WHETHER REGULATORY GUIDELINES AND SAFETY PROTOCOLS COULD REDUCE THE RISK OF RADIATION EXPOSURE IN INDIVIDUALS UNDERGOING COMPUTED TOMOGRAPHY SCANS? A SYSTEMATIC REVIEW

Abstract

Introduction: Computed Tomography (CT) scan has revolutionized medical diagnosis, enhanced treatment and prevented unneeded and costly medical procedures. In the United States, for example, more than 70 million CT scans occur annually. CT scan is one of the most vital sources of medical radiation exposure in developed nations.

Research Question/Problem: Although CT is an invaluable tool in diagnosis, the high proportion of individuals undergoing radio imaging has raised significant concerns on patient safety due to increased exposure to ionizing radiations. Hence, the present study explored one primary research question "Whether regulatory guidelines and safety protocols could reduce the risk of radiation exposure in individuals undergoing computed tomography scans?"

Methodology: The present study was based on a systematic review approach. The databases those were accessed for selecting the relevant articles include PubMed, Scopus, and SciencesDirect databases. Different keywords such as "Radiation safety", "CT scan", "Radiation Risk" were connected with appropriate connectors to select the respective articles. Thirteen articles were thematically sorted and analyzed to address the research question.

Results: The overall exposure to radiation was more minimized by bismuth shields compared to lead shields (74% versus 57%). However, lead shields offered higher protection in radiation exposure to the breast tissues compared to their bismuth counterparts (76% versus 57%). Use of detectors, sensors, noise reduction approaches, image reconstruction (iterative reconstruction), and algorithms for post-processing could minimize radiation exposure in at-risk individuals.

Conclusion: The present study highlighted the necessity of implementing regulatory guidelines and protective measures in reducing the risk of radiation exposure across at-risk individuals.

Keywords: radiation safety, CT scan, radiation exposure, regulatory guidelines, protective shield

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Introduction

Computed Tomography (CT) scan has revolutionized medical diagnosis, enhanced treatment and prevented unneeded and costly medical procedures (Brenner & Hall, 2007). Moreover, its widespread use is primarily due to its ability to create images with extraordinary accuracy and speed. In the United States, for example, more than 70 million CT scans occur annually. The management of CT scan is vital for the general wellbeing of an individual as the process involves the use of hazardous technology on human beings. Radiologists, medical physicists, and technologists are expected to maintain a comprehensive plan that seeks to provide their services at minimum risks to the patients. CT scan continues to be widely used due to two main reasons (Bell, 2016). First, it has reduced the need for exploratory surgical procedures and hence saved many of lives. Second, the test is time efficient and it has allowed physicians to save many lives and promote survival. It is imperative to devise effective ways to improve patient and staff safety when using CT scans. This study is relevant to medical professionals as it explains approaches that they can use in safety management during CT scanning. Further, it will provide valuable information about the variation of radiation dosage risks in different patient populations. Findings from the study will also guide full implementation of protocols aimed at reducing the dosage of radiation in many healthcare centers. Brenner and Hall (2007), recognize the need for physicians to base their decisions to subject patients to CT scans on the interest of the patient and the adverse risks associated with radiation. As such, this research will be able to provide sufficient evidence supporting the need to consider other safer tools before subjecting patients to CT scans.

Research Problem

CT scan is one of the most vital sources of medical radiation exposure in developed nations. Although CT is an invaluable tool in diagnosis, the medical community currently considers it a double-edged sword because it is overused and associated with carcinogens. The high proportion of individuals under exposure has recently raised concerns about the increased risk of cancer in the population and patient safety due to radiation exposure (Thrall, 2012). A CT scan exposes patients to ionizing radiation, which is a known human carcinogen that can pose damage to the cells. The mounting worries over radiation exposure have resulted in the establishment of mechanisms for safety management such as reducing radiation doses and limiting avoidable CT scans. It is also essential that the safety management practices focus on how technologists can minimize risks during the CT scan.

