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Lead exposure by drinking water: an epidemiologial study in Hamburg, Germany

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Abstract

Study objective was to investigate the extent of lead exposure via tap water in Hamburg and the relevance of preventive strategies. Two hundred and forty-eight non-smoking young women participated in the cross-sectional study program and 52 women completed the intervention program. In the cross-sectional study program most women (N = 178) didn't know anything about the material of the plumbing system at their homes. Participants with lead in the tap water above the detection limit of 5 µg/l (N = 142) showed significantly higher blood lead levels (median 31 µg/l) compared to those with no detectable lead in the tap water (N = 106; median blood lead 24 µg/l, $p <= 0.001$). There is a close correlation between the average lead concentration in the tap water and blood lead concentrations (N = 142 value pairs, Spearman's rho 0.43, $p <= 0.0001$).
In the intervention program, the women were asked to minimize exposure by flushing water or to exclude it by consuming bottled water. Intervention lowered blood lead-level significantly (median decrease of 11 µg/l, $p <= 0.001$). "Minimizers" could lower their blood lead levels by about 21% of the initial value, "excluders" by about 37% (ns, $p <= 0.17$). The majority judged neither minimizing nor excluding tap water as practicable health preventive behaviour pattern in the long run. Lead in tap water stands for an avoidable surplus exposure. These results underline the relevance of health care preventive measures for the most sensitive groups.

Key words: Lead – tap water – blood – European guideline – young women – prevention

Introduction

Background

This study tackles a quite widespread challenge in public environmental health: exposure to lead in drinking water. The WHO-Guideline value of 10 µg/l was adopted by the European Union in 1998 allowing for transitional regulations until 2013 (WHO 1996a, Richtlinie des Rates 1998). The revised German guideline was to come into force in 2003 (Verordnung zur Novellierung der Trinkwasserverordnung 2001). In view of these new regula-

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tions the actual situation in Hamburg, Germany, with respect to lead in the plumbing system, its relevance for public health and the effectiveness of preventive procedures were investigated.

Today's lead exposure is caused by food and tap water. Lead has been a well-known contaminant for the population especially with traffic, although with the switch to unleaded gasoline in 1988 it changed to the better all over Germany and especially in areas with high traffic density. There are rather small amounts of lead in foodstuff and there is a surplus exposure for a proportion of the population with lead transferred by plumbing systems to drinking water (Kommission Human-Biomonitoring 1996, WHO 1996b). In other countries, continual environmental lead exposure is related to paint, industrial pollution by smelters, and traffic, as leaded gasoline is still used.

Lead from environmental pollution is not carcinogenic, but even low dose lead exposure has been shown to have detrimental and long-lasting effects on the renal, hemopoietic and nervous system. This is especially true for fetuses and small children in whom lead might cause developmental disruption in terms of neurological impairment – so, there is well-known evidence to pinpoint the most sensitive subgroups: women in their childbearing years, pregnant women, young children and especially bottle-fed babies (e.g. Banks et al. 1997, Bellinger et al. 1987, Needleman and Gatsonis 1990, Winneke et al. 1990, Goyer 1996).

Actual situation in Hamburg

Hamburg (1.7 million inhabitants) still has a high proportion of old buildings. Lead was used for plumbing until 1970, so 12–14%, that is 100.–120.000 apartments are supposed to be supplied with lead contaminated tap water. During the past 10 years Hamburg's waterworks have offered tap water analysis to concerned persons. More than 30% of these lead determinations ranged above the former limit value of 40 μg/l, a convincing indication of the need for preventive measures. Hamburg's health authorities offer a flyer on how to examine the plumbing system and how to minimize lead exposure by flushing if necessary. Yet, several topics are open to question. Are there sensitive groups affected by lead in tap water in Hamburg? What is their level of information? Is lead in the drinking water a relevant and statistically distinguishable source of surplus exposure? How is the advice of health administration realised in daily-life? What about the suitability of behavioural changes to achieve a decrease in blood lead concentrations?

