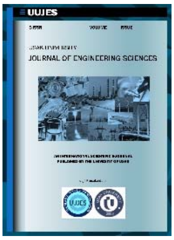

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Research article

THE DISADVANTAGES OF LEAD APRONS AND THE NEED FOR INNOVATIVE PROTECTIVE CLOTHING: A SURVEY STUDY ON HEALTHCARE WORKERS' OPINIONS AND EXPERIENCES

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Abstract

The use of state-of-the-art technical textiles instead of lead aprons is of great importance due to their lightweight, flexible, non-toxic and comfortable composition. In this study, we aimed to determine the disadvantages experienced by healthcare workers due to lead aprons and their opinions about innovative protective clothing. The survey, comprising seventeen questions, aimed to gather demographic information, design and physical properties of respondents' lead aprons, functionality, comfort, and performance of current protective clothing, and determine future design requirements. Within the scope of the research, a survey was administered to 52 radiation workers, and the results were analyzed statistically. Radiology technicians comprised nearly half of the respondents (34%), followed by physicians (25.5%) and nurses (19.1%). The most important problems encountered by the respondents during the use of lead aprons were defined as being heavy, restricting movement, and not fitting the body properly. Among the comfort descriptors, inability to move comfortably, weight and air permeability were considered "completely important" by the respondents, respectively. The study showed that 26.92% of the participants experienced complications with their lumbar spine, while 23.08% reported concerns with their cervical spine. Survey participants noted low air permeability and thermal comfort in lead aprons, making them unsuitable for various anatomical structures. To overcome these issues, technical textiles with easier shapeability and improved performance, such as mechanical properties and insulation, could be used instead. In order to overcome these disadvantages, producing and using technical textiles instead of lead aprons will provide a significant advantage.

Keywords: *Lead apron; Comfort properties; Radiation safety; Questionnaire survey*

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1. Introduction

The utilization of ionizing radiation for diagnostic and therapeutic applications in medicine is progressively increasing on a daily basis [1]. In comparison, the ionizing radiation doses employed in medical procedures for disease detection and treatment are very low compared to radiation released after a nuclear disaster. Even these low doses of radiation can have stochastic consequences on the human body [2].

Multiple protection methods have been established and continuously enhanced to minimize the avoidable radiation exposure of both radiation workers and patients. External radiation originates from an external source and can only be decreased by maintaining a safe distance, utilizing a protective shield, and limiting the duration of exposure. A protective shield refers to the utilization of any substance that can absorb and/or reflect incoming radiation [3,4]. Lead has been the choice for a long time for radiation shielding due to its ability to possess the necessary physical and mechanical qualities required for a shielding material [5,6].

Lead aprons are widely used as the primary form of personal protection in radiology departments and the broader medical imaging sector. Despite their efficacy in photon attenuation, lead aprons have specific limitations that would prevent their routine application. The basis of these limitations is that lead aprons are very heavy. According to Van et al., the weight of the garment is the most commonly mentioned comfort consideration when selecting a lead apron [7]. Regular utilization of heavy lead aprons has been observed to result in back pain or disc disease [8,9]. Ensuring appropriate thermal balance is a fundamental function of clothing, which includes providing thermal comfort [10]. Thermal comfort is susceptible to the effects of both individual and environmental factors. Engaging in physical activities, such as walking, can cause an increase in the body's metabolic rate due to the lead apron's significant weight. The existing body of research on the thermal comfort of lead aprons as protective apparel is relatively scarce.

Ergonomics is a science focused on the study of human fit and decreased fatigue and discomfort through product design [11]. The most important assumption of ergonomics may be that equipment, tools, machinery, and environmental conditions affect human performance. From this point of view, if products, tools, machines, workstations and working methods are designed with human capabilities and limitations in mind, the result will be better [12].

