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Head-and-Face Anthropometric Survey of Chinese Workers

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Millions of workers in China rely on respirators and other personal protective equipment to reduce the risk of injury and occupational diseases. However, it has been >25 years since the first survey of facial dimensions for Chinese adults was published, and it has never been completely updated. Thus, an anthropometric survey of Chinese civilian workers was conducted in 2006. A total of 3000 subjects (2026 males and 974 females) between the ages of 18 and 66 years old was measured using traditional techniques. Nineteen facial dimensions, height, weight, neck circumference, waist circumference and hip circumference were measured. A stratified sampling plan of three age strata and two gender strata was implemented. Linear regression analysis was used to evaluate the possible effects of gender, age, occupation and body size on facial dimensions. The regression coefficients for gender indicated that for all anthropometric dimensions, males had significantly larger measurements than females. As body mass index increased, dimensions measured increased significantly. Construction workers and miners had significantly smaller measurements than individuals employed in healthcare or manufacturing for a majority of dimensions. Five representative indexes of facial dimension (face length, face width, nose protrusion, bigonial breadth and nasal root breadth) were selected based on correlation and cluster analysis of all dimensions. Through comparison with the facial dimensions of American subjects, this study indicated that Chinese civilian workers have shorter face length, smaller nose protrusion, larger face width and longer lip length.

Keywords: anthropometric survey; face dimensions; ergonomics; respirator sizing

INTRODUCTION

China has the largest population in the world and is the largest supplier of international labor (Yang *et al.*, 2007). Millions of Chinese workers rely on respirators and other personal protective equipment (PPE) to reduce the risk of injury and exposure to occupational hazards. Respirators are used not only to reduce the risk of exposure to contaminants associated with mining, construction and foundries but also to protect employees from diseases in healthcare settings. The ability to achieve a proper fit, for a given respirator and its wearer, is essential for providing adequate protection to workers.

In 1958, a head-and-face anthropometric survey of 43 173 military personnel was conducted in China (She, 2002). Then, in the 1970s, measurements from 2458 civilians were added to the database (She, 2002). An additional survey of 9392 civilians was

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conducted in the 1980 by the Beijing Institute of Labor Protection and the Chinese Institute of Science (CNIS, 1981). These three datasets were used collectively to create the Chinese national standard (GB2428-81) that was published in 1981. In this standard, 13 head sizes, based on 29 dimensions, were defined for males and females separately (Xiao, 1994; Yu, 2002). In 1988, a new database of Chinese human dimensions was established from 22 300 adults. The database included seven basic head-and-face dimensions: full-head length, sagittal arc, bitragion coronal arc, head breadth, head length, head circumference and menton–sellion length (face length) (CNIS, 1988). In 1998, Xiao *et al.* measured 41 head-and-face dimensions on 393 Chinese adults. From the collected data, Xiao *et al.* was able to create regression equations to predict head-and-face dimensions from the seven basic measurements collected in 1988. The predicted dimensions were used to create the most recent Chinese national standard of head-and-face dimensions for adults (GB/T2428-1998).

However, respirator fit test panels (RFTPs) for Chinese respirator users have yet to be established. Current respirator designs in China are based on the RFTPs developed by Los Alamos National Laboratory (LANL) in 1973 (Hack and McConville, 1978). These panels were developed based on the 1967 and 1968 US Air Force survey (Hack and McConville, 1978). The Respirator Research and Development Section of LANL developed anthropometric specifications for fit testing of full- and half facepiece respirators. The full facepiece fit test panel is based on the bivariate distribution of face length and face width while the half facepiece fit test panel is based on the bivariate distribution of the face length and lip length. There has long been a concern about the applicability of fit test panels, generated from military personnel, for civilian workers. In 2003, a large-scale head-and-face anthropometric survey of US respirator users was conducted by the National Institute for Occupational Safety and Health (NIOSH) (Zhuang *et al.*, 2004; Zhuang and Bradtmiller, 2005). In these studies, the researchers compared military and civilian head-and-face measurements and found that the LANL full facepiece panel excluded >15% of the current US population. Yang *et al.* (2007) compared facial anthropometric dimensions of 461 Chinese university students and teachers to the LANL panels and found that 12–35% of the Chinese subjects fell outside the ranges of LANL panels. However, the sample size was small and may not be representative of Chinese civilian workers or respirator users. It is necessary to conduct a large-scale head-and-face anthropometric survey and study the facial characteristics of Chinese workers.

The objective of this study was to examine head-and-face anthropometric data of current Chinese civilian workers. The study population included civilian workers employed in various types of industry and healthcare settings. The factors which relate to, or may influence, head-and-face dimensions were also analyzed. Cluster analysis was also conducted to identify representative dimensions to be considered for defining new RFTPs.

