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Full Length Research Paper

Elevated Iron Concentrations in Drinking Water: A Potential Health Risk

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Abstract

Iron is an important element for animals and humans, especially needed in hemoglobin for oxygen transport to the cells. Iron is mainly lost through cell defoliation and desquamation of skin cells, but in very small amounts. Hundreds of cows and calves died after ample and bloody diarrhea, followed by loss of appetite and weight, apathy and paralysis on a Swedish farm. Water analysis of the drilled well indicated water rich in health bringing minerals such as calcium, magnesium and bicarbonate. However, iron concentration was elevated, 1.3 mg/L. Autopsy of four calves showed inflamed gastrointestinal tract. Men from the same area reported similar symptoms. Hair of the men was high in iron, and the drinking water similarly revealed a high iron concentration > 1mg/L. Problems with especially weight loss and diarrhea in horses were also reported, but from another area in Sweden. People and cattle living on this farm had similar symptoms. Well water iron concentration was 1.0-5.5 mg/L, as tested through the years. Hair of horses showed elevated iron. Microbiologically all these waters were without notes. Iron in drinking water >1 mg/L seems to be a health risk to humans, cattle and horses.

Keywords: Iron, Drinking Water, Diarrhea, Hemochromatosis, Humans, Cattle, Horses.

INTRODUCTION

Fe is essential to animals and humans. The recommended dietary allowance (RDA) is about 15 mg for adult women and 9 mg for adult men. Pregnant women need more. The human body stores 3 to 5 g of iron. About two thirds of this amount is bound in hemoglobin, and 10% in myoglobin and in iron-containing enzymes. The rest is stored as ferritin and hemosiderin in the liver. Transferrin in the blood plasma transports iron to the cells. There are two forms of dietary iron: heme and nonheme. Heme iron is derived from hemoglobin, and found in animal foods that originally contained hemoglobin, such as red meats, fish and poultry. Your body most readily absorbs iron from heme sources. Nonheme iron is from plant sources (Berne and Levy, 2006).

Iron is absorbed as Fe^{2+}, since iron in that form does not form complexes to the same extent as Fe^{3+}, and thus remains in the ionic form. The absorption takes place in the upper part of the small intestine, and is transferred from the mucosal cells to the plasma where it binds in the form of Fe^{3+} to transferrin for further transport to the cells. Absorption is generally about 2 to 15%, while the daily loss of iron in adults is small (1 mg/day) and due mainly to cell exfoliation. The remainder is lost through desquamation of skin cells. In adult females there is an additional iron loss of about 15–70 mg each month in menstrual blood (WHO, 2008). Individuals with a high iron status normally absorb proportionally less Fe (EMEA, 2014). Milk, cheese, and high intake of calcium, cobalt and Vitamin D may depress iron intake considerably. On the other hand iron absorption is increased by increased secretion of hydrochloric acid in the stomach, causing low pH, and thus increasing the solubility of Fe-complexes (EMEA, 2014). Fe^{2+} may be transformed into Fe^{3+} and vice versa in the intestines (NRC, 1980). Vitamin C, ascorbic acid and hydrochloric acid, reduces Fe^{3+} to Fe^{2+}, which is more readily absorbed (EMEA, 2014; NRC, 1980; Haug et al., 1998). One suggestion for the chemical equation describing the transformation of Fe^{2+} into Fe^{3+}, and vice versa is as follows:

Fe^{3+} + ascorbic acid (probably also hydrochloric acid, lactic acid and citric acid) ↔ Fe^{2+}

Thus, Fe^{2+} can be oxidized to Fe^{3+} while forming acids, thereby causing acidosis and Fe^{3+} may be reduced to Fe^{2+} in an acid environment. Iron in the body can be detected in hair (Young-Sang et al., 2011; Rosborg, 2003).