Significant modifications to the lead apron design have not occurred since the inception of this protective garment. Despite evidence linking design flaws to radiation exposure, this continues to occur [13]. The producers of the commercial lead apron utilized the same system-sizing chart for both males and females. Significant distinctions exist between the anatomical structures and body contours of males and females. The system of using the same design and measurements for both males and females, including expectant women, is insufficient [14]. The incorporation of anthropometric considerations in the design and production of X-ray protective garments has not yet occurred. The fit of a protective garment should conform to the user's inherent contours. Clothing comfort is the pleasing physiological, psychological and physical harmony between the human body and the environment [15]. It is one of the factors that can be changed in the human-machine-environment system. That is why clothing is so important. The clothing worn should not create any obstacle to the person and should be designed in accordance with ergonomic features and anthropometric dimensions. It should have the comfort features expected of it in that situation [16]. Primarily, lead apron protective apparel for female radiographers should be well-fitting and comfortable to ensure both protection and ease of movement, thereby facilitating efficient job performance.

Various technical textile products and their production methods are candidates for alternatives to lead aprons. The wearer's long-term use of ionizing radiation protective apparel necessitates a high level of comfort. When developing technical fabrics as a substitute for lead aprons, it is important to understand various comfort indicators that describe the temperature, moisture levels, overall comfort experience of the individuals wearing the protective garment, and the desired features of the safety garment design to be created [15]. In addition to the comfort parameters of the developed fabric construction, it is also important to develop functional designs that are qualitatively compatible with the user area, working conditions and physical properties in terms of developing radiation-shielding clothing as an alternative to the lead apron. Although there are studies on the different disadvantages of lead aprons in the literature, there is no study that examines the physical properties of lead aprons, their comfort descriptors and the musculoskeletal disorders they cause together. This study aims to examine the different perspectives of radiation workers using lead aprons on lead aprons and evaluate user demands for innovative products to be produced as alternatives to lead aprons.

2. Materials and Methods

The survey was carried out with the permission of Usak University Science and Engineering Sciences Scientific Research and Publication Ethics Board dated 12/12/2023 and numbered 2023-34.

The survey, consisting of seventeen questions, was divided into four sections. The first section included questions regarding demographic information. The second part included questions about the design and physical properties of the lead aprons used by the respondents. In the third part of the survey, the functionality, comfort and performance of the current protective clothing of the respondents using lead aprons were questioned. In addition, determining the expected requirements for the upcoming design of this type of clothing was attempted. Respondents were asked to respond on a five-point Likert scale that included a single descriptor of comfort, temperature, and humidity. Respondents were also asked to evaluate various comfort descriptors to express their expectations regarding protective clothing design, using a five-point Likert Scale ranging from 1 (indicating not at all important) to 5 (indicating very important). The last part of the survey included questions about whether the respondents had an orthopedic disorder due to the use of lead aprons. The final version of the survey was given as a result of the preliminary study conducted with ten volunteers determined by a convenience sampling approach. Thus, the clarity of the survey questions, their ability to be asked for the correct targets, and their ease of filling in by the participants were examined. Based on the sample sizes of similar studies, a sample size analysis was performed with special software (G*Power Statistical Analysis) [17]. It was concluded that 52 respondents would provide a power of 0.90 with an effect size of 0.50 and alpha of 0.05. Fifty-two radiation workers participated in this study, and all of the surveys were suitable for data entry, with the capacity deemed sufficient for the analysis.

2.1. Statistical Analysis

The Friedman test was utilized to examine the congruence between the responses provided by the respondents at diverse points in time. In the absence of conditions that permit the use of parametric tests and correlated or repeated measurements, the Friedman test serves as an alternative to single-factor analysis of variance. The subjective responses of the individuals were subjected to the Kruskal-Wallis H test, the non-parametric equivalent of one-way analysis of variance, following the execution of the Friedman test. Comparing measurements of more than two groups using non-parametric data requires the Kruskal-Wallis H Test. Applying this test to populations with comparable median values enables one to determine whether k-independent samples are random samples. The SPSS 22.0 Statistical Analysis Package was used to analyze the results.

