Available online at www.sciencedirect.com
SCIENCE DIRECT®
Chemico-Biological Interactions 153–154 (2005) 55–64
Chemico-Biological Interactions
www.elsevier.com/locate/chembioint

An overview of published benzene exposure data by industry in China, 1960–2003

You-Xin Liang [a,*], Otto Wong [b,c,d], Thomas Armstrong [e], Xi-Biao Ye [a], Li-Zhuang Miao [a], Yi-Mei Zhou [e], Qiang-En Wu [a], Hao-Jun Qian [a], Hua Fu [a]

[a] Fudan University School of Public Health, 138 Yixueyuan Road, Shanghai 200032, PR China
[b] Applied Health Sciences Inc., San Mateo, CA, USA
[c] Department of Epidemiology, Tulane University, New Orleans, LA, USA
[d] Department of Community Medicine, Chinese University of Hong Kong, Hong Kong, PR China
[e] ExxonMobil Biomedical Sciences Inc., NJ, USA

Available online 25 April 2005

Abstract

This article presents an overview of occupational benzene exposures in China based on data published in Chinese medical journals. The data were derived from 384 reports of benzene poisoning or industrial hygiene surveys published in Chinese medical journals between 1960 and 2003. The following information was extracted whenever available: industry, occupation, task, date, benzene levels, sampling location, workplace descriptions and, for case reports, medical diagnosis. Each paper provided one or more sets of benzene data, each set representing a sampling location or job title with one to several measurements including, mainly, breathing zone area concentration measurements, and much less frequently personal monitoring. Two criteria based on data quality were applied to select suitable data for analyses. The selected exposure data were analyzed by industry and time period. Nine hundred five sets of benzene measurements from 72 industries were reported in the 384 papers selected for this review, and 621 sets (68.6%) presented average benzene concentrations, which covered 55 industries. The distribution of the reported average benzene exposures was skewed with a median of 51.5 mg/m^3. The average benzene concentrations were below 100 mg/m^3 for 406 (65%) of the 621 reported average concentrations. The medians of the reported averages in mg/m^3 for the five industries with the highest exposures were: 124.8 for leather products, 98.7 for electronic devices, 75.4 for machinery, 50.4 for shoes, and 50.3 for office supplies and sports equipment manufacturing. These data describe the concentrations and changing patterns of occupational benzene exposure by industry and time period in China.

Keywords: Benzene; Occupational exposures; Benzene poisoning; Literature database; China

1. Introduction

Benzene is one of the most widely used industrial chemicals in China. A wide variety of industries and occupations particularly the shoe and suitcase industries

* Corresponding author. Tel.: +86 21 64043069; fax: +86 21 64043069.
E-mail address: yxliang@shmu.edu.cn (Y.-X. Liang).

0009-2797/$ – see front matter © 2005 Elsevier Ireland Ltd. All rights reserved.
doi:10.1016/j.cbi.2005.03.009

in China use benzene or benzene-containing solvents and adhesives [1]. The Chinese occupational medical literature is replete with reports of benzene overexposure and benzene poisoning [2,3]. In 1979–1981 the Chinese Academy of Preventive Medicine carried out a national occupational health survey of more than 500,000 workers in China who were identified as having been exposed to benzene [4]. The reported geometric mean concentration of benzene was 18.1 mg/m^3 and the 95% range at workplaces was 0.06–844.74 mg/m^3 or 0.02–266 ppm (1 ppm = 3.18 mg/m^3), with some workplaces (1.3%) having benzene concentrations in excess of 1000 mg/m^3. The data showed a skewed distribution with a second mode at approximately 200 mg/m^3 and more than 10% of the data were at or above this value [4]. The nature of the distribution makes the median of these data difficult to interpret. Measurements of area breathing zone occupational benzene exposure from the 1950s to the late 1980s taken at factories in Shanghai were reported in a recent article [5]. This database of benzene measurements is maintained by the Shanghai Municipal Institute of Public Health Supervision. The arithmetic mean of benzene measurements for workplaces reported in the database was 132.7 mg/m^3 and the median was 2.8 mg/m^3.