MATERIALS AND METHODS

Sampling plan

The populations were sampled by age and gender. Each cell was statistically independent, with a projected goal of 278 subjects per cell. The sampling strata consisted of three age strata (18–29, 30–44 and 45–66 years) and two gender strata (male and female). The expected number of sampling subjects was 1668. The sample size of each cell was calculated using the procedures outlined in International Organization for Standardization (ISO) *General requirements for establishing anthropometric databases* (ISO 15535, 2003). The international standard estimates the sample needed based on the variability in the dimension of interest and its coefficient of variance (CV), the level of relative accuracy desired (a) and the level of confidence (95%) desired in the resulting database [$n = (1.96 \times \mathrm{CV}/a)^2 \times (1.534)^2$]. Menton–sellion length (face length) is a bony landmark used in the design of respirators and also demonstrates the most variability; thus, it presents a worst-case sample size. If the level of precision is met for menton–sellion length, then it is also met for the other dimensions.

Until now, the best estimate for facial dimensions in China came from the most recent China national standard (GB/T2428-1998) (Xiao *et al.*, 1998). The mean menton–sellion length for the sample population was 119.0 mm with a standard deviation of 6.6 mm and a CV of 5.5%. Using the ISO formula, the specific parameters used in the calculation were 95% confidence and 1% of the mean (1.1 mm) as relative accuracy (a = 1). The level of accuracy was chosen because that is the best level of interobserver error that has been achieved by experienced measurers (Gordon *et al.*, 1989). The calculated sample size per sampling cell using these parameters was 278 [$(1.96 \times \mathrm{CV}/a)^2 \times (1.534)^2 = (1.96 \times 5.5/1)^2 \times (1.534)^2 = 278$]. The number of subjects sampled in each stratum is shown in Table 1.

In order to obtain a representative sample, our goal was to sample from two or three workplaces in each of the five geographical regions: north, south, central, east and west. The recruitment of the study participants occurred at workplaces that require use of respirators. Flyers were posted at each location along with materials explaining the objectives of the study and its importance for future respirator development. Technicians spoke directly to potential subjects to ensure as close to full participation as possible.

The final samples include subjects from two to three workplaces in each of the following provinces: Hubei (central), Jiangxi (eastern), Chongqing (western), Guangxi (south western) and Shanxi (north western). In an effort to ensure the capture of an adequate sampling of all selected head-and-face shapes and sizes, any individual who volunteered for the study was measured, resulting in a total of 3000 Chinese civilian workers. About half of the 3000 subjects worked in metal mines or factories and used respirators regularly. Subjects consisted of 2026 males and 974 females. They were divided into groups based on occupation (healthcare, mining, manufacturing, construction and others) and region of birth (northern or southern China). Subjects were measured at the limited number of locations, but they were born in 29 provinces. Yangzi river traverses China from west to east. Geographic region of birth was determined by the province location in relation to the Yangzi river (north, south).

Anthropometric instruments and software

Traditional anthropometric instruments were used, including a Lufkin steel measuring tape (Cooper Tools, Apex, NC, USA), a spreading caliper, a sliding caliper (GPM Instruments, Zurich, Switzerland) and a pupilometer. All measurements were entered into a computer with NIOSH-generated data entry and editing software. The software was designed to indicate to technicians any anomalous values outside of an expected range for each measurement. If data entered fell outside the specified range, the computer provided a warning and the measurement was reevaluated.

Table 1. Final sample by sampling cell

Age group	Male	Female
18–29	702	317
30–44	829	451
45–66	495	206
Total	2026	974

Measurement of facial dimensions

Dimensions were selected to satisfy respirator and PPE design and testing. Most dimensions were measured on the face (11 dimensions) and around the head (7 dimensions). The list of these measurements is shown in Table 2. Neck circumference was added to data collection because it is the primary dimension for some types of respirators, and sellion–tragion length was included for its useful role in the design of eye and face protective devices. Stature, weight, waist circumference and hip circumference were also collected. Measurements were made according to methods described by Zhuang and Bradtmiller (2005) and 'China national standard basic human body measurements for technological design (CNIS, 1999)'.