3. Results

In this study, Cronbach's alpha coefficient (α) was calculated to evaluate reliability and internal consistency. All reliabilities ranged from 0.816 to 0.843, above the recommended value of 0.7 [18]. Kaiser-Meyer-Olkin (KMO) Sampling Adequacy Measure and Bartlett's Test of Sphericity were used to evaluate the suitability of participant data for factor analysis. The KMO index was 0.822, and Bartlett's test was found to be statistically significant in factor analysis ($p<0.05$).

3.1. Demographic Information

The respondents consisted of 40.4% individuals aged 18-30, with a male-to-female ratio of 1.043 (51.1% males to 48.9% females). Almost half of the respondents were radiology technicians (34%), followed by physicians (25.5%) and nurses (19.1%). According to the chi-square test, while there was no significant difference between males and females in terms of the answers given by the respondents in the survey ($p>0.05$), there were significant differences between the answers given in terms of educational status and profession ($p<0.05$) (Figure 1).

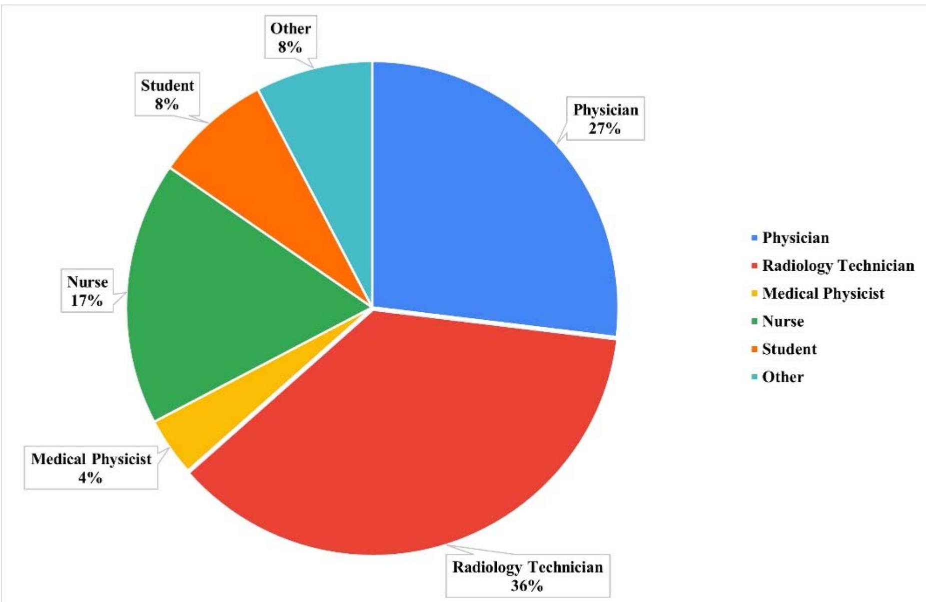

Fig. 1 Occupational distribution of the participants.

While the rate of respondents working in the field of radiation for less than five years was 38.3%, the rate of respondents working between 5 and 15 years was 36.2%.

Design and Physical Properties of The Lead Aprons

Images of various lead aprons were incorporated into the survey queries to ascertain the correlation between the comfort descriptors in the third section of the survey and the models of lead aprons utilized by the respondents. A total of 5.77% of the respondents indicated that they utilized the belted one-piece model, while 17.31% utilized the skirt and vest lead apron model, and 76.92% utilized the single-sided coated lead apron model. A total of 84.62% of the respondents indicated that they had utilized lead-based aprons; however, 13.46% of the respondents were unaware of the composition of the lead aprons they used. The primary challenges identified during the implementation of lead aprons were their substantial weight, impediments to movement, and inadequate body fit (Figure 2).