The two central hypotheses decided to work on were:

There are young women in Hamburg in between the ages of 20 and 30 years, who – as a result of consuming tap water with lead concentrations above the future limit value of 10 μg/l – show increased blood lead concentrations.

Minimizing and excluding lead exposure via consumption of tap water will lower blood lead-levels.

Materials and methods

The study program combined a cross-sectional approach with an intervention program. Objects of the study were young women in a selected area of Hamburg, central Eimsbüttel. The area is supplied by one well and has many old buildings with lead plumbing systems. The Central Registration Office and the Hamburg Statistical Department could confirm that the selected area met the demographic prerequisite: there were a sufficient number of young women living under the given address for at least one year. Local health authorities gave support and the on-site "Meeting Place Health and Environment" was eager to cooperate.

The cross-sectional approach included a questionnaire relating information about the plumbing system, water consumption, nutrition (especially with respect to the consumption of wine and dairy products) and a few background data on water sampling and blood-sampling for lead-determination: 2.6 ml of venous blood was taken with a K-EDTA Monovette (Sarstedt). Water sampling – carried out by the participants themselves – included stagnant water in the morning, fresh water after flushing for three minutes and water taken at lunchtime intended for cooking. The containers were prepared with 1 ml 25%-hydrochloric acid.

Participants were informed about the results of the cross-sectional study and introduced to the intervention program. Women with additional lead exposure (at least one lead concentration of the set of three water specimen with >= 10 μg/l) were invited to participate in the intervention program. Interested participants were by chance assigned to one of the two intervention-subgroups: the group 'Minimizing' got the official flyer from the public health services, which suggests to minimize exposure by flushing water prior to consumption. The other group 'Excluding' was supplied with bottled water and participants were requested to use this water for cooking and as a water supply any time at home. All of them were questioned again after about ten weeks of intervention and blood-lead concentrations were analysed again. The supplementary questionnaire of the intervention study comprises information on compliance and acceptance of the intervention-strategies. Both questionnaires were checked by a pretest and revised.

The Environmental Health Consulting Centre, Hamburg, was in charge of the participants. The study design was approved by the Committee for Ethical Questions of the State Medical Board and acknowledged to be in accordance with the data protection act. The investigation was realized during fall 1999.

The voluntary participants had to meet these inclusion criteria: age 20 – 30 years, non-smoker and living at this specific site for at least one year. Pregnancy, nursing or less than half a year since being pregnant or nursing were the excluding criteria because of the metabolic changes with their possible short-term effect on body-lead-concentrations (Gulson et al. 1997, Nielsen et al. 1998).

To corroborate an assumed prevalence of exposure to lead from tap-water of about 25% (worst acceptable 20%, confidence interval 95%) our sample in the cross-sectional study was supposed to count up to at least 224 persons. With a presumable response rate of 10% 2250 women were to be invited to participate. A sample size calculation for the intervention study had to assume an intraindividual correlation of about 0.5 for blood lead concentrations determined at different times. Then, a decrease of the blood-lead-concentration of about 1/2 of the geometric mean should be examined statistically with a sample of at least 51 women. As the number of participants in the intervention program is less prone to be influenced the corresponding statistical analysis with a smaller subsample does not have the power for statistical testing.

Analysis of lead concentration in the blood samples was performed by an accredited laboratory with atomic absorption spectroscopy AAS (detection limit 4.9 µg/l). For external quality control one blood sample was analysed 6 times during the investigation, the coefficient of variability was 6%. Analysis of lead concentration in the water samples was performed by a state-registered laboratory with AAS (detection limit 5 µg/l). External quality control with 5 prepared sets of three samples corroborated only small deviations from the true value (mean 2.1%).

Descriptive and analytical investigation as well as multivariate analysis was performed with SPSS (Brosius 1995).

Results of the cross-sectional study

Sample

N = 2580 women were eligible on the basis of demographic criteria, N = 2560 were locatable. N = 281 women met the inclusion criteria and were interested in participating, N = 248 completed the interviews and contributed water and blood samples.

