Original Research

OPEN

Perception and Knowledge of Mercury by Occupationally Exposed Health Care Personnel

Isabel Álvarez-Solorza, PhD; Luz D. Upegui-Arango; Víctor Borja-Aburto, PhD; Norma González-González, PhD; Felix Fischer, PhD; L. Patricia Bustamante-Montes, PhD

Thermometers and baumanometers frequently contain mercury, a toxic heavy metal. Inadequate management of this substance can constitute an occupational hazard by exposing health care professionals to health risks including memory loss, psychosomatic symptoms, fatigue, and other signs of cognitive dysfunction as reported in several studies.

Purpose: To assess Mexico's health care professionals' health and mercury-related knowledge and risk perception and to explore the measurement properties of a questionnaire assessing that level of knowledge.

Materials and Methods: Mixed methodology. A quantitative, cross-sectional study was conducted to measure health care professionals' knowledge of mercury and to validate an instrument using a Rasch analysis in 160 professionals. A qualitative study involving in-depth interviews was conducted to identify participants' risk perception for mercury exposure.

Results: The total knowledge of mercury was 19.0 ± 2.0 on a scale of 0 to 28 points. The scores for medical specialists were significantly ($P < .001$) higher, ranging between 20.0 ± 2.05 and 23.0 ± 1.63. In general, the level of risk perception for mercury exposure was low. The questionnaire presented a reasonable fit to the Rasch model (good item fit with a Bonferroni-adjusted $P = .000714$). The response categories of three items were collapsed, and two pairs of items were bundled into two super items.

Conclusion: The levels of the knowledge of the health and safety risks and risk perception for mercury exposure in the Mexican health care professionals evaluated were low. Health care professionals should receive comprehensive training in the safe use and health risks of mercury.

Keywords: health workers, occupational exposure, mercury, knowledge, thermometers

DOI: 10.1097/CEH.0000000000000399

INTRODUCTION

Mercury (Hg) is a heavy metal found in nature in inorganic and organic compounds. It is emitted into the atmosphere from natural and anthropogenic sources in the form of elemental mercury (Hg(0)). Precipitation deposits mercury in bodies of water and finally in the sediment, where microbial action transforms it into methylmercury, which is even more dangerous because of its ability to bioaccumulate in food chains and its adverse effects on the environment and health.[1–3]

Mercury easily crosses the placental and blood–brain barriers, causing permanent damage to the nervous system of newborns during their development and growth. Adult nervous systems can also be affected, as can the kidneys, and digestive, respiratory, and immune systems. Reported signs and symptoms of mercury intoxication include tremors, visual and hearing disturbance, paralysis, insomnia, emotional instability, and depression.[4–8]

Mercury can be emitted through incineration and the elimination of solids or effluents.[4] In the health care sector, this metal plays an important role because it is used in measuring

Disclosures: The authors declare no conflict of interest.

This study was funded by the Autonomous University of the State of Mexico through the Research Secretariat.

I. Álvarez-Solorza: original draft preparation, analyzed the data, and wrote the article; L.D. Upegui-Arango performed the validation and wrote; N. González-González designed the qualitative methodology; V. Borja-Aburto, F. Fischer, and L. Patricia Bustamante-Montes: supervision, writing, review, and editing.

Ethical review: This study was submitted for review and approval by the ethics and research committee of the hospital, and informed consent was obtained from all participants.

Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's Web site (www.jcehp.org).

Álvarez-Solorza: *PhD student in Health Sciences, Master of Health Science, and Research and Professor of the Faculty of Nursing and Obstetrics, Autonomous University of the State of Mexico, Toluca, Mexico.* ***Upegui-Arango:*** *Research Assistant, Institute of Medical Psychology and Medical Sociology, University Hospital of RWTH Aachen, Aachen, Germany.* ***Aburto:*** *PhD in Environmental and Occupational Epidemiology and Director of Medical Benefits, Mexican Institute of Social Security.* ***González-González:*** *PhD in Social Science and Research and Professor of Faculty of Political and Social Sciences, Autonomous University of the State of Mexico, Toluca, Mexico.* ***Fischer:*** *Psychologist, PhD, Department of Psychosomatic Medicine, Center for Internal Medicine and Dermatology, Charité – Universitätsmedizin Berlin, and Corporate Member of Freie Universität Berlin, Humboldt-Universität zu Berlin, and Berlin Institute of Health.* ***Bustamante-Montes:*** *PhD in Health Sciences and Deanship of Health Sciences, Autonomous University of Guadalajara, Jalisco, Mexico.*

Correspondence: *Isabel Álvarez-Solorza, PhD student in Health Sciences, Master of Health Science, and Research and Professor of the Faculty of Nursing and Obstetrics, Autonomous University of the State of Mexico, Toluca, Mexico; e-mail: isa_alsol64@hotmail.com.*

instruments such as thermometers and sphygmomanometers, in dental amalgams, vaccines (thiomersal), batteries, fluorescent tubes, and chemical products.[9]