In addition to ad hoc industrial hygiene surveys reported in the literature, there are incidents of acute poisoning and investigations of exposures associated with such events. For example, an investigation of 33 cases of serious benzene poisoning and nine deaths in 2002, associated with small-scale suitcase manufacturing, reported exposures as high as 2040 mg/m^3 [6].[1]

Industries in China have been regulated with occupational exposure limits (OELs) for benzene since the 1950s. These limits have gone through revisions over the years as shown in Table 1, including a shift from the prior area concentration basis to personal exposure measurements in 2002. The development of OELs in China has been discussed in a number of recent articles [1,7].

The current article presents an overview of occupational benzene exposures reported in Chinese medical journals between 1960 and 2003. The review includes 384 papers of benzene poisoning case investigations or industrial hygiene surveys, covering 72 industries in China classified according to the national industrial coding system [8]. Included in the overview is an analysis of benzene exposure data by industry and time period.

[1] No systematic monitoring data with the report were available as the governmental occupational health inspection has not always effectively accessed the informal work sectors in rural areas.

Table 1
Past and current benzene occupational exposure limits in China

Years	Standard	Reference
1956–1979	50 mg/m^3, Area breathing zone concentration	[11,12]
1979–2002	40 mg/m^3, Area breathing zone concentration	[13]
2002–Present	10 mg/m^3, Permissible concentration-short term exposure limit; 6 mg/m^3, permissible concentration-time weighted average	[14]

2. Material and methods

2.1. Information sources

Published literature was identified primarily through Internet searching of the China National Knowledge Infrastructure, which covers 1994–2003 and the Chinese Biomedical Literature Database, which covers 1978–1993. Manual searching was also carried out to supplement the online search, particularly for conference proceedings and articles published before 1978. Through this process, a total of 384 benzene poisoning case reports or industrial hygiene surveys published in Chinese journals were identified.

The benzene exposure data was systematically extracted into a database. From each paper, the following information was extracted whenever available: industry, occupation, task, year, benzene levels (minimum, average and/or maximum), workplace descriptions and, for case reports, medical diagnosis. Each paper provided one or more sets of benzene measurements, with each set representing one or more measurements for a sampling location or job title. Data for inclusion in the analyses were selected by applying standard acceptance criteria (as described below). Exposure data were analyzed according to industry and time period. Table 2 provides an example of the data extracted for the database. The analyses do not distinguish between area concentration measurements and personal measurements because personal measurements were quite rare and the reports did not necessarily distinguish them, and the rare personal samples were unlikely to alter the general conclusions of the analyses in this report.

2.2. Selection criteria

Two criteria were applied to select the published data and information for inclusion in the analyses. The first criterion was used to select data for the analysis by industry type and the second criterion was used for selecting data for temporal analysis.

For the selection of data for the comparison of exposure level by industry type, the most important factors were the number of measurements in each set of measurements and the number of sets of measurements for the industry. A set of measurements consisted of: the sampling location or job title, the benzene measurements taken, and the year. Table 2 presents data from five published articles on benzene measurements. Article B in Table 2 provided three sets of measurements, covering three different jobs, while article E in Table 2 provided two sets of data, covering two different locations.

For the analyses in this report, we chose a weighted selection score (WSS) (described further below) of 18. This criterion considers the number of samples in a set and the number of measurement sets in a given industry. A score of 18 was the minimum for an industry to be included in the analyses. For example, using the leather industry data in Table 2:

$$\mathrm{WSS} = 60 + 60 + 60 + 7 + 26 + 12 = 225$$

Alternatively, if only report C had been available for the leather industry, the WSS = 7, which is below our required score of 18 and would thus not be included in the trend analyses.

A key component of the WSS criterion for data sets in our review was the quantitative strength of the data. Our "rule of thumb" for this hinged on a commonly accepted sample size of six measurements in each set and six measurement sets in a given industry as a basis for a reliable estimate of an average concentration in typical industrial hygiene surveys [9]. It would

Table 2
Examples of benzene exposure data extracted from the published Chinese medical literature for leather manufacturing