Before conducting the study, a technician's handbook and video detailing instructions for measuring the desired dimensions were prepared. Technicians were trained according to these instructions and practised with each other until their measurement errors

Table 2. Face dimensions and landmarks

Dimensions	Tool	Landmarks	Landmark positioning
Head circumference	Tape	Infraorbitale	Right and left
Bitragion coronal arc	Tape	Tragion	Right and left
Bitragion frontal arc	Tape	Subnasale	—
Bitragion subnasale arc	Tape	Thyroid cartilage	—
Bitragion chin arc	Tape	Gonion	Right and left
Neck circumference	Tape	Frontotemporale	Right and left
Head breadth	Caliper	Zygofrontale	Right and left
Head length	Caliper	Zygion	Right and left
Minimum frontal breadth	Caliper	Glabella	—
Maximum frontal breadth	Caliper	Alare	Right and left
Face width	Caliper	Cheilion	Right and left
Bigonial breadth	Caliper	Sellion	—
Nose breadth	Sliding caliper	Subnasale	—
Lip length	Sliding caliper	Menton	—
Subnasale–sellion length	Sliding caliper	Pronasale	—
Face length	Sliding caliper		
Nose protrusion	Sliding caliper		
Sellion–tragion length	Sliding caliper		
Nasal root breadth	Sliding caliper		
Interpupillary distance	Pupilometer		

were less than, or equal to, the allowable errors. The allowable error means allowable difference between two measurements of facial dimensions by the same measurer or different measurers. The allowable errors in measurement, based on the work done by Clauser and coworkers, ranged from 2 to 8 mm depending on the dimension measured (Clauser *et al.*, 1988; Ren and Yin, 2006; Xie *et al.*, 2006).

After signing an informed consent form, the subject filled out a brief demographic questionnaire. The subject was then asked to sit calmly for 5 min prior to measurement. With the subject looking straight ahead, holding his/her teeth slightly occluded, technicians used eyeliner pencil to indicate landmark locations. Landmarks are specific skeletal points on the face or head. For this survey, a total of 15 landmarks were selected (Table 2).

After marking landmarks, the subjects were measured for each of the dimensions with anthropometric instruments. Data were recorded on the data sheet and simultaneously entered into the computers. The NIOSH software examined the values and indicated when the measurements were larger or smaller than their corresponding expected range for each dimension. In such instances, the technician measured a second time. If the problem was resolved, the second value was recorded and the first one was discarded. If the anomaly remained, both values were recorded in the electronic data file.

To evaluate the quality of the measurements, 50 subjects were selected to repeat the survey. The values obtained for both measurement sessions were analyzed by *t*-test, showing a significant difference ($P < 0.05$) between values for six dimensions: head circumference, bitragion frontal arc, bigonial breadth, neck circumference, nose breadth and subnasale–sellion length. The mean differences were within 1 mm with the exception of one dimension (i.e. bitragion frontal arc) with a mean difference of 1.4 mm. The mean absolute values of the differences were $\sim$1–2 mm.

Statistical analyses

The data were examined using regression analysis and put into a high low-value frequency distribution graph (not shown). For cases in which an unusual value was observed, hard copies were reviewed to see if there was a typographical error. A regression equation generated from the sample as a whole was sometimes used to select one of the two recorded values in an anomalous condition.

The sample distribution was not equivalent to the Chinese workforce. To accurately represent the distribution of the Chinese workforce in each of the sampling cells, the sample number needed to be proportionately weighted. A 1% sampling population of the 2005 China census data was used to calculate the weighting factors. People in the workforce were thought of as the total population between the ages of 18 and 66 years old. The census data were broken down into the same categories as those used in the sampling plan. The weighting factors were calculated as the relative frequency of a given cell in the census divided by the relative frequency of the same cell in the present study. Following the calculation of the weights, the weighted summary statistics were calculated for each measured dimension. The sample weighting factors were then used when calculating all statistics from this database. This procedure is similar to the method employed by Zhuang and Bradtmiller (2005).

Descriptive statistics were calculated for all dimensions by gender. Linear regression techniques were performed to evaluate the effects of age, gender, body mass index (BMI), geographic region and industrial sector on each of the anthropometric measurements. Regression was chosen due to its ability to properly assess the effects of both continuous and categorical variables, as well as its ability to deal with the unbalanced sample sizes present for certain variables in the dataset. In the regression analyses, age and BMI were treated as continuous variables, while gender, geographic region and industrial sector were treated as categorical variables. Dummy coding was used for gender (female being the referent category) and geographic region of birth (South being the referent). Effect coding was used for industrial sectors, meaning that the regression coefficients represent departures from the overall mean of all industry sectors. A familywise type I error rate of 0.05 was used for all regression analyses.

