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Experimental dissolution of lead from bronze vessels and the lead content of human bones from Western Zhou dynasty tombs in Hengshui, Shanxi, China

Ying Qin [a], Haomiao Li [a, *], Xiaoyong Yang [b], Huang Huang [a], Ya Qin [a], Yaoting Xie [c]

[a] Department of History of Science and Scientific Archaeology, University of Science and Technology of China, Hefei, Anhui 230026, China
[b] CAS Key Laboratory of Crust-Mantle Materials and Environments, School of Earth and Space Sciences, University Science and Technology of China, Hefei 230026, China
[c] Shanxi Research Institute of Archaeology, Taiyuan, Shanxi 043000, China

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ABSTRACT

Human skeletal lead content has been demonstrated to be related to socioeconomic status, occupation and other social and environmental factors. However, there is minimal research into the lead content found in ancient Chinese human remains.

A series of dissolving lead experiments on ancient bronze vessels containing lead revealed that lead contamination occurred when ancient people used lead-rich alloy vessels for cooking, heating and storing food and wine. 65 ancient bone and teeth samples (from occupants of tombs and sacrificed people and dogs of different tombs) excavated from a Western Zhou Period (B.C.1046~B.C.771) burial area in Hengbei, Jiangxian of Shanxi Provinces were analysed using ICP-MS to determine their lead content.

The lead content of teeth and bones from the remains of high-status individuals differs from those of the slaves and servants within the same tombs. In addition, it is observable that differences of bone lead contents are clearly related to social ranks.

1. Introduction

Elevated lead concentrations in human bones from archaeological excavations may provide evidence of lead poisoning (Aufderheide et al., 1981; Aufderheide et al., 1985; Wittmers et al., 2008; Landrigan and Todd, 1994; Erkkilä et al., 1992). In this study, we present chemical evidence of lead poisoning in elite burials in tombs of the Western Zhou period (1046–771 BCE) in China. The likely source of the lead ingested by these elites is the famous cast ceremonial bronze vessels used for eating and drinking on ritual occasions. These bronze castings typically contain 2–10% lead. In fact, Chinese forebears created their Bronze Age at the cost of human lead poisoning. In the Shang-Zhou period, a strict system of rites and music flourished, among which existed a rule of using bronze vessels. In the human body, absorbed lead is concentrated physiologically in the hydroxyapatite crystals of bone mineral, where it can be stored for decades. Hence, skeletal lead content can be a suitable indicator of lead exposure during an individual's lifetime and a mirror of the human behaviour that led to its absorption (Wittmers et al., 2002). One of the most important goals of archaeology is to reconstruct past human lifestyles; therefore, the measurement of bone lead content has the potential to make significant contributions to this effort.

To investigate this question, we performed a dissolving lead experiment and analysed the lead content of human bones from certain Bronze Age tombs (Ying et al., 2005; Ya et al., 2007; Ying et al., 2009). On the basis of previous research, skeleton samples were systematically collected from different grades of tombs in Hengbei, Jiangxian, and Shanxi provinces to test the bone lead content variation between the remains of individuals of different social status. This research proved very revealing of the social structure and living conditions in ancient China with a clear warning of the potential impact of lead pollution in the modern age.

2. Experiments on dissolving lead from bronze wares

We cast two bronze bowls that contained 88: 10: 2 and 80: 10: 10 percent by weight of copper: tin: lead, respectively. The

* Corresponding author.
E-mail address: Anne@mail.ustc.edu.cn (H. Li).

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Table 1
The result of the dissolving lead experiment.

Solution	Sample	Experiment	Lead content/mg L^{-1}
Deionized water	original sample		<0.0002
	Wb1	Bowl B1 was filled with deionized water and remained for 48 h at room temperature.	0.0025
	Wb2	Bowl B2 was filled with deionized water and remained for 48 h at room temperature.	0.149
	Wb21	Sample Wb2 was heated to approximately 70 °C for 15 min. Sample Wb2 was heated for 15 min to approximately 70 °C.	0.352
Rice wine	original sample		0.04
	Rb1	Bowl B1 was filled with rice wine and remained for 24 h at room temperature.	28
	Rb2	Bowl B2 was filled with rice wine and remained for 24 h at room temperature.	51
Vinegar	original sample		0.08
	Vb1	Bowl B1 was filled with vinegar and remained for 6 h, then was heated to 30 °C	34
	Vb2	Bowl B2 was filled with vinegar, remained for 6 h at room temperature and then heated to 30 °C for five minutes	67
	Vb21	Bowl B2 was filled with vinegar and remained for 12 h at room temperature.	18.6
	Vb22	Bowl B1 was filled with vinegar and remained for 36 h at room temperature.	25
	Vb23	Bowl B2 was filled with vinegar and remained for 60 h at room temperature.	36.2
Pork bone soup	original sample		0.06
	Tb1	Bowl B1 was filled with pork bone soup and remained for 24 h at room temperature.	1.62
	Tb2	Bowl B1 was filled with pork bone soup and remained for 24 h at room temperature then was heated until it boiled for approximately 30 min	2.14

The room temperature of the lab during the experiment ranges from 6 °C to 15 °C.

diameter of the bowls' mouth is 9 cm, and the depth is 3.5 cm. The thickness is approximately 0.2 cm. The bowls' weights are 305 g and 320 g, respectively.