The average age was 27.6 years; only 16 women had a child or children. The sample had a high educational level: about 80% had made their "Abitur", that is their school-leaving exam and university entrance qualification. The women had been living at their apartment for about 1 – 30 years (median 3.0). The great majority (81%) was working (48% full-time, 27% part-time). None of the subjects reported on a known contact to lead at work.

The information status with respect to the plumbing system is described in Table 1, anticipating the results of the water sampling.

One hundred and seventy-eight women didn't know anything about the material of the plumbing

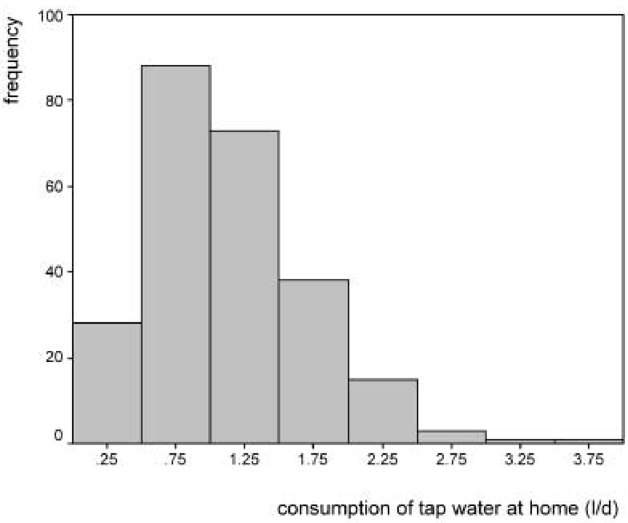

Fig. 1. Consumption of tap water (l/day) at home (N = 248)

Table 1. Knowledge about material of the plumbing system and lead concentration in water-samples with respect to the detection limit of 5 µg/l (N = 248)

Individual knowledge of the plumbing system	N	Lead concentration in the tap water < 5 µg/l	Lead concentration in the tap water > 5 µg/l
Material not known	178	77 (43%)	101 (57%)
Material including lead	51	13 (25%)	38 (75%)
Material other than lead	19	16 (84%)	3 (16%)
Sum	248	106 (43%)	142 (57%)

system at their homes, 57% of them were exposed to lead concentrations in the tap water > 5 μg/l. Fifty-one women assumed that there is lead in the plumbing system, 75% of these were right with this assumption. Altogether, 142 women, that are 57% of the sample, were exposed to detectable lead concentrations by tap water.

On the basis of information pertaining to the consumption of beverages and soup the individual water consumption at home was calculated (Figure 1).

Daily consumption of tap water ranged from 0 to 3.5 l/day (median 1.0 l/day with omission of one extreme value of 5.2 l/day). About 30% of the participants acted cautiously as they flushed tap water often or always, 70% consumed the tap water rather without flushing.

Lead concentrations in water and blood samples

Water and blood sampling has been carried out within one day for 50% of the sample, and within two days for 90%. All together there were 248 sets of water samples with three specimen each. Table 2 gives detailed concentration data for each sample type and the complete study group.

One hundred and forty-two sets showed at least one specimen with lead concentration above 5 μg/l, 117 of these displayed at least one level above the future limit value of 10 μg/l.

Table 3 gives the results of the lead concentrations in tap water from sources positive at least once.

In this sub sample more than 50% of the water lead levels ranked above the critical level of 10 μg/l. The even higher mean indicates the typical left skewed distribution; for some statistical analysis logarithmic transformation is obligatory.

Table 4 summarises blood lead concentrations of the two subsamples in the cross-sectional study depending on the detection of lead in the tap water. Participants with detectable lead in the tap water (N = 142) had significantly higher blood lead levels compared to the participants with lead concentrations below the detection limit (N = 106) (t-test, p < = 0.0001).

Bivariate analysis for the subsample with lead in the tap water (N = 142) results in a Spearman's correlation coefficient of 0.43 and the regression line depicted in Figure 2.