Article	No. of cases and diagnosis	Industry	No. of sets	Year	Task/area description	Min. conc. (mg/m^3)	Aver. conc. (mg/m^3)	Max. conc. (mg/m^3)	No. of samples
A	5 (atypical anemia)	Leather manufacturing (shoes)	1	1983		0	370	1530	NA
B	77 (chronic poisoning)	Leather manufacturing (shoes)	3	1985	Soles adhesive brushing	NA	1128.39	NA	60
					Underlay adhesive brushing	NA	440.39	NA	60
					Assembly finishing	NA	48.43	NA	60
C		Leather manufacturing (watch bands)	1	1989		45	122.5	300	7
D	17 (chronic poisoning)	Leather manufacturing (shoes)	1	NA		4.3	NA	308	26
E		Leather manufacturing (suitcases)	2	2001	Garment I	NA	191.71	NA	NA
					Garment II	NA	126.44	NA	12

NA: not available.

have been optimal if each set of measurements had six samples as well to produce a score of 36 or above for calculating the median for each industry. However, this goal of six samples per set and six sets proved to be too stringent, so a compromise weighted score of "18" was chosen in order to include more data sets for the exposure level analysis according to industry type.

The criteria used to select information for the analysis of overall temporal trends of benzene exposure by industry required the published papers for the industry to include both average exposure concentration results and the year, and have at least six sets of measurements for each year.

2.3. Statistical analysis

Nonparametric tests followed by the Kruskal–Wallis *H*-test were applied to the statistical analysis by industry type. The Linear, Quadratic and Cubic Polynomial tests of one-way ANOVA contrasts were used for the analysis of overall temporal trends of benzene exposure from 1979 to 2001. $P < 0.05$ was set to verify the statistical significance.

3. Results

3.1. General feature of occupational exposure to benzene

The articles included in the database were published between 1960 and 2003. Fig. 1 shows that few articles were published in the early 1960s and none between the mid 1960s and the late 1970s (the 10 years of the "Cultural Revolution" and its negative impact, which lasted for a few years afterwards). Starting in the 1980s, with the improvement of the national economy and health services, the frequency of inspections and air monitoring at workplaces greatly increased, resulting in a surge in the number of published papers.

Fig. 2 shows the distribution of average benzene exposure levels included in the present analysis of a total number of 621 sets data. It indicated that 264 data sets (42.4%) presented benzene concentration below 40 mg/m^3 including nine data sets (1.4%) reported having not-detected levels of benzene that were expressed as "0". There were 357 sets (57.6%) that exceeded 40 mg/m^3, the previous national benzene OEL adopted

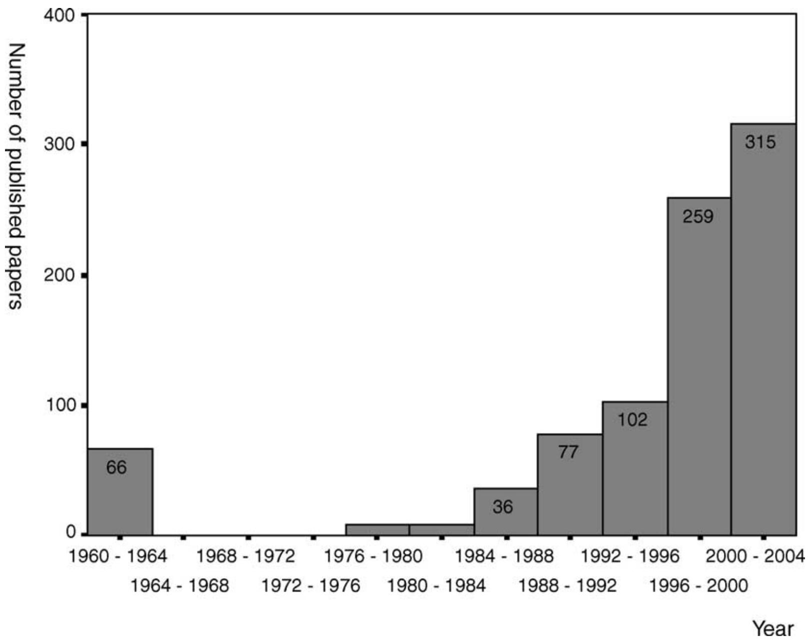

Fig. 1. Number of published reports included in the analyses by year. Numbers in each bar represent the number of reports included in the analyses for that time period.

