Association of Body Mass Index with Facial Dimensions for Defining Respirator Fit Test Panels

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ABSTRACT

The current prevalence of overweight and obesity in the U.S. and other developed nations has reached epidemic proportions, but little work has been done addressing the impact of increasing body weight upon personal protective equipment. Utilizing the newly developed National Personal Protective Technology Laboratory respirator fit panel that was derived from anthropometric data collected from civilian respirator users in a 2003 National Institute for Occupational Safety and Health survey, this study was undertaken to investigate any possible effect of overweight or obese states upon facial dimensions, and to compare prior anthropometric surveys for the purpose of analyzing study population differences that might affect facial dimensions. The database consisted of three previously published anthropometric studies (two military, one civilian) that were analyzed for homogeneity of study populations and for the impact of variables thought to influence facial dimensions (i.e., age, gender, body mass index). The mean age, body mass index (BMI), and face width were greater for the civilian survey subjects than either of the military surveys ($p < .01$ for each variable). Face width and face length were statistically associated with BMI in both genders of civilian subjects ($p < .01$), as was the interaction of race/ethnicity, age, and BMI for civilian females ($p = 0.03$) and the interaction of race/ethnicity and BMI for civilian males ($p = 0.02$). Increasing BMI impacted face width more than face length ($p < .05$). As the epidemic of overweight and obesity continues, associated increases in facial dimensions of the civilian workforce should be anticipated and considered by respirator stakeholders. Researchers developing respirator fit panels should evaluate BMI, as it is a variable that influences distribution within the panel. Further research is needed to determine quantitative weight changes that signal the need for repeat respirator fit testing and to ascertain if fit test data from more physically-fit subjects are applicable to overweight or obese subjects.

Keywords: respirator fit panels, facial dimensions, obesity, body mass index

INTRODUCTION

Respiratory protection depends, in large measure, upon the fit of the respirator that, in turn, is impacted to a significant degree by facial characteristics. Respirator fit panels are composed of 25 representative human subjects divided into 10 groupings (cells) based upon their facial anthropometric measurements. In order to certify certain types of respirators, the National Institute for Occupational Safety and Health (NIOSH) uses the results of testing for fit on a panel of human test subjects. Current respirator fit panels, presently utilized by American industrial workers, were developed by the Los Alamos National Laboratory (LANL) from anthropometric data gathered on 4,235 military personnel in 1967 and 1968 (Hack et al., 1973). Since that time, the makeup of the civilian population has changed with respect to such factors as height, weight and ethnicity. Military personnel have to meet strict entry and fitness criteria and also tend to be younger than the general civilian workforce. Military populations may not represent the great diversity in face size of the civilian population because of relatively strict anthropometric armed forces entry requirements and height/weight guidelines for troop retention. Personal protective equipment (PPE) designed and sized for a military population may not provide the same fitting characteristics for civilian workers because of the greater diversity in body size and shape seen in civilian populations.

In recent decades, overweight and obesity have reached epidemic proportions and constitute a major public health issue in the U.S. and other industrialized nations (Chopra et al, 2002). Overweight and obesity are linked to changes in facial soft tissue and bone morphology that can be associated with some increased facial dimensions (Ohrn et al, 2002; Ferrario et al, 2004). Despite an apparent relationship between elevated body weight and increased facial dimensions, published data addressing the influence of excessive body weight upon issues related to PPE are lacking, though concerns have been raised by the military with regard to the effect of overweight upon PPE fit for flight crews (Herrick J, 1999). During Occupational Safety and Health Administration (OSHA) hearings on proposed respiratory protection rule changes in 1998, the International Chemical Workers Union suggested that a change of five percent in body weight or twenty pounds should be regarded as an obvious change in body weight that requires refitting respirators. However, OSHA did not believe it possible to stipulate a given weight "trigger" for requiring a new fit test. (Federal Register, 1998) Therefore OSHA's Respiratory Protection Standard, 29 CFR 1910.134 (f) (3), states that repeat fit testing is required "*whenever an employee reports, or the employer or the physician or other licensed health care professional makes visual observation of changes in the employee's physical condition that could affect respirator fit (e.g., facial scarring, dental changes, cosmetic surgery, or an obvious change in body weight*" [italics added for emphasis]. (Occupational Safety and Health Administration, 1998) We undertook this study to determine any possible effect of overweight or obesity upon the distribution of subjects within the National Personal Protective Technology Laboratory (NPPTL) respirator fit panel, a recently described respirator fit panel that was developed utilizing principal component analysis.(Zhuang et al, 2006) This study also compared three prior civilian and military anthropometric surveys for the purpose of identifying any study population differences that might affect facial dimensions and subsequent stratification in respirator fit panels.