Cluster analysis was used to seek out relationships between head-and-face dimensions. A correlation matrix was established by calculating the correlations between all combinations of two head-and-face dimensions. The 'PROC VARCLUS' procedure in SAS for windows (SAS Institute Inc., Cary, NC, USA) was used to cluster all head-and-face dimensions into groups. This procedure starts with one cluster and splits clusters until all clusters have at most one eigenvalue >1. When choosing a cluster to split, this procedure chooses the cluster with the smallest proportion of variation explained, provided that its proportion of variation explained is <0.75.

Both the 2003 NIOSH anthropometric survey and this survey used the same measurement techniques. It was interesting to see how the Chinese population data differed from US data. Multivariate analysis of variance was employed in the comparison. In all multivariate analyses, the Wilks' Lambda was used to calculate the F value. Because the sample size in each survey was very large, the probability of type I error (rejecting the null hypothesis when it is true) was high. Therefore, in *post hoc* analysis, a difference of 2 mm (which is close to measurement error for many dimensions) or greater was required to indicate practical importance.

RESULTS

The final sample size for each cell is shown in Table 1. The sampling goal of 278 was met for all cells except women aged 45–66. The mean age and standard deviation of male and female subjects were 36.0 ± 11.1 and 35.4 ± 10.8 years, respectively. The weighting factor for each cell is summarized in Table 3 and was used for the calculations and statistical analysis provided below.

The distribution of subjects by type of workplace is shown in Table 4. It was not required that sample size be equal across types of employment because the number of respirator users is not the same in each occupation. The worker population is also not equally split between the genders. Females are the predominant users of respirators in healthcare settings while males are predominant users in the mining and manufacturing sectors. The summary of anthropometric statistics for 2026 male subjects and 974 female subjects is shown separately in Table 5.

Head-and-face anthropometric dimensions are reported to change due to many factors, including age, race, region of birth and other factors (She, 2002; Zhuang and Bradtmiller, 2005). To investigate these relationships, linear regression models were developed and the results are provided in Table 6. Regression coefficients for gender demonstrate the larger general size of males for all dimensions except hip circumference, where no significance was found. Measurements of dimensions also change significantly as age increases, but the maximum change was $<$1 mm.

BMI is the measure of individuals' weight in kilograms divided by their height in meters squared. Increases in BMI resulted in significant increases in all anthropometric dimensions, except for nasal root breadth and the subnasale–sellion length, where no significant difference was detected. This effect was most striking in waist circumference, where each increase of 1 unit BMI resulted in an average increase in measurement of 23.52 mm. Large increases were also seen in hip circumference (15.52 mm per unit BMI) and neck circumference (5.14 mm per unit BMI), with modest increases in facial measurements.

Coefficients obtained from the industrial sectors indicated that anthropometric dimensions of construction workers and miners tended to be smaller than the average of other industries. For example, face width, nose protrusion, bigonial breadth and nasal root breadth of construction workers and miners are 144.55, 17.90, 111.70 and 17.77 mm, respectively; these dimensions of the average of other industries are 145.58, 18.74, 120.76 and 18.48 mm, respectively. The differences may be due to the increased metabolic demands of performing these jobs, which might curtail the buildup of adipose tissue. Anthropometric measurements of healthcare workers and workers in the manufacturing industry were above the overall industry average, perhaps reflecting a lower metabolic workload among these workers, especially when compared to the physically demanding tasks required of construction workers and miners.

Table 3. Weighting factors by sampling cell

Age group	Gender	
	Male	Female
18–29	0.497642235	1.141502557
30–44	0.711261635	1.341827728
45–66	1.117866231	2.624538132

Table 4. Final sample by occupation

Occupation	Male		Female		Total	
	n	%	*n*	%	*n*	%
Healthcare	45	2.2	347	35.6	392	13.0
Mining	571	28.2	283	29.1	854	28.5
Manufacturing	997	49.2	124	12.7	1121	37.4
Construction	237	11.7	99	10.2	336	11.2
Others	176	8.7	121	12.4	297	9.9
Total	2026	100.0	974	100.0	3000	100.0

Comparisons of measurements obtained from subjects whose birthplaces are in the northern versus southern regions of China generally showed less influence than the other factors studied; however, some significant differences did exist between the regions. In general, measurements were slightly larger in the Northern region for bitragion chin arc, subnasale–sellion length, face length and nose protrusion (Table 6). However, some facial dimensions (head length, sellion–tragion length, nasal root breadth and nose breadth) were found to be slightly smaller in the Northern sample. Overall, regional differences were relatively minor, especially when compared to the effects of gender, BMI and industrial sector differences.

Cluster analysis was used to separate facial dimensions into five groups (Fig. 1). One dimension from each group was then selected, providing a subset of five dimensions representative of head-and-face type. Correlation analysis showed that the facial dimensions within an individual group were strongly correlated to one another. The intracluster correlation coefficient of any dimension to its own cluster is $>$0.50 for all dimensions, except for correlation coefficient of head length and face width (0.42) and of head length and nose breadth (0.37) ($P < 0.01$).

