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Toxicology and Applied Pharmacology xx (2004) xxx–xxx
Toxicology and Applied Pharmacology
www.elsevier.com/locate/ytaap

Review

Arsenic contamination and arsenicosis in China

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Received 1 July 2003; accepted 8 October 2003

Abstract

Arsenicosis is a serious environmental chemical disease in China mainly caused by drinking water from pump wells contaminated by high levels of arsenic. Chronic exposure of humans to high concentrations of arsenic in drinking water is associated with skin lesions, peripheral vascular disease, hypertension, blackfoot disease, and high risk of cancers. Lead by the Ministry of Health of China, we carried out a research about arsenicosis in China recently. Areas contaminated with arsenic from drinking water are determined by 10% pump well water sample method while areas from burning coal are determined by existing data. Two epidemic areas of Shanxi Province and Inner Mongolia are investigated for the distribution of pump wells containing high arsenic. Well water in all the investigated villages of Shanxi Province showed polluted by high arsenic, and the average rate of unsafe pump well water is 52%. In Inner Mongolia, the high percentage of pump wells containing elevated arsenic is found only in a few villages. The average rate of unsafe pump well water is 11%. From our research, we find that new endemic areas are continuously emerging in China. Up to now, epidemic areas of arsenicosis mainly involve eight provinces and 37 counties in China. In the affected areas, the discovery of wells and coal with high levels of arsenic is continuing sporadically, and a similar scattered distribution pattern of patients is also being observed.

Keywords: Arsenicosis; Arsenic

Introduction

Arsenicosis is one of the most serious environmental chemical diseases and involves a great number of populations throughout the world. Since chronic endemic arsenicosis was first reported in Bangladesh and India in 1996, it has become clear that is a severe worldwide problem. Although reports about arsenicosis in China occurred earlier than those from Bangladesh and India, they are unknown to the world due to limited scientific exchange and publication in Chinese journals. Large area of arsenicosis from drinking water was first reported in Kuitun, located in the Xinjiang Autonomy Region of China in 1980. The affected area lies southwest of the Zhungaer Basin, winds its way from the west of Aibi Lake to the east of Manasi River, and covers 250 km in length. Here the groundwater is rich in arsenic. It is a V-shaped plain. The southern and northern parts are higher land, and the endemic area is in the lowest land that is arid but rich in deep groundwater aquifers. Before 1962, residents mainly used shallow well water and surface water, but after then many deeper wells (more than 30–50 m deep) were drilled, which have been found to have arsenic levels higher than 50 μg/l. The concentration of arsenic in these deep wells increases with decreasing elevation. The population at risk has increased to more than 100 000, while more than 2000 persons have been diagnosed as having arsenicosis.

In 1989, the Inner Mongolia was reported as another endemic area of severe arsenicosis in China. This area is mainly in the southern part of Mountain Yinshan, and the region connecting the plain north of Yellow River and the alluvium plain of Heihe River, where the underground water is rich in natural arsenic. It is a long and narrow land covering 3000 km^2, winds from east to west, and links with the northern epidemic areas of Shanxi Province. More than 600 000 persons in five cities and 678 villages are potentially under exposure, while >3000 persons have been diagnosed with arsenicosis.

Arsenicosis had affected such large areas and so many persons in China that the Chinese government in 1994 declared it an endemic disease throughout the nation. A special consultative committee was then set up to advise the government. A series of research institutes were organized by the government to carry out research on arsenicosis. Our research center has been extensively involved in arsenic

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0041-008X/$ - see front matter © 2004 Elsevier Inc. All rights reserved.
doi:10.1016/j.taap.2003.10.017

research. We took part in the investigation of arsenicosis epidemic in China, participated in the formulation of the standard diagnosis of arsenicosis, and carried out research on arsenicosis prevention.

In 1994, large areas of endemic arsenicosis contaminated by drinking water were discovered in the north, middle, and south parts of Shanxi Province, including 10 counties and 129 villages, during a nationwide investigation sponsored by the Ministry of Health of China. Epidemic areas were mainly found in Datong and Taiyuan Basins extending more than 1500 km^2, with 900 000 persons at risk and >5000 patients identified. Arsenicosis found in Xinjiang, Inner Mongolia, and Shanxi Province was chiefly caused by drinking water from pump wells.