Research Questions

The study will encompass three research questions:

A. Which safety management strategies can be used to protect patients during CT scans?

B. Can the amount of radiation exposure from CT scans be safe during a scan?

C. What is the effectiveness of radiation and what is the degree of risk it exposes patients to?

Hypothesis

H1: Techniques such as reduction of radiation doses, shielding, and regular maintenance can be used to enhance patient safety management during CT scans.

H2: The amount of CT radiation dosage can be quantified to determine the safe dosage.

H3: Classification of radiation may reduce a significant degree of risk to the patient.

Objectives and Aims

The following are the objectives of this study:

- To explore and evaluate the issues that are crucial in patient radiation, such as the techniques used to minimize the dosage, as well as the feasibility and effect of tracking the lifetime exposure to radiation from human image radiation and the CT.
- To evaluate the process and the techniques used in radiation protection through the computed tomography scanning.
- To address the various concerns about increased human exposure when performing the computed topography procedures.
- To provide the optimization procedures and techniques during dose management.
- To suggest the best and comprehensive procedure that covers CT dose protocols.

Methodology

This research that is going to be used will be relevant, peer-reviewed and recent. To ensure that the articles are peer reviewed. I will use articles that are published in reputable journals. The databases searched included; PubMed, Scopus, and SciencesDirect databases. The search was completed by inputting the keywords for the intended research which are “Radiation safety”, “CT scan”, “Radiation Risk”. The articles to be used will be restricted to papers that were published between the years 2012 and 2017. Research conducted more than five years ago could have already been overtaken by time. This is especially so in technology-related research where changes are extremely volatile. When the keywords were input to the search engine, a total of 394 articles were established. The distributions of the articles were 137 from PubMed, 85 from Scopus, 172 articles from ScienceDirect databases. After controlling for duplication, a total of 35 articles were eliminated. Of the 329 articles that remained, further elimination was done based on the following criteria.

Inclusion Criteria:

I Included articles that met the following requirements:

(1) Papers that were published between 2012 and 2017.

(2) Papers that used research conducted within the United States.

(3) Articles that were written in English.

(4) Publications that were peer reviewed.

Exclusion Criteria:

I excluded the papers that were:

(1) Published before 2012.

(2) Written with research conducted outside the United States.

(3) Written in any other language apart from English.

(4) Articles that were not focused on radiation safety management in CT scan.