Table 2. Lead concentration (μg/l) in tap water in the complete study group (N = 248)

Tap water samples				Percentiles in μg/l			
	Min	Max	Mean	25.	50.	75.	95.
Stagnant water	< 5	200	24	< 5	7	25	110
Fresh water	< 5	90	6	< 5	< 5	8	21
Water taken at lunchtime	< 5	330	16	< 5	< 5	16	59
Average of the three specimens	< 5	160	15	< 5	5	19	65

Table 3. Lead concentration (μg/l) in tap water in the subgroup with detectable lead concentration in at least one water specimen (N = 142)

Tap water samples				Percentiles in μg/l			
	Min	Max	Mean	25.	50.	75.	95.
Stagnant Water	< 5	200	40	10	22	61	150
Fresh water	< 5	90	10	< 5	7	12	29
Water taken at lunchtime	< 5	330	27	6	14	28	110
Average of the three specimens	< 5	160	26	9	16	33	82

Table 4. Blood lead concentration (μg/l) in the cross sectional sample (N = 248)

					Percentiles in μg/l			
Subgroup	N	min	max	mean	25.	50.	75.	95.
Lead in the tap water < 5 μg/l	106	10	55	27	20	24	33	50
Lead in the tap water 5 < μg/l	142	10	95	33	22	31	40	66
All	248	10	95	30	20	28	37	57

Table 5. Results of the multiple regression analysis with blood lead as the dependent variable for the subgroup with detectable lead in the tap water (N = 142)

	Non standardized coefficient B	Standard error	Standardized coefficientβ	p <=
Constant	2.66	0.26		0.0001
Exposure-index	0.01	0.00	0.44	0.0001
Age	0.02	0.01	0.12	0.0350
Wine	0.08	0.02	0.23	0.0001
Dairy products	− 0.02	0.01	− 0.11	0.0540

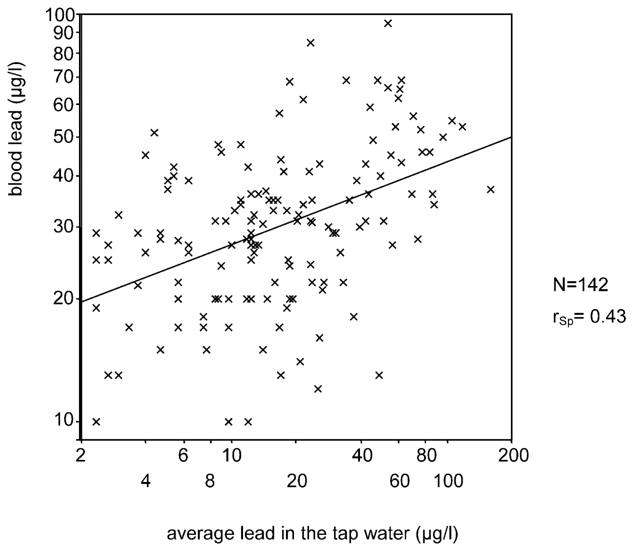

Fig. 2. Regression with blood lead as the dependent variable and water lead concentration (average of three specimen) as the independent variable; concentration of blood lead and water lead on Ln-transformed coordinates; r_{SP} = Spearman's correlation coefficient (N = 142)

The multiple regression analysis with blood lead as dependent variable takes into account the simultaneous influence of lead exposure – daily tap water consumption at home times the lead concentration of steady water –, age, consumption of wine and consumption of dairy products, that is calcium-rich food-products counteracting the lead absorption in the body. The independent variables were checked for intercorrelation to preclude collinearity. Except for a non-significant association of increasing wine consumption with age ($r = 0.23$, $p <= 0.08$) the independent variables do not correlate. Table 5 summarises the results of multiple regression analysis in the subgroup with detectable lead in the tap water (N = 142).

All four independent variables are significant predictors of the blood lead concentrations. Taken together, they explain 26% of the variability of blood lead in this subsample. Lead exposure via the consumption of tap water is the dominant influence. Alternative regression models confirm these results; alternative exposure variables (e.g. average lead concentration in the tap water) do not yield a higher proportion of explained variance. Also, the application of the regression models in the whole sample (N = 248) corresponds to the results listed in Table 5 ($r^2 = .26$).