Acute iron toxicity in humans is generally caused by the intake of iron-containing medicines and supplements, and most often occurs in children. Toxicity is manifested by vomiting. Vomits may be bloody owing to ulceration of the gastrointestinal tract, and stools may be black. This may be followed by lethargy, restlessness, hematemesis, abdominal pain and signs of shock, metabolic acidosis, liver damage, and a grey tone to the skin (Bergman et al., 1998). Late effects may include renal failure and hepatic cirrhosis. The mechanism of the toxicity is thought to begin with acute mucosal cell damage, as a direct corrosive effect of iron on tissue (Klaassen et al., 1996). Agarwal et al. (2005) state that transition metal ions, particularly iron, are involved in the generation of the highly reactive ·OH radical. The radical stimulates lipid peroxidation. Lack of treatment by chelating agents such as calcium and magnesium, or phlebotomy, can result in cirrhosis of the liver, hepatocellular carcinoma, myocardial pathology, and damage to the pancreatic function (Bowman and Russell, 2006). Magnesium hydroxide antacids (5 mg $Mg(OH)_2$ per gram of elemental iron ingested) decrease serum iron concentrations following a simulated overdose (NLM, 2014).

A major cause of chronic iron toxicity is hereditary hemochromatosis due to abnormal absorption of iron from the gastrointestinal tract. One in 200 - 400 individuals of Anglo-Saxon ancestry are affected. This has been associated with a lack of control of the iron flux across the enterocytes (Bowman and Russell, 2006).

Normally natural concentrations of iron in ground water are 0.01-1 mg/L. The concentration is lowest if the pH is about 6-7, but higher in more acid as well as in alkaline water (Aastrup et al., 1995). High concentrations give rise to rusty discoloring of cloths and sanitation facilities. The appearance of such staining, concentration exceeding ~ 0.2 mg/L, prompts consumers to install iron or iron/manganese filters, in order to avoid further stains on cloths, sinks and bathtubs. There is no health based guideline value (WHO, 1998; EU, 1998). The EU chemical and physical standard is 0.2 mg/L, and the WHO standard is 0.3 mg/L. In the United States 0.3 mg/L is included in the secondary drinking water regulation, due to aesthetic effects; "rusty color; sediment; metallic taste; reddish or orange staining" (US EPA, 2014).

The aim of the study was to investigate the causes of cattle, horses and men showing disturbed intestines through especially analysis of mineral elements in drinking water and hair

Cows and humans were investigated parallel since the well waters suspected to be cause of the problems were adjacent. Horses were situated around 600 km away, but suffered from the same symptoms.

Hypothesis: Drinking water with iron concentrations above 1 mg/L, or even 0.2 mg/L, may be harmful for cattle, horses and humans. Safe water should not have an iron level above 0.2 mg/L, suggested guideline value.

MATERIAL AND METHODS

Case one (cattle): A farmer in southern Sweden was found guilty of causing the death of about 100 cows and 500 calves during a period of 20 years. The symptoms were bloody diarrhea, loss of appetite, teeth grinding, weight loss, apathy, paralyses and finally death. Extensive drinking water analysis was performed in 2002, and hair nutrient analysis was conducted on one of the dead calves, autopsy protocols were collected for 4 calves.

Case two (men): Two men were suffering from diarrhea/constipation, loss of weight and additional symptoms that were similar to the symptoms of cows and calves. The men were interviewed about their specific symptoms, the time at which their symptoms debut, their environment, food habits and intake of medicines and drugs. Drinking water analyses and hair nutrient analyses were performed.

Case three (horses): Weight loss, diarrhea and additional symptoms were reported on horses in 2008, since the problems at that time had escalated, but existed since 2003. People living on the farm were unhealthy as well. Hair analyses were performed on people and horses and the drinking water was analyzed.

Water sampling and analysis: A sample of 250 mL of water was taken after about half a minute of flushing, from the tap used by objects at random times of day. To avoid air bubbles, all acid-washed polythene bottles were filled to the top. No filtering of the water took place before the samples were sent to the laboratory for analysis. Twenty ml of the samples were analyzed by ICP-AES or ICP-MS, after shaking and the addition of 5 ml concentrated HNO_3 (super pure) and boiling for 20 minutes at 120 °C (autoclave) (e-mail communication Bo Olsson, EUROFINS). A sample of 50 ml, no addition of acid, was used for analysis of anions.