The elites in the Xia-Shang-Zhou dynasties usually used the bronze vessels to cook, heat and store food and drink; therefore, we used real foods and drinks rather than chemical reagents throughout the dissolving lead experiment. Experimental materials, the process and the lead content of the samples for dissolving lead from these bronze wares are shown in Table 1.

The lead content test was performed in the Experiment Centre at USTC. For the analysis of Rb1, Rb22, Vb1, Vb21, Vb22, Vb23, Tb1 and Tb2, we used an atom absorption spectrophotometer (Model: PE3030). A fluorescence spectrophotometer was used (Model: AFS230a) to analyse the other samples. The reference material used for the analyses were standard materials of Pb solution for compositional analysis of the People's Republic of China (GBW (E) 080987).

Table 1 shows that the lead contents of experimental samples are a hundred to a thousand times higher than those of the original samples, which is far above the lowest national limit of lead content in certain current related food and drinks in China (0.05 mg/L in domestic drinking water and 0.2 mg/kg of alcohol). This finding indicates that using lead-bearing bronze vessels to cook foods or heat alcohol and other drinks would lead to lead contamination.

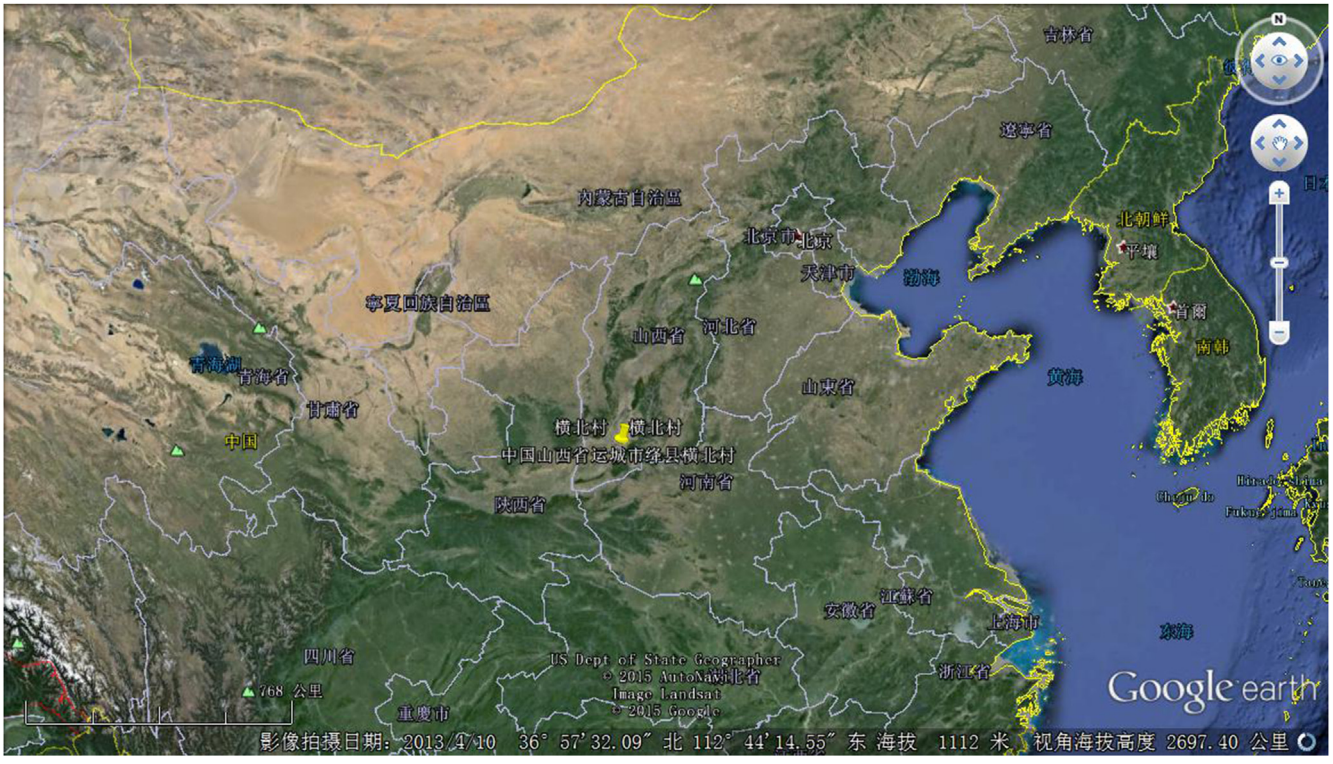

Fig. 1. Position of Jiangxian County in the map.