Mercury contamination has a substantial impact on the environment, considering that a single thermometer is enough to pollute an 8.1-hectare lake, giving rise to health risks for the general population.[10,11]

At room temperature, mercury can turn into significant amounts of gas, meaning that mercury spills in hospitals expose not only health care professionals but also patients and their families.[12] Occupational exposure leads to irritability, headache, neurobehavioral effects (memory loss, depression, behavioral changes, and sleep and personality alterations), and muscle disorders such as arthralgia in dentists or dental assistants.[13–16] In nursing professionals, certain associations have been suggested between mercury exposure and Alzheimer disease, Parkinson disease, arthritis, negative effects on the thymus gland, and the psychomotor development of nurses' children.[17–20]

In view of these health risks, the European Union has restricted the use of various mercury-containing products.

Beginning in the 1990s, the Health Care Without Harm (HCWH) coalition has been working toward replacing mercury-containing materials with mercury-free ones, to minimize the risk of exposure and help protect health workers, the general population, and the environment. The HCWH organization and the World Health Organization (WHO) have launched the Mercury-Free Healthcare Initiative for 2020, which is part of the Minamata Convention on Mercury intended to phase out mercury.[21,22]

However, in Latin America, with the exception of some countries in the Southern Cone, mercury-containing materials continue to be used, and breakages of thermometers, tensiometers, and other devices used in hospitals are handled inappropriately. Small spills are often not correctly cleaned up, and the waste is poured into sewers or mixed with ordinary trash.[23]

In Mexico, there is no regulation of the use and disposal of thermometers or other mercury-containing equipment or materials. Although some hospitals in Mexico have exchanged mercury thermometers for digital ones, there is still widespread use of mercury-containing thermometers, often because health care personnel believe that mercury thermometers provide more accurate measurements.

In 2013, the Commission for Environmental Cooperation determined the health care sector's contribution to mercury contamination in Mexico, by considering two main sources: dental amalgams and thermometers. This risk assessment estimated that more than 4.5 tons of mercury is released annually into the environment through amalgam residues, and approximately 2.4 tons originates from thermometers.[3]

In 2014, the year with the highest use of mercury thermometers by public institutions to date, 1,143,682 thermometers were used. At an institutional level, the Mexican Social Security Institute was in first place in 2015 for using 833,404 thermometers, followed by the Institute for Social Security and Services of State Workers with 122,005.[24] Although the thermometers are still being used, there are no reports on whether the management of broken thermometers is adequate. In addition, most published studies on occupational exposure to mercury in Mexico and Latin America have been conducted in miners, not in health professionals.

As a result of the above, in 2000, the United Nations Environment Program (UNEP-6) highlighted the need to understand and quantify human behavior in relation to exposure to mercury releases.

Mercury use presents a significant risk to health professionals, patients, and the environment, and although steps have been taken to reduce these risks, the use of mercury-containing instruments in Mexico is still widespread. The assessment of occupational exposure to mercury using biomarkers continues to be expensive in this country. However, given the existing evidence on health effects, it was considered important to create a knowledge assessment tool to support professional training and to influence the appropriate management and risk reduction for health professionals.

There is little evidence that shows the awareness and knowledge of the HCP on the effects of being exposed to mercury and the procedures needed to remove and inactivate given substance. Solely, three existing studies were identified, one in India, another in Croatia, and one in Sri Lanka; all of them show the lack of knowledge and awareness and the inadequate management of mercury.[25,26] There is a lack of research on this topic in Latin American. The previous reasons justify this research; the purpose of this study was to assess this population's mercury-related knowledge and risk perception by exploring the measurement properties of an instrument designed to determine the said level of knowledge using the Rasch method.

MATERIALS AND METHODS

A mixed methods study research of an explicative sequence type was conducted, where the quantitative study is privileged. In the second phase, a qualitative research was directed to produce data for clarification of the original findings.[27]

Quantitative Methodology

A cross-sectional study was designed to collect questionnaire data on health care professionals' knowledge of mercury.

Study Population

Of 480 health professionals working in a secondary hospital at ISSEMyM, we randomly selected and surveyed 30% of the personnel, including nurses (134), doctors (20), and chemists (6). We included health care professionals who were active, on any work shift, during the study period who gave their informed consent to participate in the study.

Measures

The data were collected with an instrument that consists of two sections:

1. Sociodemographic and professional data (10 questions)
2. Knowledge of mercury (16 questions with categorical answers: *no, I do not know*, and *yes*).

The questionnaire was designed after a literature review and later piloted and standardized by the research group investigating health, work, and environment in Mexico (see **Appendix A**, **Supplemental Digital Content 1**, http://links.lww.com/JCEHP/A145). Content validity was assessed by experts in the area of environmental health. This was followed by the application of a pilot in five states across Mexico to improve the clarity and comprehensibility of the questionnaire statements. The internal validity was appropriate (Cronbach $\alpha = 0.72$). Construct validity was not assessed in this phase.