Results of the intervention study

Sample

One hundred and thirteen women with verified surplus exposure by drinking water (at least one specimen concentration above 10 µg/l) and consuming tap-water at home were invited to participate in an intervention program. Fifty-two of initially 54 women completed the intervention program. These participants didn't differ from the non-responders with respect to any of the variables described above. Intervention covered a median time span of 11 weeks. The time span of intervention was more heterogeneous in the minimizing group (9 – 14 weeks) compared to the excluding group (except one case an 11 weeks time span for all participants).

The feedback given in the questionnaires showed some differences with respect to the practicability of the two procedures. In the minimizing group (n = 19), which was advised to flush tap water before consumption, 13 (68%) followed the instructions always or most of the time, 6 less often. Eleven women (58%) judged this procedure practicable, 8 not practicable. This preventive measure was evaluated as not suitable on the long run by 10 participants (53%), 9 thought it quite suitable. In the excluding group (n = 33), which had to use bottled water at any occasion, 30 (91%) succeeded to follow this instruction always or most of the time, only three succeeded less often. Also, 30 (91%) judged this procedure quite practicable and only 3 not practicable. Here, 21 participants (64%) assessed these preventive means as not suitable on the long run and 12 thought it quite suitable.

Table 6. Blood lead concentration (μg/l) before and after intervention (N = 52)

Time	Min	Max	Mean	Percentiles in μg/l			
				25.	50.	75.	95.
Before intervention N = 52	10	69	35	27	31	43	67
After intervention N = 52	1	73	24	17	22	32	51

Lead concentrations in blood samples

Table 6 shows the changes in blood-lead concentration during intervention for the entire subsample.

The distribution of the blood lead concentrations significantly changed during the intervention program. All percentiles and the mean ranked less after the intervention program. Only the maximum value has not decreased. Forty-three participants attained lower blood lead levels, which is a minimum decrease of 10% of their individual initial lead concentration. Nine women had an only small decrease or even increase (maximum value 16.5 μg/l); for some of them these observations could be related to individual behaviour. For the group as a whole there is a significant decrease of the blood lead concentration maximum (33 μg/l) with a median decrease of 11 μg/l (t-Test $p <= 0.001$). Yet, this difference amounts to only one third of the geometric mean, less than assumed for power calculation.

In conclusion the observations of the intervention program show that minimizing and excluding lead contaminated tap water lowers blood lead-levels.

The two subgroups of the intervention program did not differ with respect to lead concentration in the tap water and had a similar blood-lead level before the intervention. Table 7 gives the descriptives for the blood-lead concentration after intervention separately for the two subsamples excluding or minimizing.

All values of the excluders were below the corresponding values of the minimizing subsample.

Figure 3 depicts the changes in blood lead concentration after intervention with the two different strategies of excluding and minimizing lead exposure by tap water consumption. Minimizers could lower the blood lead level by a median of 8.2 μg/l (21% of the initial value), excluders could lower the blood lead level by a median of 12.3 μg/l (37% of the initial value). This difference could not be confirmed statistically ($p <= 0.17$).

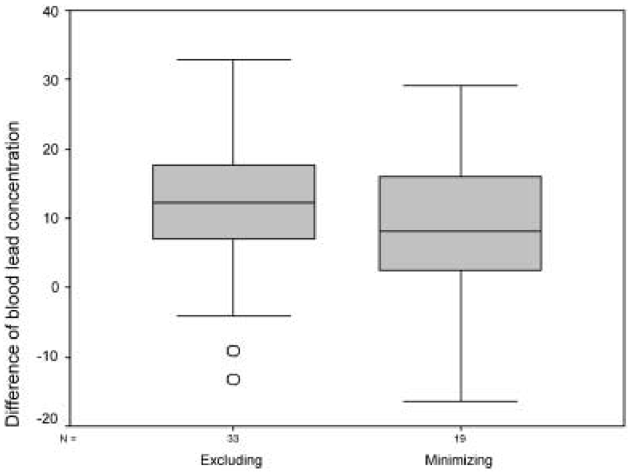

Fig. 3. Differences of blood lead concentration in μg/l during intervention for the two subsamples excluding and minimizing; positive values on the y-axis: decrease during intervention; negative values on the y-axis: increase during intervention; box-plots with extreme values, minimum and maximum, 25th, 50th and 75th percentile.