Table 5. Summary of anthropometric statistics by sex

Dimension	*N*	Mean	SD	Minimum	Maximum	Percentiles								
						P1	P5	P10	P25	P50	P75	P90	P95	P99
Male														
Bigonial breadth	2026	119.0	8.5	94	158	98	105	107	112	118	126	132	136	144
Bitragion chin arc	2026	327.6	12.9	275	417	294	303	310	317	328	337	346	352	363
Bitragion coronal arc	2026	358.7	11.8	308	406	325	335	340	350	360	368	376	380	390
Bitragion frontal arc	2026	311.7	10.1	276	365	284	292	296	303	312	320	326	330	340
Bitragion subnasale arc	2026	302.5	10.4	265	355	275	282	287	294	302	310	318	321	332
Face length	2026	117.3	5.6	92	145	103	107	109	113	117	122	126	128	133
Face width	2026	147.5	4.7	122	191	135	139	141	144	147	151	155	157	161
Hip circumference	2026	948.9	52.6	600	1170	810	850	870	909	950	990	1030	1050	1093
Head breadth	2026	157.2	5.3	112	180	144	147	150	153	157	161	165	167	173
Head circumference	2026	567.0	13.6	512	712	531	541	547	556	567	578	586	592	604
Head length	2026	185.7	5.8	160	220	170	175	177	181	186	190	194	196	201
Interpupillary distance	2026	64.2	2.7	53	76	57	59	60	62	64	66	68	70	72
Lip length	2026	52.2	3.4	38	68	43	46	47	50	52	55	57	59	63
Maximum frontal breadth	2026	120.6	5.7	101	162	105	110	113	116	120	125	129	131	136
Minimum frontal breadth	2026	108.7	5.1	89	132	96	99	101	105	109	113	116	119	122
Nasal root breadth	2026	18.3	1.9	12	31	14	15	16	17	18	19	21	23	27
Neck circumference	2026	366.1	19.4	291	463	320	330	337	350	365	380	395	405	425
Nose breadth	2026	39.2	2.4	30	54	33	35	36	37	39	41	43	44	46
Nose protrusion	2026	18.9	1.9	12	28	14	16	16	17	19	20	22	23	24
Sellion–tragion length	2026	68.2	10.7	45	108	47	50	52	55	70	75	83	90	99
Stature	2026	1703.1	49.3	1453	1900	1559	1600	1630	1670	1700	1740	1770	1800	1840
Subnasale–sellion length	2026	50.7	2.9	34	62	43	45	46	49	51	53	55	57	59
Waist circumference	2026	821.4	76.0	568	1110	650	687	705	751	820	880	940	970	1060
Weight	2026	66.9	8.1	45	102	49	52	55	60	65	73	80	84	92
Female														
Bigonial breadth	974	114.2	10.6	91	144	96	101	103	108	114	120	125	129	133
Bitragion chin arc	974	308.8	15.5	273	352	280	290	293	300	308	318	325	330	340
Bitragion coronal arc	974	344.5	16.7	275	393	309	322	328	335	345	354	360	365	374
Bitragion frontal arc	974	293.3	12.9	250	325	270	277	280	287	293	300	307	310	320
Bitragion subnasale arc	974	287.5	13.2	256	320	262	270	273	280	288	295	300	305	311
Face length	974	110.3	7.2	95	133	98	102	103	106	110	114	118	120	125
Face width	974	139.9	6.3	122	156	128	131	134	137	140	143	146	148	154
Hip circumference	974	932.3	70.1	700	1230	820	847	870	890	930	970	1009	1030	1090
Head breadth	974	150.5	7.1	132	171	138	142	143	147	150	154	158	160	164
Head circumference	974	546.2	17.2	505	603	515	523	529	537	546	555	564	570	580
Head length	974	176.7	7.5	160	201	163	168	170	172	176	180	185	187	191
Interpupillary distance	974	61.0	3.5	51	70	54	56	58	59	61	63	65	66	68
Lip length	974	49.8	4.6	36	61	40	43	45	48	50	52	54	56	58
Maximum frontal breadth	974	116.9	7.5	101	134	104	107	109	113	117	121	125	127	131
Minimum frontal breadth	974	106.6	7.5	91	126	95	97	99	102	106	111	114	116	121
Nasal root breadth	974	17.3	2.2	12	27	14	14	15	16	17	18	19	20	21
Neck circumference	974	321.6	24.9	260	415	282	293	298	308	320	334	348	357	374
Nose breadth	974	36.1	3.1	28	47	30	32	33	34	36	38	39	40	42
Nose protrusion	974	17.7	2.4	12	25	14	15	15	16	18	19	20	21	23
Sellion–tragion length	974	62.3	12.5	42	94	45	48	49	52	65	70	74	77	82
Stature	974	1596.9	59.6	1445	1750	1465	1515	1549	1568	1600	1630	1650	1680	1720
Subnasale–sellion length	974	47.3	3.9	37	57	40	42	43	45	47	49	51	52	55
Waist circumference	974	750.3	100.5	560	1103	600	635	658	692	740	800	860	910	968
Weight	974	55.9	9.2	38	95	42	45	48	50	55	60	65	70	77