In the 1980s, with the improvement of peasants' living conditions, the surface water was substituted by pump well water to improve water quality, to make irrigation more convenient, and to prevent endemic fluorosis. Many wells were more than 30–50 m deep, which was unexpectedly located in a rock stratum rich in arsenic, so drinking water was contaminated by arsenic and resulted in arsenicosis.

There was also a special type of arsenicosis due to burning coal which has been found only in China. The main cause was that some local small coal mines containing high levels of arsenic have been opened to the public over several years and residents have been able to excavate the coal freely. The concentration of arsenic in the coal is in the range of 826–2578 mg/kg, with the highest concentration being 9600 mg/kg. Local residents commonly use the arsenic-rich coal for cooking, heating, and drying corn and hot peppers, the local staples, in open stoves without chimneys, and arsenicosis was endemic, spreading to five counties in Guizhou. As the harvest season in this part of China is normally damp and rainy, corn or hot peppers must be dried before storage. As a result, indoor air and the dried corn or hot peppers are contaminated with arsenic released from the burning coal. The arsenic concentration in kitchen air was 160–760 μg/m^3 (average: 445 μg/m^3), and the arsenic levels in the dried corn and hot peppers were 1.52–11.3 mg/kg (average: 4.13 mg/kg) and 52.5–1090 mg/kg (average: 512 mg/kg), respectively. Many local residents have developed arsenicosis through consuming the arsenic-rich dried corn or hot peppers and inhaling the arsenic polluted air. In areas of arsenicosis caused by coal-burning pollution, the intake of arsenic from dried food, particularly hot peppers, is reported to cause more harm to humans than other arsenic sources such as polluted air. For this type of arsenicosis, the population at risk is about 200 000, and >2300 patients have been diagnosed.

Chronic exposure of humans to high concentrations of arsenic in drinking water is associated with skin lesions (Tondel et al., 1999; Tseng, 1997), peripheral vascular disease (Engel et al., 1994), hypertension (Chen et al., 1995), blackfoot disease (Chen, 1990; Tseng, 1997), and high risk of cancers (Bates et al., 1992; Tseng, 1997). A diagnostic standard of arsenicosis has been formulated by a group of specialists in the fields of clinic medicine, pathology, toxicology, and endemic diseases in China. According to the standard, with high arsenic exposure (from drinking water or coal burning), the grade of arsenicosis is determined by the degree of skin pigmentation, depigmentation, and hyperkerotosis on the palms of the hands and soles of the feet. High arsenic exposure means arsenic concentration in water beyond 0.05 mg/l (China Concentration Limit). The definition of high arsenic polluted areas implies such an area (usually in a village) that arsenic concentration in at least one pump well exceeds 0.05 mg/l but without identified arsenicosis patients. While the patients are identified, the area (village) is defined as epidemic area.

The following is a report of the recent research conducted by our research institute about arsenicosis in China. It is lead by the Ministry of Health of China and supported by UNICEF and JICA of Japan.

Materials and methods

Determination of areas of arsenic contaminated from drinking water. Villages around the known epidemic areas (where patients have been identified) were selected. A 10% pump well water sample method was used in which 10% of the pump wells are sampled with collection from the east, west, south, north, and middle parts of each village. Villages with at least one water sample whose arsenic concentration is beyond 0.05 mg/l would be identified as within high arsenic contaminated areas, then the map of high arsenic polluted areas in China was constructed.

Villages with arsenic contaminated in Inner Mongolia and Shanxi Province were selected to be screened well by well to measure arsenic concentration in drinking water. The fast kits for arsenic measurement bought from Germany were used. The purpose was to make it clear about the distribution of high arsenic wells in the villages and to provide recommendations for the government to carry out water mitigation.

Determination of areas of arsenic contaminated from burning coal. This type of exposure is only found in Guizhou Province of China. Therefore, high arsenic polluted areas are identified by existing data.

According to the diagnostic standard in China, the number of arsenicosis patients in these four provinces in 2002 was ascertained.

Results

The map of arsenic-contaminated areas in China

The arsenic-contaminated areas in China are shown in Fig. 1. Up to now, the arsenic-contaminated areas from drinking water include Shanxi, Inner Mongolia, Xinjiang,

Fig. 1. Epidemic areas of arsenicosis in China in 2001.