Hair sampling and analysis: For humans, untreated scalp hair was used, i.e. not permed, dyed or bleached. The hair was also free of all gels, oils and hair creams prior to sample collection. High grade stainless steel scissors were used to cut the hair. The proximal portion (one and one-half inches closest to the root) was retained, and the weight was approximately 125 milligrams. Animal hair was cut from the mane (horses) and from the forehead (calves). The hair was placed in a clean hair specimen envelope provided by the laboratory, and sent for analysis. Trace Elements Incorporated (TEI) is a licensed and certified clinical laboratory that undergoes regular inspections by the

Clinical Laboratory Division of the Department of Health and Human Services, HCFA. TEI uses ICP-Mass Spectrometry (Sciex Elan 6100 and 9000 models) for all trace element determinations, following the microwave temperature-controlled digestion technique (CEM Mars 5 Plus). Trace Elements conducts daily, weekly and monthly QA/QC studies to confirm and validate all aspects of test methodology, including precision, accuracy and verifiable detection limits (TEI, 2014).

Water analyses included pH, HCO_3, TOC, Ca, Mg, Na, K, Fe, Mn, Cu, Al, NO_3, NO_2, NH_4, F, SO_4, PO_4, and the micro elements Ag, As, B, Ba, Be, Cd, Co, Cr, Li, Mo, Ni, Pb, Rb, Se, Si, Sn, Sr, Ti, U, V, and Zn.

Hair nutrient analyses included the nutrients Ca, Mg, Na, K, Cu. Zn, P, Fe, Mn, Cr, Se, B, Co, Mo, and S, the potentially toxic elements Sb, U, As, Be, Hg, Cd, Pb, Al, and also the elements Ge, Ba, Bi, Rb, Li, Ni, Pt, Tl, V, Sr, Sn, Ti, W and Zr.

RESULTS

Cattle at a farm in south Sweden: In 1982 a farmer drilled a well with a depth of 80 m, since the old dug well could not provide the family and cattle with enough drinking water during dry periods. There were generally about 200 cows on the farm at the same time. From 1982 to 2002, about 100 cows and 500 calves died after bloody diarrhea, loss of appetite, teeth grinding, trembling, mooing, convulsions, weight loss, apathy and paralyses. Cows consumed around 100 L of water per day. The cows that survived were thin. Hay and concentrate was analyzed and the results did not cause complaints. Calves died shortly after they were taken from the cows. The cows generally suckled their calves for 4 days, and then the calves were served dry milk prepared from the drilled well water. Calves consumed 6-7 L of the well water with dry milk powder in it. In periods when the cows received mineral rich rest products from a sugar mill, or magnesium supplements, they recovered. In addition, cows in general yielded less milk than expected during these years. Throughout this entire period the farmer searched for an explanation to the problems in every conceivable way, but did not find an acceptable answer. He was found guilty of causing the death of his cows and calves at many occasions during the 1980s and 1990s.

The water from the drilled well had been analyzed by Skåne-mejerier, the dairy of the province, a number of times, and was considered safe. The water was microbiologically without notes. However, in 2002, an extensive well water analysis, including 40 drinking water parameters, was performed. The result of the analysis showed water rich in health bringing minerals, such as calcium, magnesium and bicarbonate, and without elevated concentrations of toxic metals and ions. However, the concentration of iron was high; 1.3 mg/L. Analyses performed by Skåne-mejerier during the 20-year period showed iron concentrations between 1.1 mg/L and 2.87 mg/L, but was paid no attention. Elevated bacteria levels were not reported during the 20 years. The drinking water analysis performed in 2002 is presented in Table 1, below.

Iron is one of the most abundant elements in the bedrock, as there is 2-5% of iron in all bedrocks. The high iron level in this well is due to reducing environment at the depth of 80 m (see Figure 1, Below).

Hair nutrient analysis of four of the dead calves showed elevated iron-levels in the calves, 10.0-40.6 mg/100 g (0.10-0.40 mg/g). Reference values are 5.9-20 mg/100 g (0.059-0.20 mg/g) (Puls, 1994), while the average level among healthy cattle is 5.9 mg/100 g (0.059 mg/g) at Trace Elements Inc., Dallas, Texas (personal communication Dr David Watts, Trace Elements Inc., Dallas, Texas, USA 2008). The other 37 analyzed elements did not show abnormal concentrations.