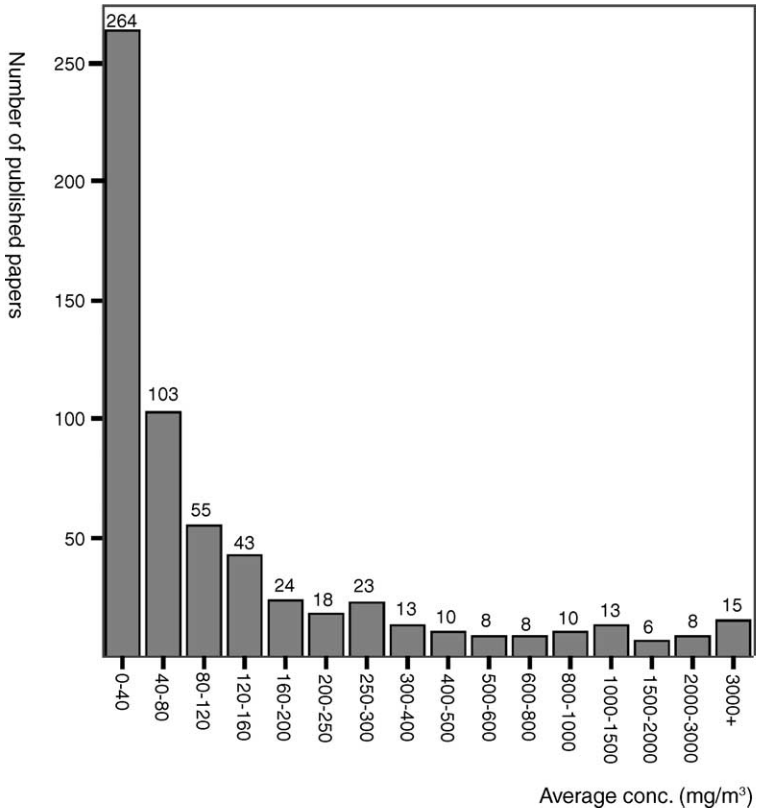

Fig. 2. Distribution of the average benzene exposure levels. Numbers in the bars denote the number of reports in the analyses in the given concentration range.

between 1962 and 2001 in China. Of those 621 sets, 142 sets (22.9%) presented concentrations between 40 and 100 mg/m^3, and 147 sets (23.7%) presented levels between 100 and 500 mg/m^3. There were 68 sets (11%) of measurements that far exceeded 500 mg/m^3, including 15 sets that reported benzene exposure concentrations above 3000 mg/m^3. The highest levels were found for the following occupations: paint coating/spraying and glue brushing (e.g., in shoes and suitcase industries). Some measurements were as high as several thousand mg/m^3. Levels of more than 10,000 mg/m^3 were reported for work in confined spaces without adequate ventilation, which was usually associated with acute benzene poisoning. As further examples, acute benzene poisoning cases were reported among workers who painted the inner walls of oil storage tanks, worked in poorly ventilated basements, or in deep wells.

3.2. Comparison of benzene exposure by industry

Reports for 39 industries included both average benzene concentration data and the number of samples. According to the selection criteria, 27 (69.2%) industries (1972–2002) of the 39 met the required WSS of 18 and were included in the analysis according to industry. The results, given in Table 3, show that the median benzene exposures in the nine industries with the highest reported concentrations exceeded the previous OEL standard of 40 mg/m^3, and 59% (16 of 27) of the industries had median exposure levels above the new standards of either 10 mg/m^3 (permissible concentration-short term exposure limit; PC-STEL) or 6 mg/m^3 (permissible concentration-time weighted average; PC-TWA).

The previous OELs for chemical substances and dusts were expressed as maximum allowable concentrations that were mainly based on stationary area