MATERIALS AND METHODS

Materials

Three anthropometric surveys were utilized in this study: the 1967-1968 U.S. Air Force (USAF) anthropometric survey (Clauser et al., 1972), the U.S. Army 1987 - 1988 anthropometric survey (Gordon et al, 1988), and the 2003 NPPTL survey (Zhuang et al, 2004). The USAF survey was conducted by the Anthropology Branch of the Aerospace Medical Research Laboratory at Wright-Patterson Air Force Base and carried out at 17 Air Force bases across the contiguous United States. The survey consisted of 2420 male flyers (mean age, 30 years) measured for 188 body dimensions including 46 head and face dimensions and 1905 enlisted women who met the Air Force body-size criteria for entry into Undergraduate Pilot Training and retention as a rated officer (mean age, 22.9 years) measured for 137 body dimensions including 46 head and face dimensions. The U.S. Army survey was conducted at 11 Army bases in the U.S. by the Science and Advanced Technology Directorate of the U.S. Army Natick Research, Development and Engineering Center. The survey consisted of 1,774 men (mean age, 27.33 years) and 2,208 women (mean age: 26.19) measured for 132 body dimensions including 48 head and face dimensions. The 2003 NPPTL survey was a nationwide anthropometric survey of respirator users that recruited 3,997 subjects (2,543 male, 1,454 female) from various industries, including manufacturing, construction, health care, law enforcement, and firefighting. Height, weight, neck circumference and 18 facial dimensions were measured. A stratified sampling plan was used with an equal sample size of 166 in each cell. The survey consisted of three age strata (18-29, 30-44, 45-65), two gender strata (male and female) and four racial/ethnic group strata (White, African American, Hispanic, Others).

The Body Mass Index (BMI), an anthropometrically-derived relationship of weight relative to height (weight in kilograms/height in meters squared), is utilized to ascertain if subjects are at a healthy weight, underweight, overweight or obese. As per the World Health Organization (WHO), BMI values <18.5 are considered underweight, BMI's =/> 18.5 - 24.9 are normal or "ideal" weight, BMI's =/>25 indicate an overweight state, and BMI's =/>30 are obese.(Bailey et al, 1995) Study populations in the three surveys were examined with respect to variables thought to influence facial dimensions (e.g., age, gender, BMI).

Analysis of Data

Subjects were placed in cells of the NPPTL fit panel (Zhuang et al, 2006) and mean BMI's of those cells were calculated. Statistical analysis was performed using the SAS® statistical analysis package (SAS Institute, Cary, North Carolina) employing a general linear model with Duncan test for post-hoc analysis. Age, gender and BMI were compared for differences between the three surveys to determine if populations were relatively homogeneous or if significant differences existed. The distribution of mean BMI (by gender) within each cell of the NPPTL respirator fit panel was compared for all three surveys to ascertain any effect of excess weight upon facial dimensions within the NPPTL respirator fit panel. BMI was also compared with race/ethnicity and age for effects upon facial dimensions.