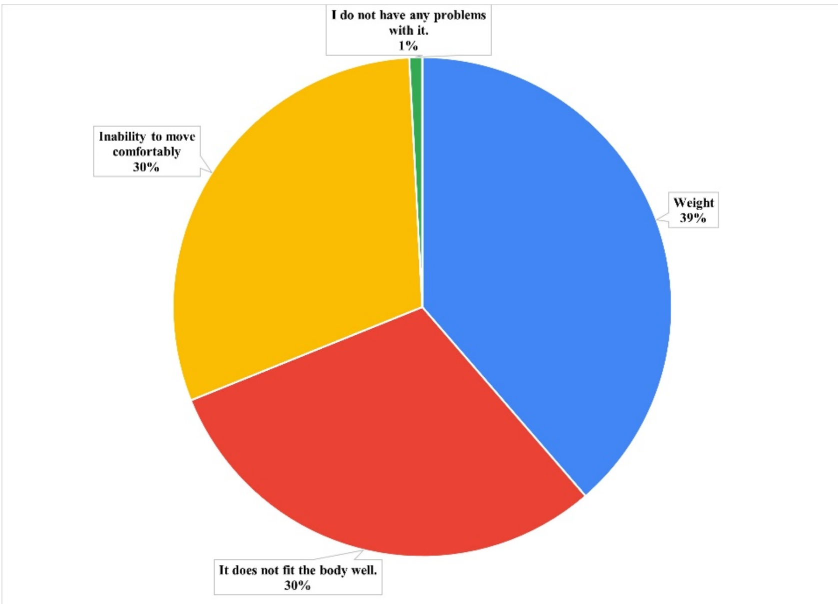

Fig. 2 The most important problems experienced by participants when using lead aprons.

33 (63.46%) of the respondents who cited weight as the most significant drawback of lead aprons stated that they only used them in specific circumstances. Among the problems experienced during use, 80.55% of those who selected the "Not Fit Well" option were men, and 19.45% were women. According to the table, the hardness factor, which will accelerate the energy decrease in long-term use by restricting direct mobility, is evaluated in the 'Important' category by 86.53% of the participants. Factors that can directly affect body health, such as 'Air Permeability' and 'Thermal Insulation', were evaluated by an average of 70% of the participants in the 'Important' and similar classes. The 'Stretching' factor, which will also affect the life of the clothing material by restricting the movement capacity of the body during use, was stated as 'Important' and similar by 73.07% of the users.

3.2. Comfort Descriptors for Lead Aprons

In this section of the survey, users were asked to answer three questions measuring temperature, humidity, and overall sense of comfort after using a lead apron for one hour. While 50% of the respondents described the feeling of warmth after using the lead apron for an hour as "warm", 3.85% described it as "cool". It is known that one of the most important problems that arise in long-term use of lead aprons is the feeling of sweating. The proportion of respondents who described the feeling of moisture as "extremely wet" and "slightly wet" after using a lead apron for one hour was 7.69% and 30.77%, respectively. The general feeling of comfort after using lead aprons for one hour was defined as "uncomfortable" and "completely uncomfortable" at a high rate (Figure 3).

Fig. 3 Respondents' thoughts on temperature, humidity and general comfort after using lead aprons for one hour.

On a scale of one to five, respondents rated each comfort descriptor. Inability to move comfortably, weight, and air permeability were regarded as completely important comfort descriptors by 25.00%, 23.08%, and 11.54% of the respondents, respectively. In numerous ways, the air permeability of a fabric can affect the well-being of the wearer.

Stress, hardness, initial coldness upon contact, and static electricity were regarded as entirely unimportant comfort descriptors by 25%, 19.23%, 17.31%, and 17.31% of the respondents, respectively (Figure 4).