Autopsy of deceased calves and cows through the years showed emaciation with almost no fat on bodies. No lesions were detected in internal organs. Inflamed and bleeding small intestines occurred frequently. One of the calves had atrophic lymphatic tissues. Pulmonary edema occurred, as well as inflamed fourth stomach (abomasums), navel and gullet. Thus, in accordance with the autopsy protocols, the whole gastric tract had been more or less inflamed or corroded. Viruses or bacteria infections were not indicated. Hair nutrient analysis, which was performed one of the deceased calves, indicated iron overload. The calves had died because their gastrointestinal tract had been severely damaged, and they most probably were unable to absorb nutrients, even though they did not drink the iron-contaminated water for more than a few days. As mentioned above, the farmer treated the cattle with magnesium supplements, as well as rest products from a sugar mill. The treatment made cattle healthier. Supplementation of magnesium to cattle suffering from Fe overload is a well-known treatment method (NLM, 2014; Bowman and Russell, 2006). The farmer himself suffered from joint pains and stiffness, but when he treated himself with the same magnesium supplement he recovered. He drank the same water as the cows and calves.

When the farmer changed to the old well water, the dug well with a low iron concentration, the problem disappeared. In 2008 the farmer mixed the two different waters in order to have access to needed amounts of water at dry periods, and installed iron/manganese filter, which reduced the iron and manganese levels to extremely low levels. All the calves and cows were afterwards reported healthy (Oral comm. owner of the farm 2008). At times when there was any kind of problem with the filter, calves developed diarrhea again. The farm is situated far from any anthropogenous activities like industries, why no such contaminants can be present in the drilled well water. Neighboring farms

Table 1. Results of analyzed parameters in the drinking water of the drilled well of cows at the farm in south Sweden, 2002. Detection limits in brackets. (Eurofins Accredited lab., 2002)

		WHO	**EU**	**Unit**
	Level (det. Limit)	**Guideline value**	**Parametric value**	
pH	6.73	6.5-8.5 (corrosion)	>6.5 and <9.5	
HCO3	40.4 (2)	n.e.	n.e.	mg/L
TOC	5.4	n.e.	n.e.	mg/L
Ca	35 (0.2)	n.e.	n.e.	mg/L
Mg	11.7 (0.5)	n.e.	n.e.	mg/L
Na	7.35 (0.5)	200 (taste)	200	mg/L
K	5.02 (1)	n.e.	n.e.	mg/L
Fe	1.34 (0,02)	0.3 (taste, stains)	0.2	mg/L
Mn	0.030 (0.01)	0.04 (taste, stains)	0.05	mg/L
Cu	0.59 (0.02)	2 (stains)	2	mg/L
Al	0.002 (0.01)	0.1 (color)	0.2	mg/L
NO3	< 0.44 (det. lim.)	50 (short term)	50	mg/L
F	0.92 (0.10)	1.5	1.5	mg/L
Cl	8.53 (1)	250 (taste)	250	mg/L
SO4	28 (1)	250 (taste)	250	mg/L
PO4	< det.limit. (0.02)	n.e.	n.e.	mg/L
Si	8.34 (0.5)	n.e.	n.e.	mg/L
Ag	0.02 (0.1	n.e.	n.e.	µg/L
As	0.08 (0.2)	10	10	µg/L
B	16.1 (5)	2400	1000	µg/L
Ba	56.8 (10)	700	n.e.	µg/L
Be	0.10 (0.1)	n.e.	n.e.	µg/L
Br	<500 (det. lim.)	(bromate: 10)	(bromate: 10)	µg/L
Cd	0.053 (0.02)	3	5	µg/L
Co	0.052 (0.2)	n.e.	n.e.	µg/L
Cr	1.17 (0.2)	50 (total)	50	µg/L
Li	<50 (det. lim.)	n.e.	n.e.	µg/L
Mo	1.42 (5)	70	n.e.	µg/L
Ni	5.16 (0.2)	70	20	µg/L
Pb	0.188 (0.05)	10	10	µg/L
Rb	3.63 (0.01)	n.e.	n.e.	µg/L
Se	0.34 (0.5)	40	10	µg/L
Sn	<0.1 (det.lim.)	n.e.	n.e.	µg/L
Sr	519 (1)	n.e.	n.e.	µg/L
Ti	<50 (det. lim.)	n.e.	n.e.	µg/L
U	0.045 (0.01)	30 (provisional)	n.e.	µg/L
V	1.93 (0.2)	n.e.	n.e.	µg/L
Zn	119 (1)	3000 prov.	n.e.	µg/L