Table 3
Comparison of the average benzene concentrations (mg/m^3) by industry

Code	Type of industry	No. of sets	No. of samples	Median	Average (range)
252	Leather products[a]	18	1487	124.8	124.1(3.7–267.8)
449	Electronic devices manufacturing[a]	6	1930	98.7	120.2(4.5–254.9)
42, 43	Machinery manufacturing[a]	6	6815	75.4	75.6(4.2–152.7)
243	Shoes manufacturing, leather[a]	70	12197	50.4	149.9(1.3–1488.6)
291	Office supplies and sports equipment[a]	6	106	50.3	79.4(10.7–256.0)
321	Spray painting	29	1186	39.8	53.4(0–226.8)
270	Furniture manufacturing	8	618	39.3	36.6(2.0–72.0)
444	Msc. electronic parts manufacturing	7	197	33.6	50.5(3.0–105.6)
472	Automobile manufacturing	6	3478	32.8	56.8(0–196.1)
314	Organic chemical industry	19	650	23.8	39.3(12.8–130.5)
341	Rubber products manufacturing	15	182	22.9	114.6(0.1–633.6)
998	Other industries	10	6799	18.5	23.8(2.2–85.5)
320	Paint manufacturing	37	525	13.2	23.9(1.0–127.5)
31	Chemical industry	18	859	7.6	19.3(0–123.9)
294	Printing industry	8	6416	6.5	7.2(0–23.6)
401	Metal-based products processing	10	77	1.4	7.5(0–38.0)
296	Toy manufacturing	2	2531	132.9	132.9(1.5–264.3)
363	Coal products manufacturing	3	23	96.0	79.8(12.8–130.5)
361	Crude oil processing	3	992	62.6	54.4(7.4–93.2)
512	Petroleum & geological prospecting	3	22	57.2	41.9(5.8–62.6)
238	Other textile industries/printing & dyeing	1	178	26.2	26.2
520	Civil engineering & construction	3	137	20.3	122.2(1.2–345.2)
374	Pottery & porcelain products manufacturing	3	26	20.2	22.4(7.1–40.0)
450	Electronic circuit manufacturing	3	26	20.2	22.4(7.1–40.0)
342	Plastic products manufacturing	2	1216	15.2	15.2(2.3–28.2)
499	Other precision instruments manufacturing	2	44	14.3	14.3(8.7–19.9)
407	Household metal hardware manufacturing	1	1139	2.3	2.3

[a] Denotes the top five industries with more than six measurement sets in an individual industry. Industries following the blank space (after 401, metal-based processing) are those for which fewer than six data sets were available.

breathing zone monitoring samples until 2001. The newly developed OELs in terms of TWA and STEL have been adopted since 2002 while the area breathing zone monitoring samples at workplace are still used because personal samplers have not been commonly available. Therefore, the data remain comparable.

Table 3 compares benzene measurements by industry, sorted by the median of the reported average exposures. Twenty-seven of the most related industries were ranked by median benzene concentrations in the table and further analyses were conducted to verify the statistical differences of exposure levels by nonparametric tests. Table 3 shows the five industries with the highest exposures (that met the criteria of six sets or more of measurements) were: leather products, electronic devices, machinery, shoes, and office suppliers and sports equipment manufacturing.

3.3. Historical trends of the benzene exposure data

According to the selection criteria described above, the reports of medians of the exposure levels for the 22 years between 1979 and 2001 were adequate for temporal trend analysis. The benzene exposure levels for the 22 years were overall significantly different ($P < 0.05$). Fig. 3 shows the trend by year for the median exposure levels.

These trends were most likely influenced by several historical events. First, the national economy started growing in the late 1970s, which resulted in increased numbers of small-scale industries (SSIs) in rural areas. Second, the improvement of occupational health services after the mid 1990s brought about more stringent health inspections and workplace monitoring and resulted in more published data. Third, the new Occupational Disease Prevention and Control Act was adopted