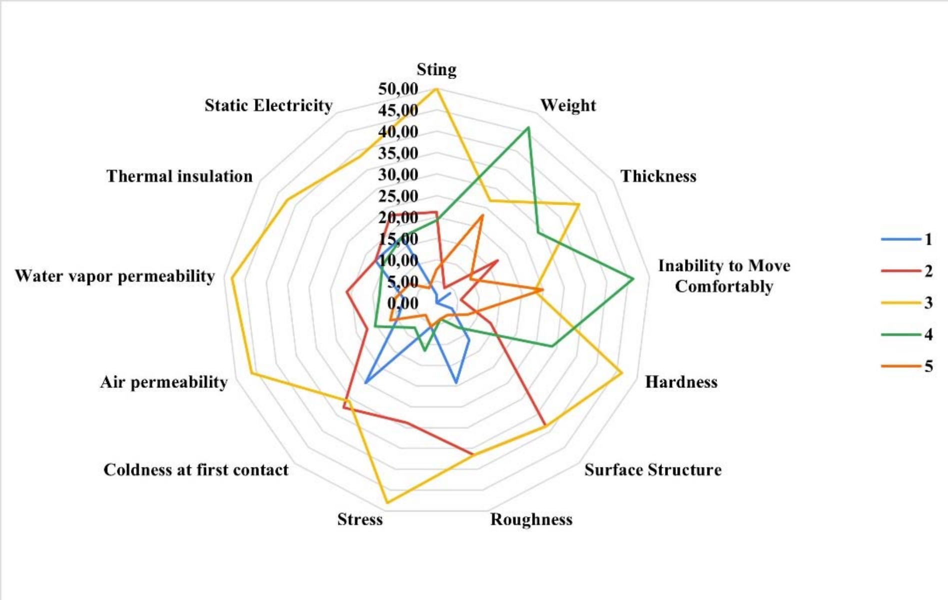

Fig. 4 Comfort identifiers for lead aprons.

3.3. Occupational Musculoskeletal Complications

Toward the conclusion of this research endeavor, subjects were queried regarding the presence of cervical/lumbar spine and hip/knee/ankle complications. The study revealed that 26.92% of the respondents had issues with their lumbar spine, while 23.08% reported problems with their cervical spine. 11.54% of the population reported suffering from hip, knee, or ankle complications. A significant proportion of the respondents who reported experiencing orthopedic issues had accumulated work experience ranging from 5 to 15 years (Table 1).

Table 1 The relationship between occupational musculoskeletal complications and years of working in the profession.

Length of employment (years)	Cervical Vertebra	Lumbar Vertebra	Hip Knee Ankle	p value
<5	3 (25.0%)	2 (14.29%)	1 (16.67%)	0,036
5–15	7 (58.33%)	7 (50.0%)	3 (50.0%)	0,055
16–25	1 (8.33%)	2 (14.29%)	1 (16.67%)	0,026
>25	1 (8.33%)	3 (21.43%)	1 (16.67%)	0,042

4. Discussion

This study assessed the perspectives of radiation workers about lead aprons within the framework of textile engineering, textile design, physical factors, and occupational disorders. The primary drawback of lead aprons is their substantial weight. Furthermore, the inability to manufacture lead aprons in various patterns, similar to technical textile items, has a detrimental impact on crucial comfort factors like as air permeability and thermal stability. The rate of lead apron non-use is thought to be exacerbated by factors such as the size and weight of the apron, suboptimal ergonomics and lack of practicality [19]. Most survey respondents indicated that lead aprons were ill-fitting, resulting in limitations on movement. This issue has demonstrated that lead aprons lack the requisite ergonomic requirements.

A substance that exhibits permeability toward air is generally expected to demonstrate permeability toward water, whether in its liquid or vapor state [20]. Therefore, the transmission of liquid moisture and the water vapor permeability are typically correlated with the air permeability. In addition, the thermal resistance of a fabric is predicated on the presence of still air within it, which is impacted by the structure of the fabric and its air permeability [21]. In our study, 70% of the participants reported that the air permeability and thermal resistance properties of lead aprons are important. 7.69% and 30.77% of users, in that order, characterized the sensation of sweating as "extremely wet" and "slightly wet" after wearing a lead apron for a duration of one hour. The results indicate that the utilization of lead aprons during activities lasting one hour or more has a notable drawback in terms of thermal comfort. There are innovative technical textile studies in the literature that are equivalent to lead aprons in terms of radiation absorption capabilities but more successful in terms of user comfort [5]. Since the chemical forms of ordinary textile fibers have poor photon attenuation characteristics, textiles have not been explored for X-ray shielding, while having the light weight and flexibility needed to protect against ionizing or electromagnetic radiations [22]. Nevertheless, other treatments, including a densely woven satin or twill and subsequent laying of the fabrics, might enhance their shielding efficacy by decreasing the textile's porosity [23]. Furthermore, sufficient protection against radiation exposure can be obtained by creating a textile with radiation-absorbing components included into the fibers and forming these fibers into a fabric [22]. Effective radiation shielding is dominated by metal components in the fabric's yarn composition. The absorption/transfer ratio is determined by the metal density per unit surface area of the fabric [24].