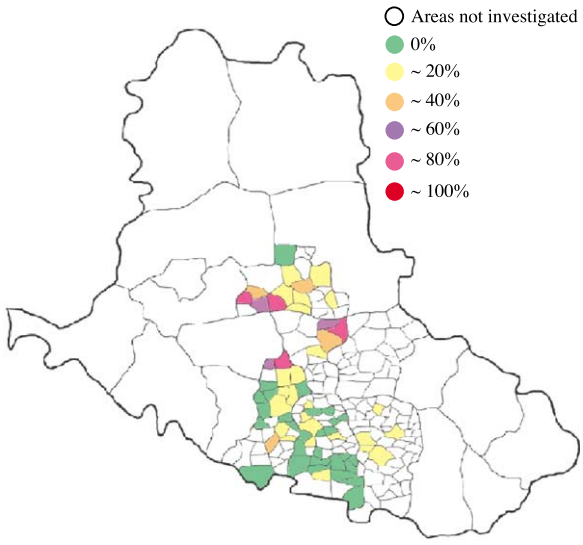

Fig. 3. Distribution of pump wells in one epidemic area of arsenicosis of Inner Mongolia (each small unit represent a village).

Jilin, Qinghai, and Ningxia Province. Guizhou is the only province in which arsenicosis from coal burning is found.

Distribution of pump wells with high arsenic concentration

The distribution of pump wells containing high arsenic in one epidemic area of Shanxi Province and another area of Inner Mongolia is shown in Figs. 2 and 3. It can be seen that wells of all the investigated villages of Shanxi contain high arsenic (>0.05 mg/l). In some villages, all the pump wells contain high arsenic (shown in red). The average rate of unsafe pump well water (>0.05 mg/l) is 52% (see Table 1). In Inner Mongolia, most of the investigated villages were within safe limits, because not a single pump well has been found to be unsafe (shown in green). A high percentage of pump wells containing elevated arsenic is found only in a few villages. The average rate of unsafe pump well water is 11% (see Table 1). Thus, the distribution of pump wells containing high arsenic is different in different areas. Moreover, pump wells containing high arsenic are usually scattered in each village.

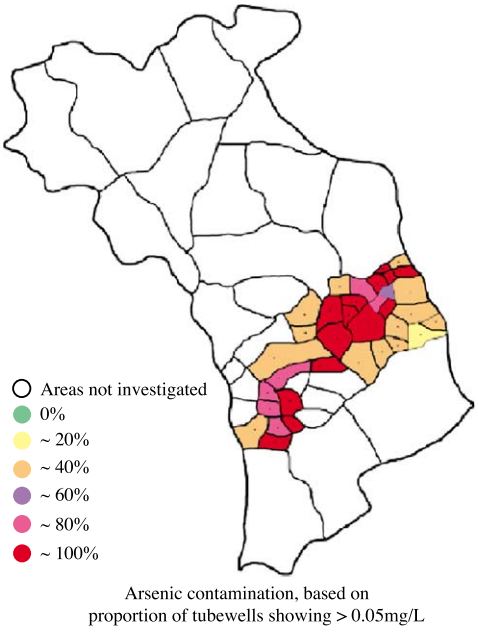

Fig. 2. Distribution of pump wells in one epidemic area of arsenicosis of Shanxi (each small unit represents a village).

Four provinces, including Shanxi, Jilin, Ningxia, and Qinghai, were investigated for the prevalence rate of arsenicosis in 2002. The findings are shown in Table 2. From these data, it is clear that the rates of arsenicosis in Shanxi, Qinghai, and Ningxia are much higher than in Jilin. However during our investigation, we found that although there are relatively few patients in Jilin compared to other provinces, the symptoms of patients found in Jilin were the most severe. Nearly all cases of arsenicosis were

Table 1
Arsenic concentration in pump well water investigated in six provinces of China in 2002

Province	Villages	Wells investigated	Unsafe wells (>0.05 mg/l)	Percent of unsafe wells
Shanxi	35	3079	1612	52.35
Inner Mongolia	64	5885	665	11.30
Xinjiang	463	14050	670	4.77
Jilin	125	8200	1001	12.21
Ningxia	22	8276	88	1.06
Qinghai	4	24	2	8.33

Table 2
Patients of arsenicosis investigated in four provinces of China in 2002

Province	Villages investigated	Population at risk	Population investigated	Patients	Prevalence rate (%)
Shanxi	79	60324	31320	3371	10.8
Jilin	27		7745	161	2.08
Ningxia	22	5382	4609	486	10.5
Qinghai	4	9001	1896	260	13.7

classified as severe. In contrast, most of the cases in the other provinces were classified as moderate.