Discussion

The European Guideline for Drinking Water is currently implemented by transitional regulations in Germany. The metropolitan area of Hamburg still has many houses with plumbing systems containing lead to a considerable degree. Thus, we aimed to

Table 7. Blood lead concentration (μg/l) after intervention in the two subsamples excluding (N = 33) and minimizing (N = 19)

Subsample of intervention	N	Min	Max	Mean	Percentiles in μg/l			
					25.	50.	75.	95.
Excluding	33	1	40	21	16	20	28	35
Minimizing	19	8	73	30	21	28	35	72

combine a documentation of the actual situation with an evaluation of prevailing preventive measures. The results should enhance risk communication of local health authorities with worried citizens as well as house owners.

The situation in Hamburg differs from Germany: The data from a recent representative survey in Germany (Becker et al. 2001) show, that 9.2% of 3226 samples of stagnant water range above the WHO-limit value of 10 µg/l. The higher concentrations are found more frequently in the new federal states than in the old ones. Yet, in Lower Saxony 3.1% of 1434 tap water samples of stagnant water had lead concentrations of more than 10 µg/l. In Berlin, 2109 households were sampled, and in daily profiles up to 7.1% exceed 10 µg/l (Zietz et al. 2001a, b). These are samples of households with new-borns and within each sample regional difference are notable.

In our investigation the response rate is low: with the exclusion criterion of smoking about 43% (Thefeld 1999) of the young women written to were not eligible to participate. Six percent were supposed to be pregnant or in their post-partum time, an estimate based on the number of live births per year in this age group in Hamburg. On this basis, the response rate for the cross sectional part might be estimated to be about 20%.

The response rate of the intervention program attained initially 48% and 52 of the 54 women completed the intervention program. A selection bias for higher education and social class can be assumed for both parts of the study. Our conclusion is that representivity cannot be assumed. The results of the intervention program rather depict optimal effects. In a non-selected population effects of this kind of intervention-program would probably turn out lower.

The results of this study are of relevance for health care preventive measures in several respects. First, the sensitive subgroup chosen in this study is definitely not well informed about the plumbing system at their homes. Second, more than 50% of them are exposed to lead from tap water, as at least one of the water samples exceeds the new guideline value of 10 µg/l. Blood lead concentrations reflect this as distinguishable surplus exposure. In addition, the decrease of blood lead following intervention might not last because the behavioural changes called for are unsuited for every-day life (see also Lommel et al. 2002 a, b).

All blood lead levels ranked below 100 µg/l, the guideline level "HBM I" of the German Federal Environmental Agency's 'Human Biological Monitoring' Commission. This guideline value is not a reference value but – derived by expert judgement – represents a concentration where there is no risk for adverse health effects and, consequently, no need for action. This specific evaluation for blood lead is in accordance with international statements, e.g., of the WHO and the US EPA (Kommission Human-Biomonitoring 1996, Banks et al. 1997).

Although the 100 µg/l guideline level for blood lead is not reached, our sample confirms previous observations with respect to the association of lead exposure and body load - here examined by blood-levels – even in the low range. Tap water with lead concentrations above 10 µg/l results in higher blood lead concentrations and gives evidence for avoidable exposure. Any additional unfavourable circumstances with calcium-deficient nutrition and/or additional lead exposure and/or metabolic changes induced by pregnancy might result in concentrations higher than 100 µg/l.

So, here is a good argument for the public health services to put more pressure on home-owners to inform their tenants about the current situation and – in a medium-term time span – to take care of the plumbing system to suit water quality to the new guidelines. The results of the multivariate analysis confirm the suspected dominant influence of lead exposure via tap water and also point to the protective effects of the consumption of dairy products. So, on an individual level this topic should not be omitted from counselling.