There are many studies in the literature showing that occupational orthopedic disorders occur as a result of long-term use of lead aprons [25–29]. Weight distribution, pressure, and forces exerted on the body are all influenced by the physical characteristics. For example, a 6.8 kg garment causes pressures to exceed 2,000 kPa in intervertebral disc spaces [30]. There were 67 (54.5%) people who reported orthopedic problems in the study by Akebia et al. with 123 respondents. Of these, 41 (61.2%) reported having problems in the waist area, 8 (11.9%) in the shoulder, 6 (9.0%) in the knee, and 5 (7.5%) in the neck due to the use of lead aprons [25]. In the study by Goldstein et al., 42% of respondents reported spine problems, while 27% reported issues with the hip, knee, or ankle [31]. Moore et al. reported that 12% of those who frequently used lead aprons and 8% of those who rarely used them experienced severe back pain [7]. In determining the extent of exposure reduction or musculoskeletal alleviation for the operator, the frequency or accuracy with which they utilize the specific shield is a critical factor [32]. This study discovered a correlation between the length of time lead aprons were worn and the occurrence of orthopedic diseases. Workers exposed to radiation for a period of 5 to 15 years reported experiencing pain in their lower back and neck.

Several possible limitations were included in this research. Firstly, this research is limited by the limits of survey research, with the main focus being on respondent bias. Participants may have intentionally provided inaccurate information about their exposure, and on the other hand, they could have exaggerated their level of compliance. In addition, Likert scales are susceptible to consent bias and social desirability bias, which increases the likelihood of overestimating pleasure. Additionally, the size of the sample in our study may have resulted in sampling bias. In order to compensate for this constraint, the survey was spread throughout a broad geographic area. We acknowledge that the institutions administering the poll may have influenced the survey replies towards similar opinions due to a disproportionately greater response rate. Nevertheless, by gathering data from eight distinct cities, the extent of this heterogeneity is expected to be constrained.

To our knowledge, this is the first study of its kind to examine lead aprons in terms of their textile and design properties. This study, focusing on the comfort properties of lead aprons, is part of a larger research aiming to produce an innovative technical textile alternative to lead aprons.

5. Conclusion

This study aimed to evaluate the attitudes of radiation workers regarding lead aprons from a broad perspective. It is known that lead aprons have many disadvantages. However, user evaluations are very important for the design of an alternative product that can replace lead aprons. Although the production of a fabric equivalent to the radiation absorption ability of lead aprons is the most important issue, the lighter weight of the new fabrics to be produced is of great importance for radiation workers. In addition to the weight factor, the most important problems were that lead aprons did not fit the body properly and restricted movement. Another disadvantage that the survey participants emphasized about lead aprons was that their air permeability and thermal comfort properties were quite low. It is not possible to produce lead aprons specifically for different anatomical structures and body lines during the design process. At the same time, although it is not possible to improve textile comfort parameters in these aprons, it will be an important advantage to use technical textiles that can be shaped more easily and provide efficiency in terms of technical performance (such as mechanical properties, strength, insulation) and functionality instead of lead aprons in order to overcome these problems.

Conflicts of Interest

The authors declare that they have no competing interests.

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Informed consent

Ethical approval of this study was obtained from the institutional ethics committee of the Usak University Science and Engineering Scientific Research and Publication Ethics Board (12.12.2023 / 2023-34).

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