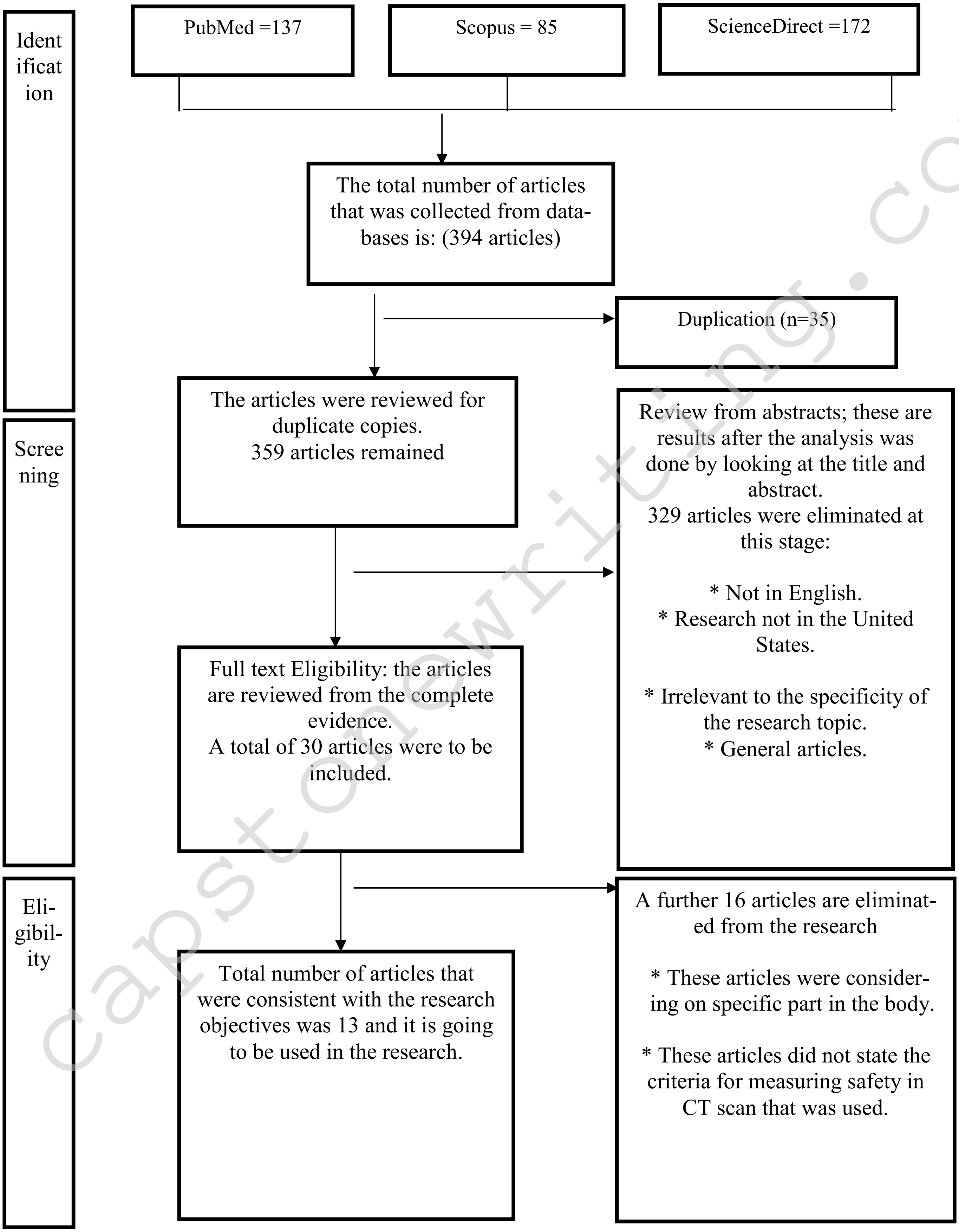
Data Extraction Protocol:

The data extraction protocol aimed at extracting the names of the authors, the date when the publication was published, study purpose , the methodologies used the number of participants, the results, and the conclusion. (Figure -1)

Quality Assessment Method:

The quality of the papers was determined by the fact that they were peer reviewed and published and therefore ascertained to be valid. Further assessment was done by looking at their sample sizes and the limitations encountered when carrying out research. Conflicting interests among the authors was reviewed to determine possibilities of bias.

Study Selection Protocol



Literature Review

Safety Management Techniques used to Protect Patients during CT Scans

A special report by DeMaio, Turk, & Palmer (2014) sets out to examine the most commonly used techniques during CT scans and examinations. The authors establish that ever since the initial development of CT scans in the early 1970s, contact shielding has been viewed as the most viable approach to prevent or limit excessive radiation dosages to patients. Lead and other metals can be placed directly above the anatomical areas of the patients and prevent the intrusion or infiltration of excessive x-rays on the patient (Costello et al., 2013). According to Kalra, Sodickson, and Mayo-Smith (2015), the goal of shielding in any CT scan or CT examination is to absorb scatter radiation that is produced due to interactions between the beam, the table, the patients, and any other surrounding medical equipment. It is important to note that in their evaluation, DeMaio and Turk observe that the rising complexities in modern CT scans introduce chances for errors in shielding. Hence, the introduction of lead and similar contact materials could serve to reduce or even increase the patient dose depending on how the shielding is done (2014). The author identified two major shielding models as the lead and the bismuth shielding techniques.