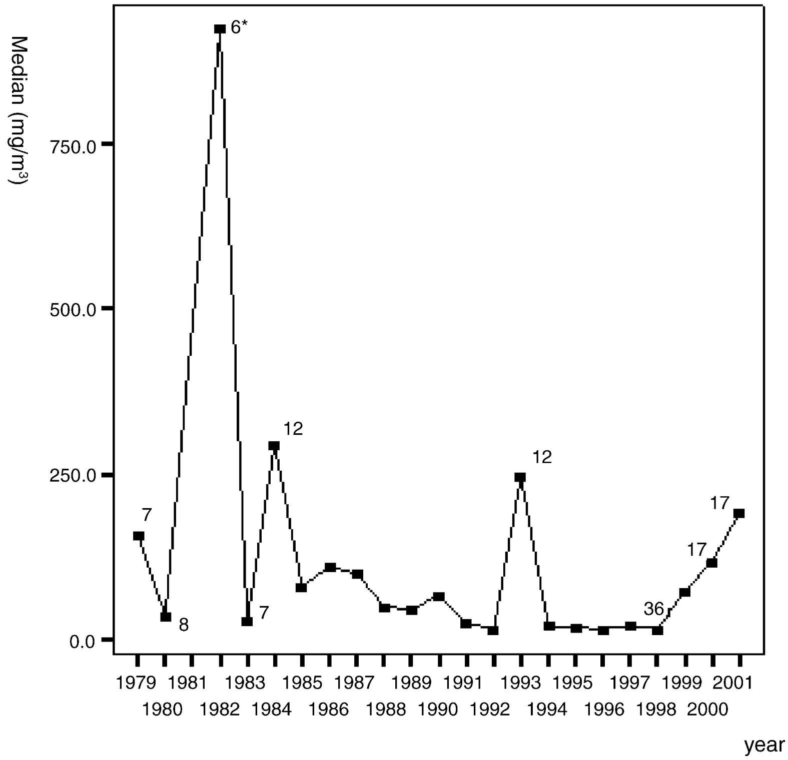

Fig. 3. Overall trend in median benzene exposure in Chinese industry, 1979–2001. (*) Indicates the number of measurement sets in the database.

by the Standing Committee of the National People's Congress in 2001, which required the reporting of benzene over-exposures in industries, including in the SSIs in rural areas [10].

As shown by Figs. 4–7, average benzene exposure levels in several major industries showed a similar but variable decline over the years. More significant declines were evident for the earlier periods. Most of these industries show slightly increased exposure concentrations at the beginning of the 21st century. The industries (Figs. 4–7) were chosen for the analysis according to industry type mainly because of the amount of data available for them. This may in part be due to more frequent investigations of these particular industries.

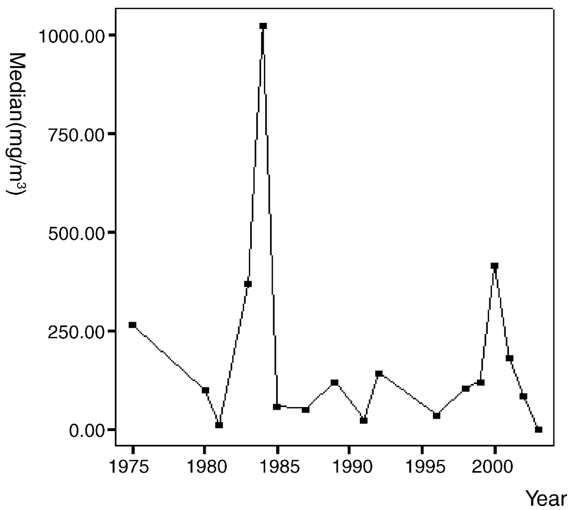

Fig. 4. Change in average benzene exposure levels in leather manufacturing over time (1975–2003).

4. Discussion and conclusions

This review article describes the Chinese data for occupational benzene exposure and its changing patterns according to industries and time period based on

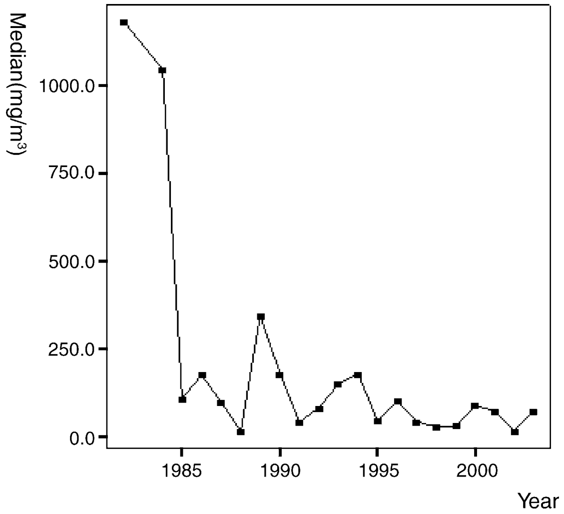

Fig. 5. Change in average benzene exposure levels in leather shoes manufacturing over time (1982–2003).