Civilian worker sample weighted to represent Chinese population aged 18–66 (weight in kilograms, all other values in millimeters). SD, standard deviation.

Table 6. The regression coefficients of regression analysis for anthropometric measurements by age, gender, BMI, geographic region and industry sector

Dimension	Constant	Age	Gender	BMI	Region	Construction	Mining	Healthcare	Manufacturing	Adjusted R^2
Head circumference	508.39	−0.23	17.25	2.14		−5.66			2.60	0.41
Bitragion coronal arc	333.84	−0.46	11.84	1.28		−2.09	3.18	−2.73	2.05	0.31
Bitragion frontal arc	268.95	−0.21	14.17	1.52			−1.24	−1.74	4.52	0.48
Bitragion subnasale arc	249.24	−0.17	11.19	2.06		−2.15			3.13	0.45
Bitragion chin arc	253.97		12.81	2.56	3.00	−1.65	−3.27		3.32	0.47
Neck circumference	207.09		38.04	5.14		−10.26	2.03	4.27	6.42	0.77
Waist circumference	193.87	0.90	46.79	23.52		−21.52		23.52	12.90	0.76
Hip circumference	587.53			15.52		−27.58		10.06	15.56	0.61
Sellion–tragion length	68.12	−0.24	4.39	0.25	−2.77	3.92	−12.3	1.63	8.33	0.67
Head breadth	142.65	−0.15	6.05	0.64		−1.29	−0.76			0.33
Head length	168.32		8.84	0.41	−1.17	1.92		−2.38	−1.36	0.34
Minimum frontal breadth	95.55	−0.04	2.12	0.58		−4.16	−3.95	3.89	1.83	0.38
Maximum frontal breadth	106.92	−0.10	3.45	0.60		−5.72	−3.24	4.13	3.46	0.45
Face width	124.02	−0.10	5.97	0.92		−1.01		−1.16	0.66	0.46
Bigonial breadth	80.86		2.70	1.54		−4.08	−6.11	5.67	3.84	0.48
Nasal root breadth	20.03	−0.08	1.06		−0.75	−0.71	0.75	−0.50	0.89	0.20
Nose breadth	30.89	0.02	3.62	0.19	−1.15	−0.97		0.67		0.30
Lip length	41.76	0.13	2.53	0.13			−0.46	1.19		0.24
Subnasale–sellion length	45.25	0.06	2.97		0.64	0.55	−1.23	0.64	0.69	0.24
Face length	102.3	0.09	6.48	0.22	1.37	3.98		−1.20	−1.99	0.34
Nose protrusion	15.21	0.04	1.04	0.06	0.36	−0.42	−1.12	0.73		0.13
Interpupillary distance	57.51	−0.03	2.54	0.21		−1.78	0.37		1.27	0.30

Constant represents the regression intercept. Age and BMI are continuous variables. The regression coefficients for categorical variables represent differences of male versus female (referent), north versus south (referent) and industry sector versus the overall mean industry sectors (effect coding). Coefficients in the table are significant at a family-wise type I error rate of 0.05. For empty cells, coefficients were not statistically significant.

The intercluster correlation coefficient of any dimension to the next closest cluster is <0.33. The five groups contribute to 66.9% of the difference among all head-and-face dimensions. Five groups are (1) lip length and nose protrusion; (2) face length and subnasale–sellion length; (3) bitragion chin arc, bitragion frontal arc, bitragion subnasale arc, neck circumference, interpupillary distance, nose breadth, head circumference, head length, bitragion coronal arc, face width and head breadth; (4) bigonial breath, maximum frontal breath and minimum frontal breath and (5) nasal root breadth.