Psychometric Analysis of the Questionnaire

The measurement properties of the questionnaire were assessed according to the Rasch model, assuming a single underlying construct (mercury knowledge). A particular advantage of the Rasch model is that items and persons can be calibrated separately along a latent variable. In this case, for example, the calibration of the individual reflects the participants' level of mercury knowledge and the calibration of the items indicates the level of knowledge of mercury that this represents. Another advantageous property is the model's specific objectivity, meaning that the measurements do not depend on the conditions under which they have been obtained. That is, in this case, the difference between two people regarding their level of knowledge of mercury is independent of the items that were used to estimate the measurement. Likewise, the estimates of the items are not influenced by the distribution of the sample.[28]

The following criteria was taken into account[29] in the Rasch analysis:[30]

Examination of the thresholds: The scoring hierarchy was examined in the response categories, in which the items with disordered thresholds were rescored to improve the overall fit to the model.

Fit statistics: The item/person fit was evaluated to evaluate the fit to the model, expecting residual estimates between ± 2.5 and nonstatistical significance. A correction by multiple comparisons for the estimates of statistical significance (with a base probability ≥ 0.01) was performed.

Local dependence: This occurs when the answers given to the items examined depend not only on the individual's level of knowledge about mercury but also on his or her responses to other items. Correlations greater than 0.3 indicated local dependence between the items evaluated.

Unidimensionality: This was explored by comparing subsets of items determined by the factor loadings on the first residual from the principal component analysis (PCA) using a paired t test, to determine whether the person estimates derived from these subsets are significantly different. A percentage of significant t tests of less than 5% was needed to achieve strict unidimensionality.[31,32]

The estimates reported after conducting the Rasch analysis constitute the logit unit of measurement, given that the Rasch model is a log odds model. The differences between the raw scores of the level of knowledge of mercury stratified by the variables of interest such as the profession, sex, and age of the participants were evaluated. The Rasch analysis was performed using RUMM2030 software.[33]

Knowledge Analysis

The data were recorded in duplicate to avoid errors. The primary outcomes were the knowledge estimates from the Rasch analysis described above. The data are expressed as means ± SD. For the assessment of group differences, nonparametric tests were used. A $P < .05$ was considered statistically significant. These statistical analyses were performed using Stata 14.0 software (StataCorp).[34]

Qualitative Methodology

A sample of 30 participants was collected through convenience sampling. The sample was made up of HCP (nurses, doctor, and chemists) and decision makers, all with an average of 10 years working in the hospital. Of these, 15 were women and 15 were men (ages 35–40).

Data Collection Technique

A semistructured interview was designed from the following categories: knowledge of mercury, regulatory policies, and risk perception (see **Appendix B, Supplemental Digital Content 2**, http://links.lww.com/JCEHP/A146).

Qualitative Data Analysis

Data were collected through interviews and reviewed to obtain an overview of the materials. Verbal data were transcribed to the text and classified according to categories. We identified the units of analysis, then openly coded the units, and then assigned them a category and a code through axial coding; that is, we grouped categories into topics and patterns, related the categories, and exemplified the patterns and relationships with units of analysis and developed explanations.[35,36]

Finally, ATLAS.ti 7[37] software was used to recover the text from the codes and analyze the content of that text.

Joint Analysis of the Information

In accordance to the sequential explanatory strategy of the mixed study used, after performing both phases (quantitative–qualitative), the interpretation of the conjoint results was conducted, for which an integral analysis method from both results based on the theoretical references took place and for which a triangulation of the information according to the information source and the informants.

Ethical Review and Informed Consent

This study was submitted for review and approval by the hospital's ethics and research committee, and informed consent was obtained from all participants.

RESULTS

The quantitative study sample comprised 160 professionals, of whom 80% were women and 20% were men; 75% (134) were nursing staff, 25% (20) were doctors, and 4% (6) were chemists (Table 1). The median age was 33.5 years (interquartile range: 24–58 years), and the average number of years of seniority was eight.

TABLE 1.
Description of Sociodemographic Variables

Sociodemographic Variables	N	%
Sex		
Women	129	80
Men	31	20
Age (y)		
≤28	37	23
29–33	43	27
34–39	38	24
≥40	42	26
Profession		
General physician	16	10
General nurse	34	21
Nurse specialist	59	37
Medical specialist	4	2
Licensed nurse	41	26
Chemist	6	4