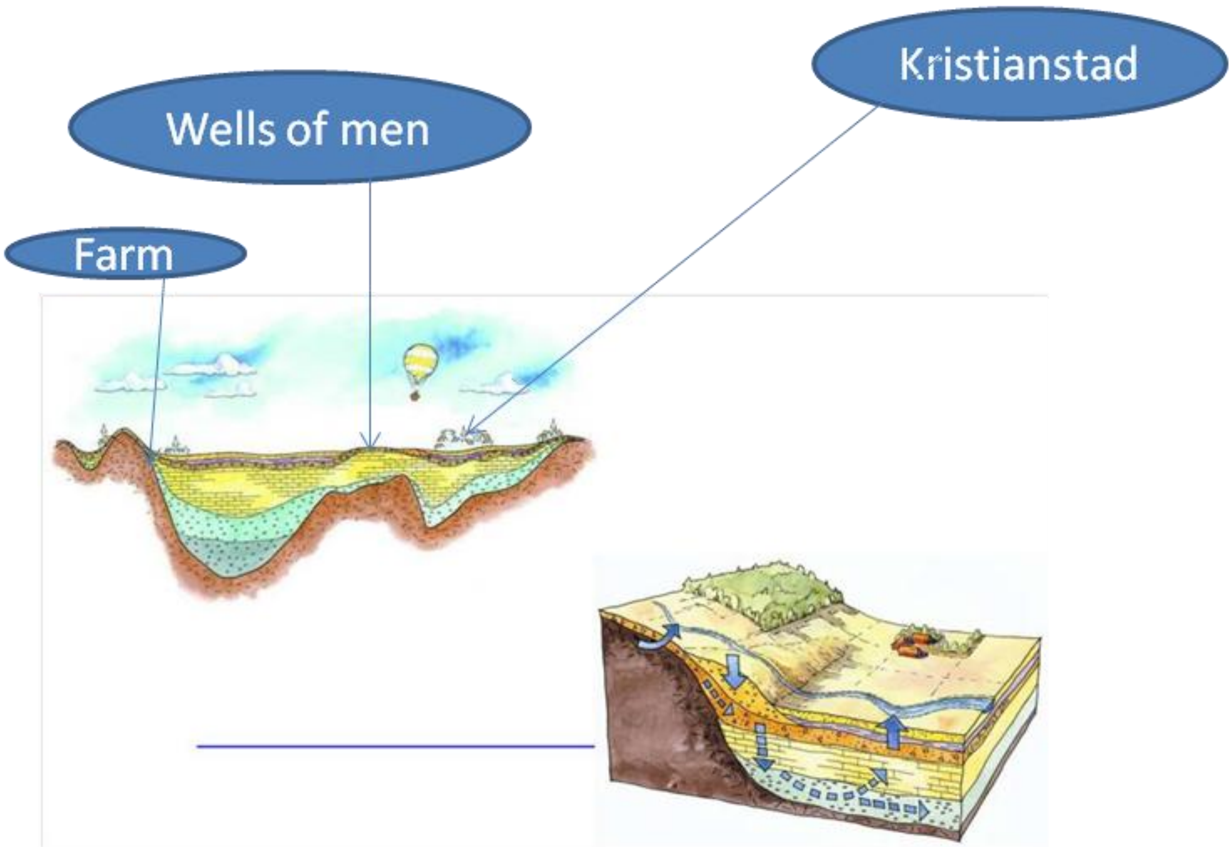

Figure 1. The Kristianstad flatland, glauconite sand (upper picture in turquoise) underneath the limestone cliff (upper picture in yellow, www.kristianstad.se).

have all installed iron/manganese filters after the problems on this specific farm were notified.

The farmer reports that the cattle is doing well and stays healthy, since the iron level is extremely low after installing of the iron/manganese filter,<0.02 mg/L, and when supplemented with copper, some years later they are even healthier (oral comm. Farmer 2015).

Man # 1: A 45-year-old man had severe constipation. His neck was aching and so were his hips and arms. Headache tormented him constantly and he had gastric ulcer. In addition, he suffered from muscle cramps during nights, and had rapid pulse at times. He had noticed that when he was sweaty, his white shirts became rusty. His wife had no intestinal problems or other symptoms. Since his symptoms were quite similar to the cows and calves at the farm and he lived close by, a hair nutrient analysis was performed. The analysis showed an extremely high iron level. His eating habits included red meat, one source of iron from food, but not more than once or twice a week. Daily drinking water consumption was approximately 2 Liters, including drinks of different kinds, like coffee and tea. The water was microbiologically without notes.