Lead Shielding

Lead shielding is primarily made to reduce the impact of scatter radiation in lead-sensitive or radiation-sensitive patient organs. A typical lead shield has a thickness ranging from 0.25 mm to 1.0 mm and comes in a variety of shapes and sizes. The most common types of lead shields include thyroid collars, wrap-around aprons, protective gear, eye shields, and male gonadal capsules (DeMaio, Turk, & Palmer 2014). Regardless of the shape, size, or the design of the lead shield, the primary goal is to reduce the radiation dose to the parts of the patients beneath the shield. For example, DeMaio, Turk, & Palmer (2014) demonstrated that during a CT scan of the head, lead shielding could be utilized to reduce excessive radiation from accessing the breasts, thyroid, and even the eyes. The shielding restricts the radiation waves and scatter radiation within the targeted organ to prevent unnecessary damage harm from them. For instance, DeMaio, Turk, & Palmer (2014) estimated that a 0.35mm lead-equivalent apron can reduce radiation spread as much as 57%. In a head CT scan, there was an average dose reduction of 45% in the thyroid region and 76% in breast tissue using a head or a collar lead-equivalent shield and there was a further 51% reduction in the entrance skin dosage with 0.25 mm shield that is a lead equivalent for the thyroid shield (Demaio et al, 2014).

It is important to note that in investigating the significance of lead shielding, scholars have established that it may be of particular importance when scanning pregnant women. For example, according to Demaio et al (2014), found that there was a 35% reduction in fetal dosage when a lead protection apron was placed on the anterior parts of the patient. Furthermore, they observed that when a 0.25 mm and 1.0 mm of the lead protective cover was placed to shield pregnant patients, the results indicated a 55% fetal dose reduction. Demaio et al, (2014) revealed that a 0.35 mm thick, double-layered shield, similar to 0.70 mm shield the best protective layer and achieved the maximum patient safety and comfort. Clearly, of all the lead shield thickness tested, a double-layered 0.70 mm shield offered a stable balance between patient comfort and fetal dose reduction.

Bismuth Shielding

The bismuth shielding is a new type of protection composed of latex rubber and the bismuth material. It is designed to significantly reduce the surface radiation dosages to specific radiosensitive organs. The bismuth is placed within an acquired radiation range and acts as a selective filter to scatter radiation. Demaio et al. (2014) identified that a bismuth shield dose not allow an excessive amount of photons to pass from the tube to the detectors. During the CT examination, it is noted that the bismuth shielding of a padded form is placed directly above the radio-sensitive organs. The bismuth shield is re-usable and it is important to note that during a CT scan the bismuth shields are 1mm thick and are used in conjunction with a foam pad to provide comfort between radio-sensitive organs and the imaging material. For instance, during a chest scan of a female patient, the bismuth shields can be placed directly over the chest organs of a supine female body to selectively filter out any radiation exposure to sensitive areas like the breast and stomach.

In researches involving the eyes, the thyroid, and the breasts, the bismuth has been known to reduce radiation dose by nearly 74%, and during cardiac CT scans, the shields can reduce dosage to the breast by close to 57%. Moreover, Demaio et al. (2014) concluded that it is a major advantage of bismuth shielding over lead shielding is that the bismuth is recyclable and re-usable when used in combination with a padded form. The bismuth is also more effective in trapping scattered radiations because it combines both the latex rubber and bismuth materials. The main advantage with the lead shielding is that it is mainly beneficial during the scanning of pregnant women. The lead shielding is also relatively inexpensive and can be equally as effective as the bismuth particularly when there is a double-layered 0.35 mm thick protector.

Quantification of radiation exposure from CT scans that is safe during the scan

First, it is important to understand how to monitor radiation exposure from CT scans. Boone .et al, (2012) examined that the knowledge gaps and monitoring approaches from CT scans and they summarize the proceedings from a Radiation Dose Summit to bring insight to the means and ways to monitor radiation exposure from CT scans. The authors contend that in cases of stark uncertainties regarding the biologic effects of radiation exposure, the most fulfilling course of action is to keep the radiation dosages as low as possible. Information should be sufficient to guide intervention approaches and to enhance the prescription of accurate dosages (Boone, Hendee, McNitt-Gray, and Seltzer, 2012). This paper further contends that reasonably accurate radiation doses should be administered during scans that are dangerous to radio-sensitive patient's organs. It is essential, however, to observe that reasonable estimates should take into account the scanner factors, patient sizes, and the use of accurate estimates in the identification of methods that allow practitioners and physicians to identify where further reduction efforts should be applied (Boone et al, 2012). It is important to note that in enhancing radiation safety management in CT patients, there is the need to integrate reasonable dosage estimate into a patient's medical records. Such integration should be done in a scalable fashion to permit for the tracking of the patient's periodic dosages.