Psychometric Analysis

Disordered response categories were observed in items 2 (*From my point of view, the use of mercury in health may involve risks of toxicity)*, 3 (*I consider the use of mercury-based equipment risky)*, and 4 *(The use and handling of mercury-based equipment requires special care)*. These disordered thresholds were observed in the response categories 0 "no" and 1 "I do not know" that were subsequently collapsed (from 012 to 001) to improve the fit to the model. Moreover, local dependence was found between items 3 and 5 *(I consider that exposing myself to medical supplies and equipment with mercury is risky to my health)*, as well as between items 7 (*I prefer to use conventional medical equipment to new digital equipment)* and 8 (*I believe that with conventional medical equipment works better than does digital equipment)*. These items were joined into a pair of items; that is, items 3 and 5 were combined into a single item, as were items 7 and 8. In general, the items presented adequate adjustments to the Rasch model, except for item 16, which only adjusted to the model after the implementation of the aforementioned instrument refinement strategies. A good item fit was therefore obtained with a Bonferroni-adjusted $P = .000714$ (see **Appendix C**, **Supplemental Digital Content 3**, http://links.lww.com/JCEHP/A147). Finally, strict unidimensionality was observed in the questionnaire with a percentage of 3.8% of statistically significant *t* tests (adequate, less than 5%). The questionnaire presented a reasonable fit to the Rasch model according to the evaluation of its measurement properties.

Mercury Knowledge Results

Only half (48%) of the participants knew that mercury was a metallic and a liquid (at room temperature) element of the periodic table. In total, 56% had no knowledge of the specific uses of mercury, whereas 33% correctly referred to its use in thermometers and baumanometers. Although 71% reported that exposure to mercury is a health risk, 64% of the surveyed personnel had no knowledge of any specific effects of mercury on human health. Only 27% knew that exposure through inhalation is the most dangerous, and 59% believed that their knowledge of mercury is insufficient, and 90% received no training in the dangers of mercury exposure.

From the respondents, 71% preferred conventional mercury-containing thermometers over digital ones and 69% reported that they believed that mercury-containing thermometers worked better than digital ones. In total, 78% reported not having received training in the handling and caring of mercury-containing equipment.

Of the respondents, 40% responded that when a thermometer broke in their work area, they sent it to municipal waste and 37% exchanged it for another. Regarding baumanometers, 64% of the staff reported that they sent these instruments to the biomedical waste area when they deteriorated.

In the interpretation of the raw scores of the items with categorical answers, we found an average knowledge score of 19.0 ± 2.0 (95% CI: 18–19). The raw scores range from 0 to 28, and all the items were quantified equally, where higher scores showed higher levels of knowledge. When evaluating the averages stratified by sex, women presented a higher level of knowledge than that of men, with an average score of 20.0 ± 2.05. When the results were stratified by the age group, the highest level of knowledge was observed in people aged 34 to 39 years (average score = 20.7 ± 2.43). Regarding the types of professions evaluated, the highest level of knowledge of mercury was found in medical specialists, with an average score of 23.0 ± 1.63. The differences in the knowledge scores stratified by sex, age, and occupation were statistically significant ($P < .01$) (Table 2).

Results of the Qualitative Study

A subsample of 30 health care professionals was taken from the total sample of nurses and doctors. The subsample consisted of 15 men and 15 women who had worked in the hospital for an average of 10 years and were aged between 35 and 40 years (Table 3).

In general, the levels of knowledge were similar both in the interview findings as well as in the quantitative evaluation, specifically in matters such as the lack of knowledge about what mercury is and how it affects health. Interviews helped identify that not everybody received training. Therefore, they do not recognize the tools that contain mercury, causing the tools to be directly disposed instead of doing it safely.

The informers inadequately defined mercury as "a metal that cannot be destroyed, divided, or created"; as "a contaminant"; and as a "substance that pollutes the natural environment." They were able to identify that "it is hazardous to one's health" but failed at explaining precisely how. The respondents emphasized that it affects the renal and pulmonary systems, but few knew that mercury is one of the most neurotoxic metals.

Regarding the care that should be taken with mercury-containing equipment before it is replaced by digital ones, the health care professionals were trained but did not apply the training. For example, when a thermometer broke, it was exchanged for a new one; "they picked it up and kept it in the pocket of their scrub top or lab coat," whereas the residual Hg "remained on the floor" was swept up by "the cleaning staff . . . [who] remove[d] it with a dusting cloth" or was "[thrown] in the trash." Some informants even mentioned that "they played with [it] on the palm of their hand" because they did not know that the metal is toxic.

TABLE 2.
Knowledge Evaluation

Variables	Knowledge score*	*P*
Sex		
Female	20.0 (2.05)	<.01†
Male	19.6 (2.79)	
Age (y)		
≤28	17.9 (2.05)	<.01†
29–33	19.4 (2.64)	
34–39	20.7 (2.34)	
≥40	20.6 (2.61)	
Profession		
General physician	20.2 (2.00)	<.01‡
General nurse	20.2 (2.41)	
Nurse		
Specialist	20.3 (2.88)	
Medical specialist	23.0 (1.63)	
Degree in nursing	18.1 (6.65)	
Chemist	18.3 (1.80)	

*The level of knowledge is given in raw scores for the interpretation of results.

†Probability (Mann–Whitney test).

‡Probability (Kruskal–Wallis test).