RESULTS

The mean age of NPPTL male subjects (39.2 years) was greater than USAF (29.5 years) or US Army (27.2 years) male subjects ($p < .01$). The mean age of NPPTL female subjects (41.2 years) was greater than USAF (23.1 years) and US Army (26.2 years) female subjects ($p < .01$). The mean BMI for NPPTL male subjects (29.4) was higher than USAF (25.0) or US Army (25.4) male subjects ($p < 0.01$). The mean BMI for NPPTL females (29.6) was greater than the USAF (22.1) or US Army (23.4) females ($p < .01$). The mean face width of NPPTL male subjects (143.5 mm) exceeded that of USAF (142.2 mm) or US Army (140.4 mm) males ($p < .01$). The mean face width of NPPTL females (136.4 mm) differed significantly from that of USAF (130.1 mm) or US Army (131.4 mm) females ($p < .01$). Mean face length for NPPTL male subjects (122.8 mm) was greater than that of USAF (120.3 mm) or US Army (121.8) male subjects ($P < .01$) The face length of NPPTL female subjects (114.4 mm) differed significantly from USAF (107.4 mm) or US Army (113.5 mm) females ($p < .01$)(Table I). Controlling for race/ethnicity and age, the associations of face width and face length with BMI were noted to be significant ($p < .01$) for all three survey groups, by gender, with the one exception of the association of face length and BMI in USAF male subjects.(Figure 1) BMI impacted face width more than face length. ($p < .05$)

The distribution of mean BMI's for male and female subjects within individual cells of the NPPTL respirator fit panel demonstrated that NPPTL subjects had greater proportional representation in a majority of cells.(Figure 2) Mean BMI's of NPPTL females were significantly greater than their study counterparts in all cells of the panel ($p < .01$), with the exception of cell #10 (this may have been a reflection of the small sample size in that cell [i.e., four NPPTL female subjects, one Army female subject]). Mean BMI's of NPPTL males were significantly greater than their study counterparts in cells 4 – 10 of the panel ($p < .01$). (Figure 1) The association of BMI with facial dimensions in NPPTL females was significant ($p < .01$), as was the interaction of race/ethnicity and age with BMI ($p = .03$). Variables that were each independently associated with NPPTL male facial dimensions included BMI ($p < .01$), age ($p < .01$) and race/ethnicity ($p < .01$). The interaction of race/ethnicity with BMI was also significant for NPPTL male subjects ($p = .02$). (Table I)

Table I. Variables in USAF, US Army and NPPTL Surveys

Variable (means)	USAF females	USAF males	US Army females	US Army males	NPPTL females	NPPTL males	*p-value
Age (yrs)	23.1	29.5	26.2	27.2	41.2*	39.2*	<.01
BMI	22.1	25.0	23.4	25.4	29.6*	29.4	<.01
Face width (mm)	130.1	142.2	131.4	140.4	136.4*	143.5*	<.01
Face length (mm)	107.4	120.3	113.5	121.8	114.4*	122.8*	<.01
Association of face width with BMI	*	*	*	*	*	*	<.01
Association of face length with BMI	*	N/S	*	*	*	*	.<.01
Interaction of Race-ethnicity, age and BMI	N/S	N/S	N/S	N/S	*	N/S	.03
Interaction of Race-Ethnicity and BMI	N/S	N/S	N/S	N/S	N/S	*	.02

* Statistically significant at the p-value of the corresponding row;
N/S represents "not statistically significant".