One index was selected from each group to account for a different aspect of head-and-face type. In the LANL panels, the dimensions of face length, face width and lip length were suggested as the key indexes because the full facepiece panel was based on the bivariate distribution of face length and face width and the half facepiece panel was based on the bivariate distribution of face length and lip length. Face length is menton–sellion length in group (2), face width is bizygomatic breadth in group (3) and lip length is in group (1). Lip length is a dimension that is difficult to measure because it varies depending on how a subject holds their jaw. Nose protrusion is a fixed dimension and is clustered with lip length; so for ease of measurement, it was chosen as the specific index from group (1). In addition to these three indexes, bigonial breadth in group (4) and nasal root breadth in group (5) are also independent factors that were chosen as representative dimensions. Face length, face width, nose protrusion, bigonial breadth and nasal root breadth were chosen to represent the main characteristics of head-and-face type among Chinese adults in the present study based on the statistical results.

DISCUSSION

It has been >25 years since the first survey on facial dimensions of Chinese adults was published. They have never been completely updated. However, due to the economic development of China over the last 20 years, the physical characteristics of the population have changed. This study provided current head-and-face anthropometric data for 3000 Chinese civilian workers. During subject sampling, age and gender were considered. The occupational distribution of subjects was also considered to reflect potential respirator users in China. To ensure that results

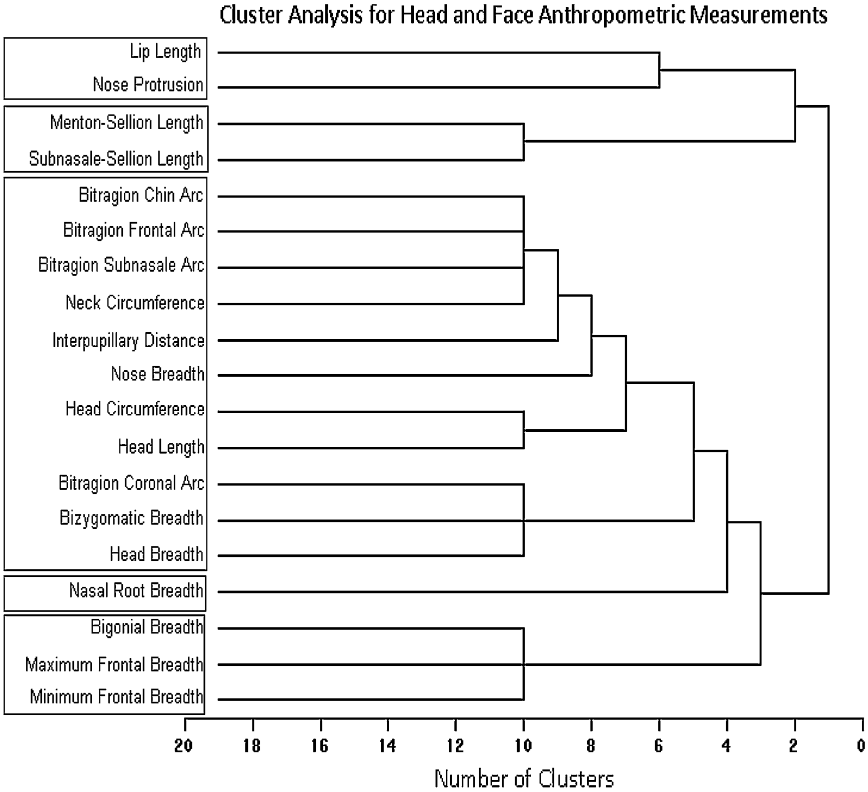

Fig. 1. Cluster analysis for head-and-face anthropometric measurements.

were representative of the Chinese national workforce, all data were weighted to account for subject distribution differences in various age and gender strata. The average variance explained by the regression models (Table 6) was 41%, with a range of 13–77%. Larger anthropometric dimensions tended to be associated with higher R^2 values. Examination of the coefficients suggests that gender, BMI and industrial sector effects were most influential in anthropometric differences, while age and regional differences had more minor influences.

In order to find the representative indexes of facial dimension for the Chinese population, cluster analysis was used to determine five facial dimensions to represent the main characteristics of Chinese head-and-face type. These 5 dimensions (face length, face width, nose protrusion, bigonial breadth and nasal root breadth) are a subset of the 10 dimensions that were selected for principal component analyses by Zhuang *et al.* (2007). In addition to the dimensions noted in this study, other dimensions have been found to impact respirator fit: nose breadth, minimum frontal breadth, interpupillary distance, head breadth and subnasale–sellion length (Zhuang *et al.*, 2005).