Since the hair iron level was so high, a water analysis was performed, as well. The iron concentration was 3.5 mg/L, indicating that he had received the iron in his hair from the drinking water. Shortly after the analysis, he shifted to consuming municipal water with a low iron concentration. It is not clear whether this man suffered from the genetic disorder, hemochromatosis, or not, since he had not been tested for this.

Man # 2: Another man suffered from bloody feces, but not diarrhea. He had pains around his navel and could not digest food. A water analysis showed a high iron concentration, 3.2 mg/L. Hair nutrient analysis was performed and the result was in the same range as man #1. His eating habits included red meat, but not more than once or twice a week. He drank daily around 2 Liters of water. The water was microbiologically without notes.

All the drilled wells in the study had high iron concentrations, since almost all types of bedrock has an iron content of 3-5%, including the limestone on the Kristianstad flatland, and the environment is anoxic at the depth of the wells. (Figure 1).

Iron problems at a stud: In 2008 a woman reported problems with weight loss, diarrhea, and other symptoms of her horses. There were 19 horses, all but one were more or less unhealthy. The problems had escalated during autumn 2003 after shifting from municipal water to water from a dug well on the farm. Horses, around 500 kg weight, consumed 30-50 L of waters during this period, a little more than usual, probably due to having feed of low water content, mostly hay, and especially years when the winter was snow-free. The horses were finally taken care of by the municipality, since somebody had reported that two horses were lying on the ground, unable to rise. The stable owner was suspected of mistreatment of her horses, since analyses on hay and other kinds of cattle food had been performed without conclusive results. People and cattle on the farm also suffered from severe diarrhea and additional health problems, during certain periods. After deforestation near the farm and during spring floods, the well water quality deteriorated, due to anaerobic environment and dissolution of iron(II) from soils. In tractor tracks, stagnant water was brown and sluggish due to rusty precipitates of iron(III) compounds. Besides hay the horses were fed concentrate.

In general, the horses experienced diarrhea and lost weight in connection to returning to the stable after a summer in the enclosed pastures, where they had mostly been drinking natural water. The diarrhea and weight loss also appeared in the spring, the time of spring floods, as surface water from a moss nearby ran into the well. In order to exclude the presence of worms, the owner tried de-worming the horses, with minor results. During periods in which she gave the horses fiber and mineral rich food their health improved. At times, she gave the horses a double or triple amount of hay, to decrease their weight loss. During those periods they needed to drink more than usual, but the horses did not want to drink more water. Thus, she added sugar beets to the water, which prompted them to drink a little more of it. One horse chose the municipal water and refused to drink the well water, when served both. Another horse, a Shetland pony, was generally grazing on the family lawn. This horse received water from the house, the municipal water, and stayed healthy. If the pony was served water from the well, it upset the bucket.

An autopsy protocol on one of the horses reported a number of fractures on ribs, which might be caused by acidosis, which is one consequence of elevated iron intake (Young-Sang et al., 2011). In addition, wounds, edema, bleeding muscles, cutis and bone marrow, as well as bad nutritional status was reported. Detected intestinal parasites were not regarded as being the cause of any of the problems.

An extended water analysis indicated high fluoride concentration, 1.8 mg/L, which is well above the health-based limit of 1.5 mg/L (WHO, 1998). A large number of previous water analyses from the same well had shown elevated Fe levels, from 1.0 mg/L to 5.5 mg/L, this analysis 4.9 mg/L. Table 2.

The hair nutrient analysis of hair from the mane of three horses is presented in Table 3, below. The iron concentration was substantially elevated in the hair of all three horses. All other elements were low to very low in mane of all the three horses, indication malabsorption, which can be due to corroded intestines.

DISCUSSION

The major finding in this study is that elevated iron levels in drinking water, >1 mg/L, is health threatening to humans as well as cattle and horses, and that iron from the drinking water is mirrored in hair. The symptoms include disturbed intestinal function, especially diarrhea, loss of appetite, weight loss, apathy and in the worst cases death.