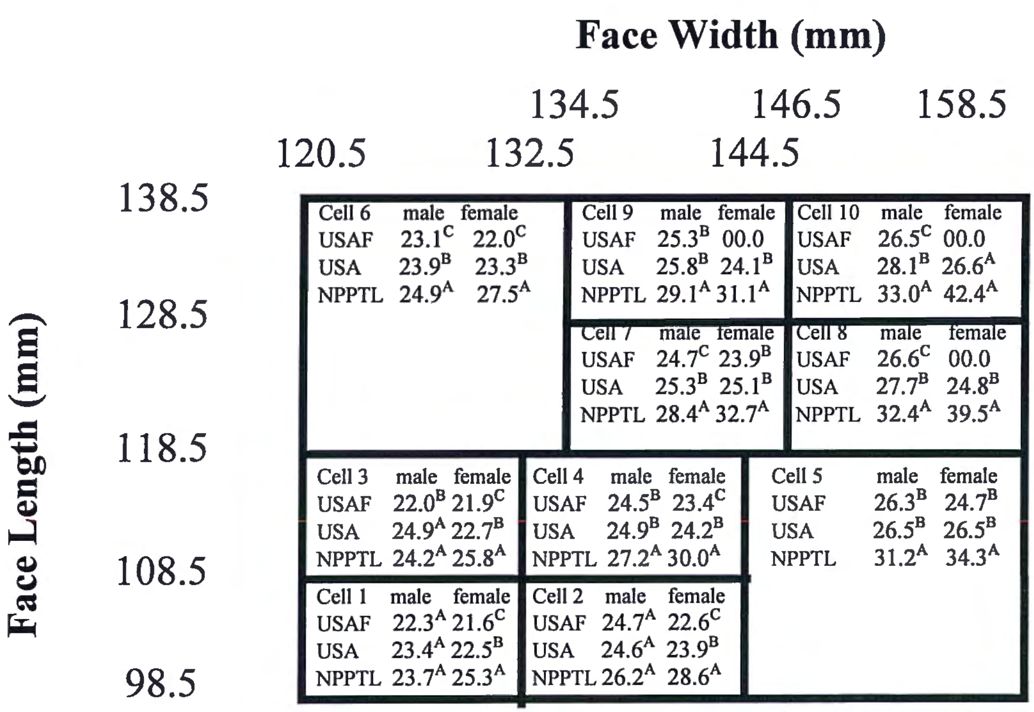

Figure 1. Gender distribution into cells of the NPPTL respirator fit panel by mean Body Mass Index* from US Air Force (USAF), US Army (USA), and NPPTL anthropometric surveys. BMI means with the same superscript designation (A,B, or C) are not significantly different.

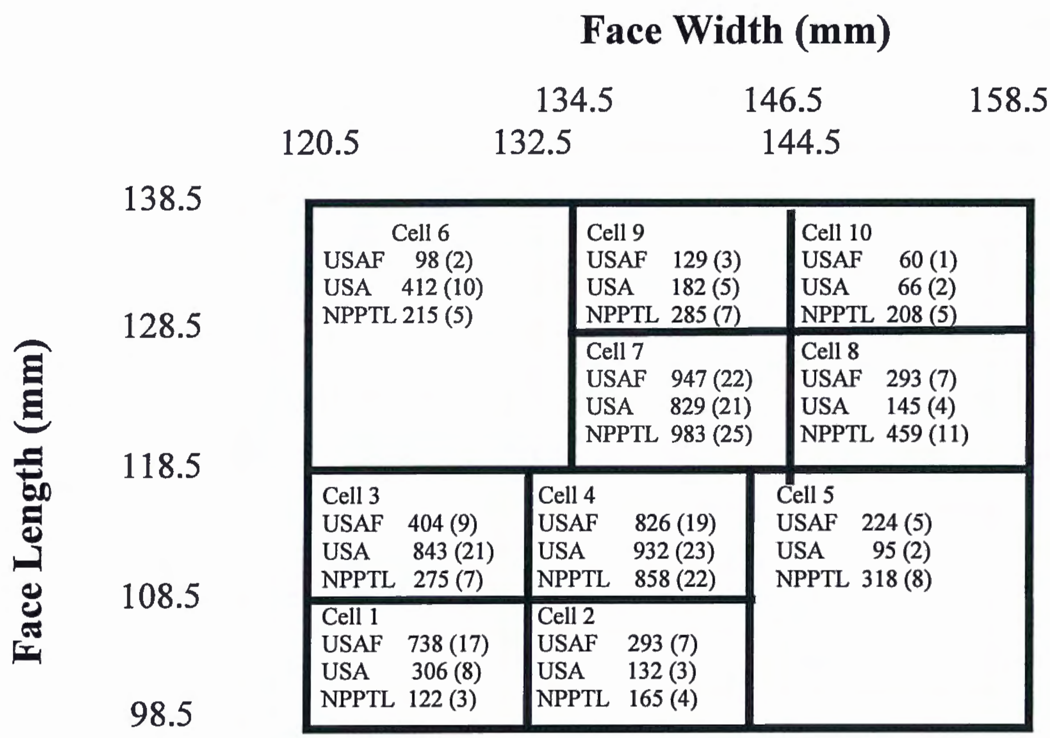

Figure 2. Combined male/female subject distribution* in US Air Force (USAF), US Army (USA) and National Personal Protective Technology Laboratory (NPPTL) anthropometric surveys into cells of the NPPTL respirator fit panel. Numbers in parentheses indicate percentages.