Table 7 lists measurements obtained in various surveys for a subset of facial dimensions. Each survey employed the same measurement techniques. In comparison with the facial dimensions of the Chinese national standard published in 1981 and 1998, lip length, face width and bigonial breadth (jaw width) for both genders in this study are elevated. The face length of male subjects in this study is smaller than Chinese national standard. The mean value of nose protrusion for females was larger than that of national standard. The face length of females and nose protrusion of males in this study are between national standard values of 1981 and 1998 (CNIS, 1998; She, 2002).

When compared with facial anthropometric dimensions of the US survey (Zhuang and Bradtmiller, 2005), we found that the mean values of lip length and face width for all Chinese subjects are significantly larger than those of the 2003 NIOSH survey ($P < 0.05$). However, the mean values of face length and nose protrusion for both genders in this study are significantly smaller than those of the NIOSH survey ($P < 0.05$). For bigonial breadth, it varies by gender; the values for Chinese male subjects were significantly smaller than that of NIOSH subjects ($P < 0.05$). On the contrary, the values for Chinese females were significantly larger than the American females ($P < 0.05$). Thus, the facial type of Chinese subjects tends to be slightly shorter in face length and nose protrusion and larger in face width and lip length in comparison with American test subjects. The head-and-face characteristics of Chinese

Table 7. Comparison of the facial dimensions among various anthropometric surveys

	This study	CNIS 1981[a]	CNIS 1998[b]	NIOSH 2005[c]
n	2026	6095	214	2543
Male				
Lip length	52.2 ± 3.4	50.4	48.0 ± 1.2	51.1 ± 4.2
Face width	147.5 ± 4.7	144.5	143.0 ± 3.9	143.5 ± 6.9
Face length	117.3 ± 5.6	125.8	119.0 ± 6.6	122.7 ± 7.0
Bigonial breadth	119.0 ± 8.5	115.6	116.0 ± 3.1	120.4 ± 10.4
Nose protrusion	18.9 ± 1.9	18.1	20.0 ± 1.1	21.1 ± 2.7
n	974	3297	179	1454
Female				
Lip length	49.8 ± 4.6	47.7	48.0 ± 1.7	48.0 ± 4.0
Face width	139.9 ± 6.3	139.0	136.0 ± 3.7	135.1 ± 6.5
Face length	110.3 ± 7.2	119.0	109.0 ± 5.7	113.4 ± 6.1
Bigonial breadth	114.2 ± 10.6	111.3	113.0 ± 2.9	110.1 ± 8.9
Nose protrusion	17.7 ± 2.4	16.8	17.0 ± 0.6	19.8 ± 2.7

[a]China national standard (GB2428-81) (from She, 2002).
[b]China national standard (GB/T2428-1998) (by Xiao *et al*., 1998).
[c]NIOSH study (Zhuang and Bradtmiller, 2005).

subjects in this study differ from American face size and shape.

Pneumoconiosis is a common occupational respiratory disease of workers exposed to workplace dust. A total of 616 442 pneumoconiosis cases were reported from 1949 to 2006 by Chinese Department of Health. New cases of pneumoconiosis in China are ~8000–10 000 each year in the last several years (Liu *et al.*, 2008). Possible reasons for high pneumoconiosis incidence in China are the high dust concentration in workplaces and inadequate use of respiratory protective equipment by workers. To provide more comfortable and effective respiratory protective equipment for the millions of workers exposed to occupational hazards, new RFTPs designed specifically for the Chinese populations may be needed. A companion paper will report the new RFTPs for Chinese civilian workers. The new face dimension data collected in this study and the new RFTPs can be used for designing respirators with improved fitting characteristics. This database can also be viewed as a normative database for the cost-effective design of other protective devices (e.g. eye and face protective devices) that people wear on their head and face.

CONCLUSIONS

This study responded to the need for establishing a large anthropometric database of head-and-face dimensions for Chinese civilian workers. A total of 3000 Chinese civilian workers was measured using traditional methods. As age of the subjects in this survey increased, the measured dimensions changed minimally. Coefficients for gender indicated the larger general size of males for all collected dimensions than that of females. Increases in BMI resulted in significant increases in all anthropometric dimensions, except for nasal root breadth and subnasale–sellion length, where no significant difference was detected. Coefficients obtained from the industrial sectors indicated that anthropometric dimensions of construction workers and miners tended to be below the average over all industries. Comparisons of measurements obtained from subjects whose birthplaces are in the Northern versus Southern regions of China generally showed less influence than the other factors studied.

Five representative indexes of facial dimension (face length, face width, nose protrusion, bigonial breadth and nasal root breadth) were selected based on correlation and cluster analysis of all dimensions. Through comparison with the facial dimensions of American subjects, this study found that Chinese civilian adults have shorter face length and nose protrusion and larger face width and lip length.

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