In accordance with results in this study, Beede (2006) concludes that besides sulfate and chloride, iron in drinking water probably is the most frequent and important anti-quality consideration for dairy cattle and excess iron (greater than 0.3 mg/L) in drinking water is much more absorbable and available than iron from feedstuffs, and thus presents a greater risk for causing iron toxicity. Higgins et al. (2008) and Johnson (2012) also conclude that iron from drinking water is a threat to animal health.

High dietary iron increased concentrations of iron in the liver, and Duodenal manganese concentrations were lowered (Hansen et al., 2010). In accordance with Hansen et al. (2010) manganese deficiency was fund in one of the cows in this study. Elevated liver enzymes, which may indicate negative influence on the liver from excess iron, and a fistula close to his rectum, due to corrosion of the intestine, was noticed on one of the men.

None of the men, the woman with the stud or the farmer reported metallic or bad taste of the water. However, 69 individuals were tested for metallic flavor threshold in water. In 84% of the tested persons individual ferrous flavor thresholds fell well below the aesthetic level of 0.3 mg/L (WHO and USEPA). Only 16% (11 persons, 9 of which were >50 years of age) were unable to taste 2 mg/L of ferrous iron Mirlohi et al. (2011). In addition, in a study by Genther and Beed (2013) lactating dairy cows were served water with different concentrations of iron, 0, 4 and 8 mg/. Water intake was reduced when the concentration was 8 mg/l. The horse that refused to drink the water with elevated iron concentration as confirmed from Puls (1994) concludes that dark slime formations in plumbing and waters formed by iron-loving bacteria affects water intake.

Transferrin and lactoferrin normally bind iron in blood and tissues to control its reactivity. However, if iron is in excess reactive oxygen species (e.g., peroxides) are formed that cause oxidative stress, increasing the

Table 2. Results of analyzed parameters in the drinking water of the stud. Detection limits in brackets. (Eurofins accredited lab., 2008).

		WHO	EU	Unit
	Level (det. limit)	Guideline value	Parametric value	
pH	7.8	6.5-8.5 (corrosion)	>6.5 and <9.5	
HCO3	210 (2)	n.e.	n.e.	mg/L
Ca	49 (0.2)	n.e.	n.e.	mg/L
Mg	7.4 (0.5)	n.e.	n.e.	mg/L
Na	23 (0.5)	200 (taste)	200	mg/L
K	2.7 (1)	n.e.	n.e.	mg/L
Fe	4.9 (0.02)	0.3 (taste, stains)	0.2	mg/L
Mn	0.55 (0.01)	0.04 (taste, stains)	0.05	mg/L
Cu	0.0019 (0.02)	2 (stains)	2	mg/L
Al	0.0016(0.01)	0.1 (color)	0.2	mg/L
NO3	< det.limit.(0.44)	50 (short term)	50	mg/L
F	1.8 (0.10)	1.5	1.5	mg/L
Cl	7.9 (1)	250 (taste)	250	mg/L
SO4	9.1 (1)	250 (taste)	250	mg/L
PO4	0.06 (0.02)	n.e.	n.e.	mg/L
Si	10 (0.5)	n.e.	n.e.	mg/L
As	4.2 (0.02)	10	10	µg/L
B	44 (5)	2400	1000	µg/L
Ba	2.8 (10)	700	n.e.	µg/L
Cd	<0.02 (det. lim.)	3	5	µg/L
Co	<0.2 (det. lim.)	n.e.	n.e.	µg/L
Cr	<0.2 (det. lim.)	50 (total)	50	µg/L
Mo	<5 det. lim.)	70	n.e.	µg/L
Ni	<0.2 (det. lim.)	70	20	µg/L
Pb	0.15 (0.05)	10	10	µg/L
Rb	1.9 (0.01)	n.e.	n.e.	µg/L
Se	<0.5 (det. lim.)	40	10	µg/L
Sn	<0.1 (det. lim.)	n.e.	n.e.	µg/L
Sr	130 (1)	n.e.	n.e.	µg/L
Ti	<50 (det. lim.)	n.e.	n.e.	µg/L
U	0.2 (0.01)	30 (provisional)	n.e.	µg/L
V	<0.2 (det. lim.)	n.e.	n.e.	µg/L
Zn	42 (1)	3000 prov.	n.e.	µg/L

Table 3. Nutrient element levels in the mane of three horses compared to the average among healthy horses (Trace Elements Inc. 2008). All other elements were very low, and are not presented in the table.