DISCUSSION

Our investigation highlights the fact that BMI's in the present civilian workforce, as exemplified by the NPPTL survey subjects, are significantly greater than those in two prior military anthropometric surveys. This is not a surprising finding, given the greater average age of the NPPTL subjects and the physical fitness requirements of the military services, coupled to the fact that civilian BMI's have consistently increased over the past four decades. The Third National Health And Nutrition Examination Survey (NHANES III), a continuous survey of the health and nutritional status of the U.S. civilian, non-institutionalized population, demonstrated that U.S. men and women gained, on average, more than 11 kilograms between 1960 – 2002.(Ogden et al, 2004) A majority of NPPTL survey subjects (71.6%) were overweight or obese, a figure that is somewhat higher than recent national estimates of 66% overall for overweight and obesity but correlates well with the 73.1% prevalence nationally for workers in the 40 – 59 year age group that more closely approximates the mean age of the survey NPPTL subjects.(Ogden et al, 2006) Certain occupational groups (e.g., firefighters, security personnel, healthcare workers) are associated with a higher prevalence of overweight and obesity. Prior large surveys carried out in the 1990s have shown a 51% rate of overweight in nurses, 80.7% overweight in firefighters, and 82.6% overweight of law enforcement officers.(Hu et al, 2000; Clark et al, 2002; Franke et al, 1997) More recently, in the 2003 NPPTL survey (Zhuang et al), subjects had rates of overweight and obesity of 87%, 73% and 91% for firefighters, healthcare workers, and law enforcement personnel, respectively, a reflection of the continuing increases in excess weight of the American working public. As demonstrated by the current study, inherent differences in military and civilian populations (e.g., age, physical fitness, ethnic/racial composition, etc.) suggest that the development of respirator fit panels derived from military subject anthropometric data may not be totally applicable to the current civilian worker population.

Craniofacial growth is dependent on interactions between genes, hormones, nutrients and epigenetic factors.(Ohrn et al, 2002) As the craniofacial complex reaches maturity, growth as volumetric or surface change generally stops, but the process of remodeling continues through old age (Sameshima and Smahel, 2000; Milner et al, 2001), leading to increases in dimensions throughout life.(Israel, 1977) Facial aging and associated bone remodeling are impacted by numerous factors, including (but not limited to) trauma, surgery, dental loss, disease (e.g., Paget's disease), and endocrine disorders (e.g., acromegaly, hyperparathyroidism, etc.).(Taister et al, 2000) Variables such as older age and ethnicity have previously been shown to be associated with larger facial dimensions on respirator fit panels (Zhuang et al, 2004), but relatively little data exist with regard to the effect of BMI upon craniofacial dimensions.(Ferrario et al, 2004) Significant increases in abdominal adipose (fat) tissue are commonly associated with concomitant increases in facial adipose tissue and, conversely, significant weight loss is often initially most apparent in the facial region (primarily neck and cheeks) and the upper half of the body.(Sierra-Johnson et al, 2004) This association suggests that increasing abdominal girth may be an indicator of increasing facial dimensions in otherwise-healthy individuals. Indeed, a prior study utilizing computerized tomography scan soft tissue measurements noted a positive correlation between facial (cheek) fat and abdominal fat, suggesting that these two anatomically separate fat depots share similar metabolic properties.(Levine et al, 1998) The greater metabolic activity associated with the higher blood flow of the microcirculation to facial and abdominal visceral adipocytes (fat cells), as compared with that of the lower half of the body, offers some rationale for the concordant changes in facial dimensions observed with abdominal fat gain or loss.(Tan et al, 2004) Increased bony craniofacial dimensions, thought due, in part, to obesity-related altered hormonal influences (e.g., insulin-related growth factor effects, leptin, etc.), further contribute to the larger facial sizes noted in overweight states.(Ohrn et al, 2002) In the current study, the associations of mean BMI with facial dimensions (i.e., length, width) were significant ($p < .01$ for each gender) for subjects in all three surveys.(Table I) Although age, race, and race-by-BMI interaction variables have previously been reported to be independently related to percentage of body fat in both sexes (Jackson et al, 2002), in the current study, lesser statistical significance was noted for the combination of age, race/ethnicity and BMI in female NPPTL subjects ($p = .03$) and the combination of race/ethnicity with BMI for male NPPTL subjects ($p = .02$). This suggests that overweight and obesity have at least as prominent an effect upon increasing facial dimensions (and resultant distribution within respirator fit panels) as other variables (i.e., age, sex, race/ethnicity). This concept is further supported by a recent study noting that obesity alone was responsible for the increased facial dimensions noted in a group of obese adolescents when compared to normal weight counterparts matched for ethnicity, age and gender.(Ferrario et al, 2004) The higher representation of NPPTL subjects in those respirator fit panel cells defining dimensions of greatest facial widths (i.e., cells 5, 8, 10) further supports the concept that overweight and obesity are associated with increased facial dimensions (Table I), as do previous studies demonstrating an association of BMI with facial (cheek) fat .(Levine et al, 1998; Gravante and LoGrasso, 1997) A worrisome example of the importance of the association of BMI with respirator fit is the recent attention given by the medical community to the role of excess weight (i.e., BMI >26) as a predictor of difficulty with bag-mask ventilation, an often lifesaving procedure (Langeron et al., 2000).