Discussion

The current situation of endemic arsenicosis in China is considered a grave public health problem. At present, the population exposed to high amounts of arsenic is estimated to be more than three million, and more than 30000 arsenicosis patients have been confirmed. New endemic areas are continuously emerging. Since 2001, we had been carrying out a nationwide survey of arsenicosis in China. Besides the known epidemic areas, that is, Xinjiang, Inner Mongolia, Shanxi, and Guizhou, new areas have been found in Jilin, Ningxia, and Qinghai provinces. Up to now, the epidemic areas of arsenicosis mainly involve eight provinces and 37 counties in China.

In the affected areas, the discovery of wells and coal with high levels of arsenic is continuing sporadically, and a similar scattered distribution pattern of patients is also being observed. Therefore, extensive investigation of arsenic concentration in the pump wells should be carried out in the areas around the known epidemic areas.

Although nearly 30000 persons have been identified as patients of arsenicosis, not a single one has been found having the symptom of blackfoot disease in mainland China. This is quite distinct from Taiwan, where arsenicosis patients often have blackfoot disease. A major question is what has resulted to cause this marked difference between the mainland and Taiwan. How blackfoot disease is formed, and what factors are contributing to it.

Another extremely serious issue is that a high cancer incidence has been observed some areas. Thus, the populations in most endemic areas, who have been exposed to high levels of arsenic for about 20 years, could have a greatly elevated risk of developing cancer within the next 10 years. Our research center has found that 8-hydroxy-2′-deoxyguanosine (8-OHdG) in the urine of arsenicosis patients is significantly higher than non-patients living in the same village (data not shown). DNA damage occurs in human lymphocytes cultured with arsenic in vitro for 24 h as measured by single cell gel electrophoresis (SCGE) (Li et al., 2002). The relationship between arsenic exposure in the epidemic areas of arsenicosis and the occurrence of arsenic-related cancers is still uncertain. Defining the exact mechanism of carcinogenesis caused by arsenic will require additional research. Moreover, the toxicological basis of individual difference observed in patients of arsenicosis is another undefined issue that could have important public health implications.

Acknowledgments

We express our sincere thanks to UNICEF China and JICA of Japan for the financial supports which enable us to carry out investigations and studies in the selected areas.

References

Bates, M.N., Smith, A.H., Hopenhayn-Rich, C., 1992. Arsenic ingestion and internal cancers: a review. Am. J. Epidemiol. 135, 462–476.

Chen, C.J., 1990. Blackfoot disease [Letter]. Lancet 336, 442.

Chen, C.J., Hsueh, Y.M., Lai, M.S., Shyu, M.P., Chen, S.Y., Wu, M.M., Kuo, T.L., Tai, T.Y., 1995. Increased prevalence of hypertension and long-term arsenic exposure. Hypertension 25, 53–60.

Engel, R.R., Hopenhayn-Rich, C., Receveur, O., Smith, A.H., 1994. Vascular effects of chronic arsenic exposure: a review. Epidemiol. Rev. 16, 184–209.

Li, X., Sun, X.C., Sun, G.F., Jin, Y.P., Li, B., Guo, X.Y., Liu, S., 2002. Study on the effect of different DNA damage caused by arsenicals in human lymphocyte. Chin. J. Ind. Hyg. Occup. Dis. 20, 327–330.

Tondel, M., Rahman, M., Magnuson, A., Chowdhury, I.A., Faruquee, M.H., Ahmad, S.A., 1999. The relationship of arsenic levels in drinking water and the prevalence rate of skin lesions in Bangladesh. Environ. Health Perspect. 107, 727–729.

Tseng, W.P., 1997. Effects and dose-response relationships of skin cancer and blackfoot disease with arsenic. Environ. Health Perspect. 19, 109–119.