TABLE 3.
Description of Sociodemographic Variables: Qualitative Methodology

Sociodemographic Variables	N	%
Sex		
Women	15	50
Men	15	50
Age (y)		
35	6	20
36	5	17
37	7	23
38	2	7
39	6	20
40	4	13
Profession		
Doctor	12	40
Nurse	13	43
Decision maker	5	17

Regarding the training of the cleaning staff, the health care professionals do not know whether the company has continuous training programs because they are constantly transferred to different working facilities.

Generally, the interviews showed that, at policy level, the substitution of digital thermometers for mercury thermometers was implemented to comply with the "Mercury-Free Hospitals" initiative. In this process, economic limitations were identified, so "low-quality thermometers were acquired, which can cause more contamination through the use of mercury-containing batteries." The health professionals, specifically nurses, expressed that "they did not receive training in the use of digital thermometers." Furthermore, in the first week, several broke, and for this reason, "the nursing professionals still personally purchase mercury-containing thermometers" because they consider them accurate and easy to use.

Regarding the risk perception for mercury exposure, health professionals do not consider mercury spills a risk and they expressed that "[mercury] is something that does not cause visible damage." They emphasize "that for years, they had used it and never saw [anyone] affected by it."

DISCUSSION

In this study, we found that medical specialists have greater knowledge of mercury than do nurses and chemists. These statistically significant differences were found not only when the participants were stratified by profession but also when they were stratified by sex and age.

Similar studies[25,26] have quantitatively evaluated the knowledge and use of mercury but have not evaluated risk perception. Karam[38] considers risk perception to be not only the perception of the probability of an event occurring but also a set of direct and indirect experiences in various situations that the individual presents, which, together with the acquired knowledge, result in an interpretation. In this study, health professionals were identified not to perceive that there is a risk attendant on mercury exposure because of their lack of knowledge. They were found to have no basic information about mercury, including its definition, application in the health care area, exposure routes, the risks it poses to human health, or about its proper disposal.

This lack of knowledge can lead to a greater risk for health care professionals because a significant number of professionals ignore exposure routes, in particular the olfactory pathway. When there is a mercury spill, the mercury is volatilized at room temperature, and the 80 percent that becomes vapor is inhaled, and subsequently passes into the blood through the lungs.[9] The lack of knowledge increases the risk because, as shown by the qualitative results, the appropriate cleaning process and proper disposal of mercury residue do not tend to be applied. Mercury can remain in the environment for a month, contributing to continuous exposure risk for health care professionals.

Of the health professionals evaluated in this study, nursing personnel had less knowledge than did medical personnel, which coincides with the results of the study conducted by Halder et al,[25] which compared the knowledge of professionals who work in government hospitals with that of those who work in corporations. Halder et al[25] reported that generally, medical personnel have more knowledge than do nurses, and, when comparing nursing personnel, those with the least knowledge were those who worked in government hospitals. Although the study was conducted in a public hospital, it cannot be asserted that this is why the nursing personnel knew less. By contrast, another study conducted by Senanayake and Gunawardena,[39] which assessed the knowledge, attitudes, and practices related to the handling of mercury-containing devices and the factors associated with that knowledge among nursing personnel, found that the level of knowledge was generally good.

Previous studies have reported that nursing centers in hospitals tend to present high levels of mercury, possibly because of the health professionals' lack of appropriate knowledge.[41] In this qualitative study, respondents stated that they continued to purchase mercury thermometers with their personal resources and that there is no hospital control over these thermometers because it is assumed that the health personnel only use the digital thermometers supplied.

In previous studies, no differences were reported among the types of doctors evaluated, suggesting that all had the same level of knowledge, whereas in the current study, the medical specialists were found to have better knowledge than did general practitioners.[26]

Likewise, qualitative data showed us that there was a lack of concern for the proper management of mercury residues and the care that must be taken when handling the instruments that contain it. This coincides with the findings of the study by Senanayake and Gunawardena[40] in which mercury spill management practices were found to be deficient. Training is not necessarily associated with the adequate management of mercury spills. In our study population, health professionals were only trained on one occasion; they did not receive follow-up training and had not received previous training during their professional education.

A considerable percentage of health professionals are inclined to use thermometers and sphygmomanometers that contain mercury because they believe that they are more precise. A study by Janev Holcer et al[26] reported that nurses prefer mercury-containing thermometers because they are accurate and reliable, although they may be slower. According to the study by Halder et al,[25] they prefer mercury-containing thermometers to digital thermometers because of their availability, affordability, precision, and ease of use. This indicates that the geographical area does not matter; specifically, precision is the reason for the preference for mercury-containing thermometers in three studies. In this study, this information was corroborated by both qualitative and quantitative results.

Although mercury-containing devices are preferred for their precision, studies report that mercury sphygmomanometers fail calibration tests between one and 28% of the time, with aneroid sphygmomanometers failing up to 61% of the time. Regarding thermometers, research has shown that digital thermometers are as accurate as mercury-containing thermometers under conditions of constant maintenance and calibration[40–42]; the same is true for aneroid sphygmomanometers.