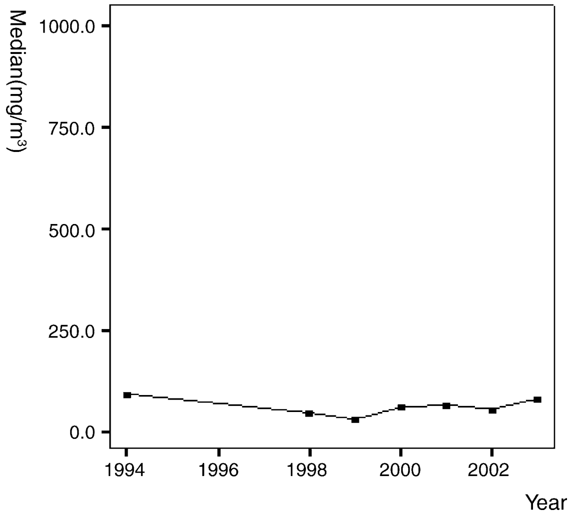

Fig. 7. Change in average benzene exposure levels in furniture manufacturing over time (1994–2003).

the data extracted from the published Chinese medical literatures between 1960s and 2003. The results provide important information for prioritizing the prevention strategy of benzene poisoning. The median values of the reported average concentrations and the ranges of the averages for the five highest industries (with six or more sets of measurements) are: leather products, 124.8 (3.7–267.8 mg/m^3); electronic devices, 98.7 (4.5–254.9 mg/m^3); machinery, 75.4 (4.2–152.7 mg/m^3); shoes, 50.4 (1.3–1488.6 mg/m^3); and office supplies and sports equipment manufacturing, 50.3 (10.7–256.0 mg/m^3). These coincide with previously reported industries with higher prevalence of benzene-related hematopoietic diseases [4]. The percentage of industries with reported medians exceeding the prior OEL of 40 mg/m^3 was 33% (9 of 27). For 59% (16 of 27) of the industries, medians of the exposure levels were below the prior OEL (40 mg/m^3) but above the new standards of either 10 mg/m^3 (PC-STEL) or 6 mg/m^3 (PC-TWA).

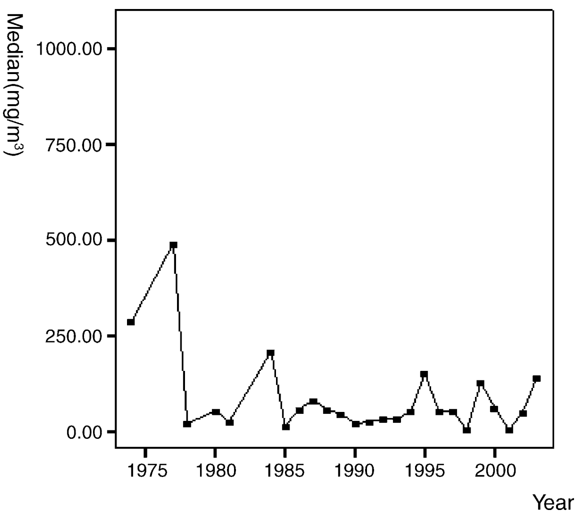

Fig. 6. Change in average benzene exposure levels in spray painting over time (1974–2003).

With innovations in production technology, which included the use of toluene and xylene instead of pure benzene and improved working practices, and the improvement of occupational health services, overall average benzene exposure levels appeared to decline over the years. In particular, industries traditionally with high exposures such as leather products manufacturing, shoes, paint spraying and furniture industries showed declines. Relatively high levels (270.38 mg/m^3) were observed during the period between 1981 and 1985, but dropped to 73.85 mg/m^3 in the second half of 1980s. The exposure levels declined further to 48.42 mg/m^3 during the period between 1996 and 2000. However, the exposure levels fluctuated due to the influence of the national economic development and newly implemented legislations. For example, the average of the reported exposures rose to 121.25 mg/m^3 at the beginning of the 21st century, which might partially be due to the wider disclosure of over-exposures in small workshops commonly found in rural areas. Additionally, the current public awareness and the frequency of health inspection might bias the results to a certain extent. The declining tendencies of occupational benzene exposures were also shown by a Job-Exposure Matrix investigation in Shanghai based on a database maintained in Shanghai Municipal Institute of Public Health Supervision (1953–1989) [4].