The findings in the current study have implications of potential importance to various stakeholders. OSHA has indicated that repeat respirator fit testing is required when any obvious change in body weight is observed by the employee, employer, physician or other licensed health care professional. (OSHA, 1994) However, the actual weight change that would trigger a repeat fit test has not been quantified. Nonetheless, the findings in this study are in concordance with the notion that elevated BMI is associated with increased facial dimensions as applied to the NPPTL respirator fit panel, and lend support to OSHA's directive for repeat fit testing when an employee experiences significant weight gain.

Our findings may also be of significance to respirator stakeholders (e.g., manufacturers, distributors, etc.) because changes identified in anthropometric studies (e.g., increasing facial dimensions due to the prevalence of obesity) can often be accommodated by changing the distribution or tariff of clothing and mask sizes rather than adjusting the clothing designs and adding new sizes.(Yakota, 2005) This can be of considerable economic importance to the aforementioned stakeholders. Lastly, given that the current epidemic of overweight and obesity in industrialized nations is not likely to rapidly reverse course, it is the authors' hope that the findings of this initial study relating overweight and obesity with respirator fit will spur future studies looking at the effects of excess body weight upon PPE performance.

Limitations of our study include the fact that the populations of the three surveys were not truly homogeneous. African American female participation was considerably greater in the NPPTL (43.1%) and US Army (41.8%) surveys than the USAF survey (7.67%), as was the proportion of African American males in the NPPTL (21.4%) and US Army (25.8%) surveys compared to the USAF survey (1.1%). Also, because BMI is not a direct measurement of body fat and cannot reliably differentiate between excess bodyweight in the form of increased muscle mass or that due to fat accumulation, fluid accumulation (e.g., ascites, edema) or other physiological states of elevated body weight (e.g., pregnancy, lactation, etc.), some subjects may be misidentified as overweight or obese when, in fact, they do not harbor excess body fat. Similarly, individuals with excess body fat and concomitant loss of muscle mass might be misidentified as normal BMI when, actually, their proportion of body fat has increased. Given the current prevalence of obesity in the civilian workforce, misidentification by BMI in this group is less likely to be a significant factor, whereas it may be more noteworthy when dealing with military populations that inherently have more physically fit subjects with associated greater muscle mass or decreased body fat. Further investigation will be required to more fully elucidate the effect of BMI upon facial dimensions in civilian workers as they relate to PPE.

CONCLUSIONS

The multiple ramifications of the current epidemic of overweight and obesity in the U.S. and other industrialized nations include effects upon facial dimensions that may potentially have a bearing upon respirator fit. Elevated BMI is associated with increased facial dimensions. As the prevalence of overweight and obesity continues to rise, associated increases in facial dimensions of the civilian workforce should be anticipated and considered by respirator stakeholders. Researchers developing respirator fit panels should evaluate BMI, as it may offer a clue to changing facial dimensions and influence distribution within the panel. Further research will be required to determine how much increase in body weight signals the need for repeat respirator fit testing and to ascertain if fit test data from more physically-fit subjects (e.g., military populations) are applicable to overweight or obese subjects.

The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

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