mean age of cows slaughtered in the Czech Republic are not fully available for the entire examined period, but it is apparent that it was growing with time up to about 72 months. The decrease of concentrations that was observed in muscle tissue for both groups of bovine animals can also be related to methodological improvements and primary reporting left censored data ($< \text{LOQ}$) from laboratories over the entire time period. The average concentration of Cd in cow muscle ($0.008\text{ mg}\cdot\text{kg}^{-1}$) was comparable with young bovine muscle ($0.006\text{ mg}\cdot\text{kg}^{-1}$). The average concentration of Cd in cow liver ($0.113\text{ mg}\cdot\text{kg}^{-1}$) was higher in comparison with young bovine liver ($0.078\text{ mg}\cdot\text{kg}^{-1}$). Similar results were reported by Doganoc (1996) who examined Cd concentrations in several hundreds of bovine animals for slaughter and detected the following values: $0.004\text{ mg}\cdot\text{kg}^{-1}$ meat, $0.094\text{ mg}\cdot\text{kg}^{-1}$ liver, and $0.350\text{ mg}\cdot\text{kg}^{-1}$ kidney. Niemi et al. (1991) detected the following Cd content: $0.001\text{ mg}\cdot\text{kg}^{-1}$ meat, $0.061\text{ mg}\cdot\text{kg}^{-1}$ liver, and $0.350\text{ mg}\cdot\text{kg}^{-1}$ kidney.

The experimental question posed was what these findings meant for food consumers. The long-term dietary exposure monitoring program for the Czech population (Total Diet Study) regularly describes the most important exposure sources of Cd (Ruprich 2014). The three most important sources of common exposure of the population aged between 4–90 years are (1) grains and grain-based products (39%), (2) starchy roots and tubers (16%), and (3) vegetables and vegetable products (16%). The contribution of meat and meat products (including offal) is only about 6%. While the estimated burden of the entire population is worthy of attention (10% is over the TWI EFSA), for younger children of

four to six years of age this burden is even more critical. More than 50% of children are exposed to doses equal to TWI, 5% of children are exposed to doses at 190% TWI EFSA. The three most significant sources of usual exposure of children are (1) grains and grain-based products (38%), (2) vegetables and vegetable products (14%), and (3) starchy roots and tubers (14%). The contribution of meat and meat products (including offal) is only about 4%, while e.g. milk and dairy products could potentially represent more than 8% of usual exposure. This analysis confirmed the assumption that although the Cd concentration in some cattle tissues is growing up, total usual exposure from these tissues is still relatively low. However, due to emerging total exposure doses, the food safety recommendation is not to use cow kidney as food, especially for younger children. Even as small a portion as 70 g of cow kidney consumed within one week, with about 0.8 mg Cd·kg⁻¹, can pose a certain health risk.

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