At the same time, it is evident that little importance is given to the occupational risks of mercury exposure in professional education because the health care personnel were not trained about the risks to which they are exposed in a hospital, especially in relation to mercury. Thus, when practicing their profession, these professionals do not have the necessary mercury-management skills and they do not know the minimum level of care needed to handle this substance. In this study, those who knew comparatively less about mercury were people younger than 30 years of age, although the opposite result might have been expected, given the greater access relatively younger people have to information through digital media. In addition, medical and nursing degree programs at the main universities in Mexico have learning units on health ecology, occupational health, and environmental toxicology, in which the topics focus on risk prevention. Thus, it is important to analyze whether these topics are really being taught.[43–45]

Regarding the validation of the instrument used in this study, a moderate fit to the Rasch model was identified following the refinement strategies. In the evaluation of local dependence, four items provided redundant information and a strong correlation was observed between the information related to the risk perception provided by item 3 (*I believe that the use of mercury-based equipment is risky*) and item 5 (*I believe that exposure to medical supplies and equipment with mercury is risky for my health*). Similarly, item 7 (*I prefer conventional medical equipment to the new digital equipment*) and item 8 (*I think conventional medical equipment works better than digital equipment does*) also exhibited local dependence, suggesting that both pairs of items cover similar content regarding conventional and digital equipment. Therefore, it is suggested that items 3 and 5 should be combined to form a single item to avoid redundant information, as should items 7 and 8. Future studies with larger samples could serve to confirm whether it is necessary to recode those items that showed initial clusters in their measurement categories, such as item 2 (*from my point of view, the use of mercury in health care involves the risk of toxicity*), item 3 (*I believe that the use of mercury-based equipment is risky*), and item 4 (*I believe that the use and handling of mercury-based equipment requires special care*). In addition, the inclusion of items that measure other aspects of knowledge about mercury in health personnel would be advisable to offer a more comprehensive measure of this construct. However, it is recommended that the relevant validation process should be conducted, such as that conducted in this study, where the measurement properties of the items were improved after the application of improvement strategies.

Study Strengths

This study included a representative sample of health professionals working in public institutions in the State of Mexico. Qualitative interviews were used to evaluate the risk perception, offering a contrast to findings exclusively obtained by quantitative procedures, because the responses can be clarified, and there are follow-up questions and answers, as well as a better understanding of the responses.

Psychometric Analysis of the Questionnaire

This study used a questionnaire that works reasonably well as a whole, that is, with a unidimensional measure of the knowledge of mercury. The findings obtained using the Rasch model demonstrate that there is clearly room for improvement in its psychometric properties in future applications, such as the need to rescore the response options in some items and eliminate redundant items.

Limitations

One of the limitations of this study was its design, given that cross-sectional studies do not allow causal inferences. Another limitation is that this study was conducted in a single hospital rather than comparing results among hospitals as was performed in the studies in Croatia and India. Regarding the psychometric analysis of the questionnaire, the people and items were distributed in a range of -0.4 to 0.4 throughout the evaluated continuum. However, not all domains may be fully explored in the highest and lowest ranges of knowledge, resulting in a suboptimal assessment of knowledge in the ranges between -0.4 and -0.3 and 0.3 and 0.4. We recommend that in future studies, items with highest and lowest measure levels are added. Nevertheless, the interpretation of the scores in this study is based on scores obtained in the range of -0.3 to 0.3, indicating that the evaluated items measure a large part of the construct of knowledge about mercury in health personnel. It is also recommended that future studies should evaluate the differential functioning of items in a large sample size stratified by interest groups, such as sex, age, and occupation, to strengthen the construct validity of the questionnaire.

The findings of this study cannot be widely compared with previous findings because no similar studies were found. As such, it serves as a guide for similar studies in hospital contexts at especially high risk for mercury use.

Regarding research methods, each method allows to achieve the objective; we do not identify limitations when applying. If the qualitative methodology was used, it was to clarify the quantitative results.

CONCLUSIONS

The research objective was achieved in identifying a low level of knowledge about mercury and no perceived risk of mercury exposure among health professionals, suggesting the need to modify current practice in hospitals in Mexico.

The results of this study suggest the need of another research phase for awareness creation, educational programs to increase knowledge, and validation of effective interventions that help create a clear understanding of the correct management of mercury to reduce risks, thus, empowering medical and nursing personnel to become agents of change on this matter between their medical peers, patients, and general population. At the same time, this will help the spread of environmental health and strengthen the roles of HCP in the management of "mercury-free" hospitals.

The refinement strategies used based on the Rasch analysis approach made it possible to improve the knowledge assessment tool. These findings are valuable in providing a basis for future applications of this scale, such as the prior identification of two pairs of highly correlated items that provide similar information and problems related to the order of response categories in some items.