There are a number of limitations associated with the published information and the analyses currently presented. These include:

1) Different sampling and analytical methods were employed over the decades covered. Although this may introduce some bias, we believe that the differences are minor and will not significantly alter the findings of this review.
2) Our analysis did not distinguish between benzene poisoning case reports and industrial hygiene surveys. Benzene poisoning case reports refer to investigation of the Chinese regulation-defined occupational benzene poisoning. Either acute or chronic benzene poisoning cases may thus represent high-end exposures. On the other hand, industrial hygiene surveys were commissioned for a variety of reasons, and are not necessarily targeted at facilities with benzene poisoning cases or high benzene exposures. The industrial hygiene survey reports thus may or may not better represent typical conditions.
3) Our selection criteria may have excluded some informative but smaller data sets. We believe the criteria gave us the more reliable data to use in our analysis, resulting in more robust summaries.
4) The original investigators who reported the data may have had a range of investigative needs and approaches that introduced indeterminate biases into their reported data. For example, what motivated or initiated the authors to write up benzene poisoning reports or industrial hygiene surveys and submit them for publication?
5) The data in the original reports are area samples that represent concentrations in the air at the location and time measured. However, these concentrations might not directly reflect worker exposures, particularly for full-shift exposures, because they did not account for various potential exposure zones.
6) The data for trend analyses in this report are averages given in the reports. These averages should give a good estimate of the typical concentrations. However, the averages do not give insights into the range and variability of the concentrations in the industries covered.

Acknowledgements

We are indebted to the Benzene Health Research Consortium for sponsoring the Shanghai Health Study, as well as Dr. Jerry Rice, Chair, Scientific Review Panel, Dr. Patrick Beatty, Chair, Technical Committee, Prof. Richard D. Irons, Dr. A. Robert Schnatter, and Gail Jorgensen for their continuing support and encouragement in conducting the investigation of benzene exposures. The authors are also grateful for colleagues and medical students working at the University of Colorado Health Sciences Center and Fudan University Medical Center Joint Clinical and Molecular Laboratory, who contributed to the literature searching and database development.

References

[1] O. Wong, Regulation of occupational exposures in China, Regul. Toxicol. Pharmacol. 38 (2003) 109–111.
[2] O. Wong, Letter from Shanghai, Occup. Environ. Med. 60 (2003) 233.
[3] O. Wong, Investigations of benzene exposure, benzene poisoning and malignancies in China, Regul. Toxicol. Pharmacol. 35 (2001) 126–135.
[4] S.Y. Yin, Q. Li, Y. Liu, F. Tian, C. Du, C. Jin, Occupational exposure to benzene in China, Br. J. Ind. Med. 44 (1987) 192–195.
[5] S.R. Zhu, W. Lu, S.Z. Xue, J.S. Xu, Y.L. Jiang, Job-exposure matrix of Shanghai: the analysis of the intensity of occupational benzene exposure during 1953–1989, J. Environ. Occup. Med. 21 (2004) 52–54 (in Chinese).
[6] C.X. Zhao, R. Luo, J.G. Li, H.B. Zhou, W. Zhao, Analysis of the benzene poisoning episode in Gaobeidian suitcase industry in 2002, Chin. Occup. Med. 30 (2003) 32–34 (in Chinese).
[7] Y.X. Liang, Z. Su, W.A. Wu, B.Q. Lu, W.Z. Fu, L. Yang, J.Y. Gu, New trends in the development of occupational exposure limits for airborne chemicals in China, Regul. Toxicol. Pharmacol. 38 (2003) 112–123.
[8] State Bureau of Statistics, State Bureau of National Standards, Office of State Council of Census, Industrial Classification and Coding System of National Economy (official document for the 3rd National Census) (in Chinese), 1982.

[9] J.R. Mulhausen, J. Damiano (Eds.), A Strategy for Assessing and Managing Occupational Exposure, 2nd edition, AIHA Press, Fairfax, VA, 1998.
[10] Standing Committee of National People's Congress, Occupational Disease Prevention and Control Act, P.R. China (official document, in Chinese), 2001.
[11] State Commission of Economy Construction and Ministry of Health, P.R. China, Provisional Hygienic Standards for the Design of Industrial Premises (Standard-101-56) (official document, in Chinese), 1956.
[12] State Commission of Economy Planning and Ministry of Health, P.R. China, Hygienic Standards for the Design of Industrial Premises (GBJ) 1–62 (official document, in Chinese), 1962.
[13] Ministry of Health, P.R. China, Hygienic Standards for the Design of Industrial Premises (TJ36-79) (Official document, in Chinese, 1979).
[14] Ministry of Health, P.R. China, Occupational Exposure Limits for Hazardous Agents in the Workplace (GBZ 2–2002) (official document, in Chinese), 2002.