The results of the intervention study give – on first sight – the reassuring observation, that with behavioural changes lead exposure by tap water can be cut down. Within a time span of 2–3 months the blood concentration of lead could be decreased. This is in accordance with the known half-life of blood-lead. Yet, this decrease might be still an under-estimate of the possible effects, as lead mobilisation of the skeleton could not be taken into account.

The feedback given by the participants however warrants reservations: to practice the avoidance behaviour in everyday live was critically evaluated by the majority of our intervention group. No matter whether the participants got accustomed to flush water or the use of bottled water, many disapproved the application of these preventive strategies in the long run. Herein we find another argument to underline the importance of renovating works on the plumbing system rather than to call for prevention behaviour on the individual level.

More than that, we obtained some hints to differences in the effect of the two strategies in the presumed direction: Excluding seemed more effective than minimizing the consumption of tap water. These results in the two subgroups could not be confirmed statistically because of the small sample sizes. Yet, this observation gives hints that the flyer of the health authorities cannot be relied on as most suitable under present circumstances. The difference in practicability and effectiveness of the two procedures in everyday-life might also indicate a similar difference in reliability. It should be pointed out, that after intervention the blood-lead levels of the excluders lie within the background concentrations as determined in the German Environmental Health Survey in 1992 (Krause et al. 1996). The blood-lead levels of the minimizing group still exceed these levels.

The approach of young women also gives way for prevention of lead exposure for other highly sensitive groups – unborn babies and bottle-fed babies when formula-feeding being prepared with tap-water. Based on the lead concentrations observed in our affected subsample with at least one specimen of tap water above 10 µg/l (N = 142; mean tap water concentration 26 µg/l) a bottle-fed baby of 3–6 months, with 5 kg body weight and consuming 900 ml formula/day (Betke and Künzer 1984) would be exposed to 23 µg/d with formula feeding. This exceeds the value of 18 µg/d classified as tolerable value by the WHO (WHO 1996b). The recent investigation of Canfield et al. with respect to children's neurobehavioral functioning at blood lead levels below 10 µg/l has confirmed this aspect (Canfield et al. 2003). So promotion of these results should be directed to possible multipliers as midwives and gynaecological practitioners.

The matter is not yet closed: European (Watt et al. 1996, Osman 1999, Rubin et al. 2002, Meyer et al. 2003) as well as worldwide investigations (Heinze et al. 1998, Pirkle et al. 1998, Khan et al. 2001, Gao et al. 2001, Gallicchio and Scherer 2002, Mathee et al. 2002, Krieger et al. 2003) discuss lead exposure by different sources and to various degrees. Many studies explore the possible effects of blood levels close to the currently defined lowest adverse effect level of 100 µg/l for infants and children. These studies encompass, e.g., kidney function (Fels et al. 1998) and hematologic parameters (Jacob et al. 2000) as well as deficits in cognitive and academic skills (Lanphear et al. 2000) and intellectual impairment (Canfield et al. 2003). With respect to the unborn and neonates the effects of modifying factors as maternal anthropometric variables and maternal iron, calcium and vitamin D intake have been explored (Schell at al. 2003). With respect to young children intervention measures – inhome educational visits encompassing recommendations for cleaning procedures and dietary suggestions – were demonstrated to lead to a significant decrease in blood lead levels (Schultz et al. 1999). Yet, Markowitz et al. (1999) concluded, that follow-up of children with elevated blood lead levels was inadequate within an urban ambulatory care network.

This study involves empowerment of a small group of adults to take responsibility for their individual health potential. These young women were not only the object of our study but – actively joining the program of investigation and especially the intervention – took responsibility of their individual health care. Eventually they might as well protect their progeny from unwanted lead exposure. They gave valuable feedback to the management of the public health care services in charge as they critically evaluated behavioural strategies to avoid lead exposure via tap water. Lead in tap water stands for an avoidable surplus exposure. These results underline the relevance of lasting health care preventive measures for the most sensitive groups.

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