Lessons for Practice

- The establishment of a program and a constant epidemiological vigilance for the control, management, and disposal of mercury and other substances hazardous for medical staff. The participation in the design, implementation, and evaluations of the different-area integrative, as well as the multidisciplinary staff of the institution is of a high importance.
- Implementation of health educational programs to empower the health care professionals in the decision-making process and the modification of reactions and behavior through the acquisition of knowledge.
- Expand the research to other institutions in the territory to identify the knowledge and perceptions to mercury exposure, thus insisting on the policy implementation that rules out the use of given substance.

ACKNOWLEDGMENTS

The authors thank the Social Security Institute of the State of Mexico and Municipalities (ISSEMyM) for the support.

REFERENCES

1. Agency for Toxic Substances and Disease Registry (ATSDR). *Toxicological Profile for Mercury*. Availabe at: https://www.atsdr.cdc.gov/toxprofiles/tp.asp?id=115&tid=24. Accessed June 20, 2018.
2. Health Care Without Harm (HCWH). *Mercury*. Availabe at: https://noharm-uscanada.org/issues/us-canada/mercury. Accessed June 27, 2018.
3. Commission for Environmental Cooperation. *Evaluation of Primary and Secondary Mercury Supplies in Mexico*. Availabe at: http://www3.cec.org/islandora/es/item/11208-assessment-primary-and-secondary-mercury-supplies-in-mexico-es.pdf. Accessed June 20, 2018.
4. Sundseth K, Pacyna JM, Pacyna EG, et al. Global sources and pathways of mercury in the context of human health. *Int J Environ Res Public Health* 2017;14:105.
5. Lando AM, Zhang Y. Awareness and knowledge of methylmercury in fish in the United States. *Environ Res*. 2011;111:442–450.
6. Svendsen K, Syversen T, Melo I, et al. Historical exposure to mercury among Norwegian dental personnel. *Scand J Work Environ Health* 2010;36:231–241.
7. Echeverria D, Woods JS, Heyer NJ, et al. The association between serotonin transporter gene promotor polymorphism (5-HTTLPR) and elemental mercury exposure on mood and behavior in humans. *J Toxicol Environ Health A*. 2010;73:1003–1020.
8. Nagpal N, Bettiol SS, Isham A, et al. A review of mercury exposure and health of dental personnel. *Saf Health Work* 2017;8:1–10.
9. Obrist D, Kirk JL, Zhang L, et al. A review of global environmental mercury processes in response to human and natural perturbations: changes of emissions, climate, and land use. *Ambio* 2018;47:116–140.
10. Toxics Link for a Toxics Free World. *Mercury in Hospital Indoor Air: Staff and Patients at Risk*. Availabe at: http://toxicslink.org/docs/bmw/MercuryCamp/Mercury_in_Hospital_Indoor_Air.pdf. Accessed June 27, 2018.
11. Álvarez C, Moreno M, Grano AM, et al Elimination of mercury (Hg) in the health sector: the case of a hospital in the city of Hermosillo, Sonora, Mexico. In: *Proceedings of 3rd International Workshop, Advances in Cleaner Production*. Brasil, Switzerland, 2018.
12. World Health Organization. Position of the world health organization about mercury in the health sector. Availabe at: www.who.int/entity/water_sanitation_health/medicalwaste/mercurypolpaper.pdf. Accessed June 20, 2018.
13. Ritchie KA, Burke FJ, Gilmour WH, et al Mercury vapour levels in dental practices and body mercury levels of dentists and controls. *Br Dent J*. 2004, 197, 625–632; discussion 621.
14. Chaari N, Kerkeni A, Saadeddine S, et al. Mercury impregnation in dentists and dental assistants in Monastir city, Tunisia. *Rev Stomatol Chir Maxillofac*. 2009;110:139–144.
15. Naimi-Akbar A, Englund GS, Ekbom A, et al. Cognitive function among sons of women who worked in dentistry. *Scand J Work Environ Health* 2012;38:546–552.
16. Peshin SS, Halder N, Jathikarta C, et al. Use of mercury-based medical equipment and mercury content in effluents of tertiary care hospitals in India. *Environ Monit Assess*. 2015;187:145.
17. Farahat SA, Rashed LA, Zawilla NH, et al. Effect of occupational exposure to elemental mercury in the amalgam on thymulin hormone production among dental staff. *Toxicol Ind. Health* 2009;25:159–167.
18. Palacios N, Fitzgerald K, Roberts AL, et al. A prospective analysis of airborne metal exposures and risk of Parkinson disease in the nurses' health study cohort. *Environ Health Perspect*. 2014;122:933–938.
19. Bahcecik N, Ozturk H. The occupational safety and health in hospitals from the point of nurses. *Coll Antropol*. 2009;33:1205–1214.
20. Environmental Working Group (EWG). *Nurses' Health and Workplace Exposures to Hazardous Substances*. Availabe at: https://www.ewg.org/research/nurses-health#.WzH-0GcUmUk. Accessed June 20, 2018.
21. United Nations Program for the Environment. *Minamata Convention about Mercury*. Availabe at: https://treaties.un.org/doc/Treaties/2013/10/20131010%2011-16%20AM/CTC-XXVII-17.pdf. Accessed June, 27 2018.
22. Health without Harm. *Towards a Health Sector that Promotes Healthy Environments for All. Guide for the Elimination of Mercury in Health Establishments*. Availabe at: www.saludsindanio.org. Accessed June 20, 2018.
23. World Health. Toward the tipping point: WHO-HCWH global initiative to substitute mercury-based medical devices in health care. In: *A Two-Year Progress Report*. Availabe at: http://www.noharm.org/lib/downloads/mercury/Toward_the_Tipping_Point.pdf. Accessed May 20, 2018.
24. Navarrete C. Contaminación por mercurio en unidades médicas del sector salud de México. *Rev CES Salud Pública*. 2018;9:1–11.
25. Halder N, Peshin SS, Pandey RM, et al. Awareness assessment of harmful effects of mercury in a health care set-up in India: a survey-based study. *Toxicol Ind. Health*. 2015;31:1144–1151.
26. Janev Holcer N, Maricevic M, Miocic-Juran A. The use of mercury-based medical devices across Croatian healthcare facilities. *Arh Hig Rada Toksikol*. 2012;63:41–47.
27. Pluye P. L'intégration en méthodes mixtes. Cadre conceptuel pour l'intégration des phases, résultats et données qualitatifs et quantitatifs. In *Évaluation des interventions de santé mondiale. Méthodes avancées. Sous la direction de Valéry Ridde et Christian Dagenais*, pp. 187–212.Québec : Éditions science et bien commun et Marseille: IRD Éditions; 2019.
28. Tennant A, Conaghan PG. The rasch measurement model in rheumatology: what is it and why use it? When should it be applied, and what should one look for in a rasch paper? *Arthritis Rheum*. 2007;57:1358–1362.
29. Prodinger B, O'Connor RJ, Stucki G, Tennant A. Establishing score equivalence of the Functional Independence Measure motor scale and the Barthel Index, utilising the International Classification of Functioning, Disability and Health and Rasch measurement theory. *J Rehabil Med*. 2017;49(5):416–422. doi:10.2340/16501977-2225
30. Boone JW, Staver RJ, Yale SM. *Rasch Analysis in the Human Sciences*. 1st ed. Netherlands: Dordrecht: Springer; 2014.
31. Tennant A, Horton MC, Pallant JF. *Introductory Rasch Analysis: A Workbook: Department of Rehabilitation Medicine*. UK: University of Leeds; 2011.