Element	Horse #1	Horse #2	Horse #3	Average healthy horses	Unit
Ca	1.2	1.28	0.44	1.84	mg/g
Mg	0.226	0.274	0.107	0.375	mg/g
Na	0.02	0.05	0.04	0.42	mg/g
K	0.08	0.26	0.12	0.57	mg/g
Cu	0.006	0.005	0.005	0.009	mg/g
Zn	0.12	0.11	0.12	0.15	mg/g
P	0.30	0.36	0.24	0.44	mg/g
Fe	0.086	0.132	0.093	0.059	mg/g
Mn	0.00806	0.01	0.00602	0.0068	mg/g
Cr	0.0005	0.0008	0.0006	0.001	mg/g
Se	0.0006	0.0006	0.0003	0.0013	mg/g
B	0.0023	0.0038	0.0013	0.0056	mg/g
Co	0.00005	0.00009	0.00005	0.00016	mg/g
Mo	0.00009	0.00025	0.00011	0.00028	mg/g
S	31.71	31.37	29.3	39.5	mg/g

demand for antioxidants (Beede, 2006; NRC, 2001). This can explain the recovering of cattle and horses when they were fed sugar beets and magnesium supplement. Laine et al. (1988) states that corroded areas of hemorrhoids and wounds may be the result of high oral iron intake, and in extreme cases obstruction of the intestines (Banner and Tong, 1986), as was found in calves in this study. Acute iron poisoning may lead to the death of foals, since they naturally have high levels of Fe in their serum (Aiello and Mays, 1998).

Klaassen et al. (1996) report, that excess iron in the intestines leads to absorption of ferrous ions directly into the circulatory system. The elevated iron levels in the hair of cattle, horses, and men indirectly supported this, since blood passes the hair roots. The symptoms are also in accordance with electrolyte deficiency and general nutrient deficiency after diarrhea, as stated by Klaassen et al. (1996). Treatment with magnesium supplements decreased the symptoms of the cattle at the farm in Scania, which is in accordance with Puls (1994), and even the owner of the farm was helped by megnsium supplementation.

The autopsy protocol of one of the horses showed fractures on ribs that can be caused by acidosis, as a result of elevated iron intake (Young-Sang et al., 2011). Wounds, edema, bleeding muscles, cutis and bone marrow, as well as bad nutritional status, can also be results of acidosis.

Infections were not reported in the autopsy protocols in this study. However, the metabolism of copper and iron was altered in humans suffering from infections (Arain et al., 2014).

Swedish newspapers and web sites have warned the public against eating too much red meat, since the iron level, in hem-form, is relatively high, and can cause gastrointestinal disorders, due to the formation of free radicals (e.g. Hälsa, 2012). Iron from drinking water is probably as dangerous, since it appears as free ions in water, which can also easily be absorbed from the intestines.

For humans, an Indian study showed that when the iron concentration in drinking water exceeded 0.400-0.780 mg/L, changes were reported in the gastrointestinal tract (Subba Rao, 2008). The concentrations of iron in the drinking waters of the Men exceeded that level 5 to 10 times. Man # 1 had noticed that his white shirts became rusty when he sweated a lot during hot days in the summer. This is in accordance with WHO (2008), where it is concluded that about two-thirds of iron loss occurs from the gastrointestinal tract and from the skin. The wife of this man did not suffer from intestinal disturbances, which possibly may be explained by her age and that she still had her periods WHO (2011), where iron is excreted with the blood.

CONCLUSIONS

- Iron concentrations exceeding 1 mg/L, or even 0.2 mg/L, in drinking water may be potentially toxic to humans, horses and cattle.
- Acute mucosal cell damage in the intestines due to the formation of free radicals, a direct corrosive effect on tissues, seems to start the process causing especially diarrhea.
- Different inner organs may be negatively influenced by an overload of iron, especially the liver.
- More studies are needed before setting a health based guideline value, but a suggested guideline value for iron in drinking water is well below 1 mg/L for both animals and humans, a first proposal is 0.2 mg/L.

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