32. Vincent JI, MacDermid JC, King GJ, et al. Rasch analysis of the patient rated elbow evaluation questionnaire. *Health Qual Life Outcomes* 2015; 13:84.
33. Smith EV. Detecting and evaluating the impact of multidimensionality using item fit statistics and principal component analysis of residuals. *J Appl Meas*. 2002;3 2:205–231.
34. Andrich D, Lyne A, Sheridan B, et al. *Interpreting RUMM2030*. Perth: RUMM Laboratory; 2010.
35. StataCorp. *Stata Statistical Software: Release 13*. College Station, TX: StataCorp LP; 2013.
36. Hernández-Sampieri R, Mendoza Torres CP. *Metodología de la Investigación: Las rutas cuantitativa, cualitativa y mixta*. México: McGrawHill; 2018.
37. Organización Panamericana de la Salud. Brasil, Universidade Federal de Santa Catarina. Investigación cualitativa en enfermería. Metodología y didáctica. Washington, DC: OPS; 2013. (Serie PALTEX Salud y Sociedad 2000; 10).
38. Friese S. *ATLAS.ti 7 User Manual*. Berlin, Alemania: Scientific Software Development; 2013.
39. Karam CMA. *Perception of the Young People on the Risk Associated with the Use of Pesticides in Villa Guerrero, Mexico*. Thesis.
40. Senanayake SJ, Gunawardena NS. Knowledge, attitudes and practices regarding handling mercury containing medical devices among nurses in a tertiary care paediatric hospital in Sri Lanka. *Work* 2016;55:311–319.
41. Jason JS, Manesh G, Julie R, et al. Hidden errors of aneroid sphygmomanometers. *Blood Press Monit*. 2002;7:309–312.
42. Pickering TG. What will replace the mercury sphygmomanometer?. *Blood Press Monit*. 2003;8:23–25.
43. sin Daño S. *Guía para la sustitución de químicos peligrosos en el sector salud*. Availabe at: https://saludsindanio.org/sites/default/files/documents-files/2755/guia-quimicos-sept-2015.pdf. Accessed June 22, 2018.
44. Autonomous University of Mexico State. *Programa de Estudios: Ecología de la Salud, aprovado por el consejo académico y el consejo de gobierno*; 2018.
45. Curriculum of the Surgeon's Degree. Availabe at: http://ri.uaemex.mx/handle/20.500.11799/63172. Accessed June 25, 2018.