Management and minimizing of radiation doses during CT procedures

As part of examining the safety protocols, Bell, (2016) observed that practitioners and clinicians should implement desirable dosage estimates. The author further established that practitioners should understand a range of factors to determine the radiation dosage, including kilovoltage peak, radiation span, slice thickness, milliampere seconds, pitch, and anatomical coverage. It is further crucial that the CT technologist comprehends the connections between the imaging parameters to properly execute the desirable safety protocols in each CT examination, such as adjusting the longitudinal scan length and patient size to monitor radiation transmissions (Bell, 2016). Moreover, Chintapalli, Montgomery, Hatab, and Katabathina, examined existing protocols and established the best practices for safety and effectiveness (2012).

Using CT scan protocolos to control the amount of radiation dose

The most promising technological best practice discussed pertained to the use of x-ray including detectors, sensors, noise reduction, image reconstruction, and algorithms for post-processing (McCullough et al., 2012). Access to standard data sets for raw processing was also identified as a critical requirement of radiation safety management. McCullough et al (2012), revealed that current commercially present techniques such as beam-shaping filters, the optimization of tube potential, and automatic exposure control critically underpin the enhancement of safety in CT scanning. Similar methods and techniques that are increasingly gaining widespread acceptance, including noise reduction, iterative reconstruction, and post-processing algorithms were also seen as fundamental to achieving safety in routine CT scanning reducing radiation doses (2012).

There are additional tools and methods that show potential for dosage reduction, but developments in safe and effective radiation control devices have led manufacturers to focus on radiation dose reduction tools. Three major radiation dose reduction techniques and devices are identified in the literature, including; iterative reconstruction, automated tube selection, and the automated tube modulation (Ramah et al. 2013). A similar study by Trattner (2014) showed that the central principle of the automated tube moderation is to allow for constant image quality of CT scans regardless of patient's varied characteristics, by maintaining such constant image qualities and it is possible to reduce the amount of dosage. The three fundamental operational principles for the automated tube modulation is to adapt the tube to the current stage of the body, increase the automated tube for more attenuating areas, and decrease the automated tube for less attenuated areas. Ramah et al., (2013), demonstrated that the modulation tube has four areas of modulation, with the first being the angular modulation, followed by the longitudinal modulation, then the temporal, and finally the combination modulation. These attenuations allow the moderated tube to maintain the quality of CT scan images while at the same time reducing the radiation dosage.

The automated tube selection uses a software program to reduce dosage usages in CT scans. The results show that the ATPS system or device achieves a statistically significant reduction of radiation dosages when compared to the standard protocols that use a 120-kVp setting (Ramah et al. 2013). This software-based technique uses a programmed setting that alters the radiation dosages depending on the set parameters and key changes in a patient's sensory organs. For instance, when the ATP system is used, the automated tube selection makes it possible to alter the levels of radiation dosages depending on changing characteristics, such as changes in the body's functioning (Ramah et al. 2013). This analysis hence supports that both software and hardware-controlled techniques are critical additions to CT scanning innovations. Other than reducing the tube current, the ATP leads to a sharp decline in photons in both abdominal and chest imaging practices. The iterative reconstruction (IR) provides an alteration of algorithms to improve the image quality and lower the radiation dosage. Key improvements in IR and its consequent implementation make it possible to enhance image quality and reduce exposure to dangerous, excessive radiation (Trattner, 2014). These major techniques provide better analysis of CT scans, program the CT machinery to desired levels, and, in the process achieve the desired reduction in dosage levels much needed to achieve safety management.

The effectiveness of radiation and the degree of risk it exposes patients to

Radiation has a variety of therapeutic benefits for patients but also can cause several life-threatening diseases. Cancer and other complex illnesses may require radiotherapy and the application of radiation doses (Fletcher et al., 2017). CT has played the most significant role in the treatment of these diseases and has proven to be quite effective. In the past 50 years, there have been improvements in the control of these diseases and people undergoing radiation treatment have had better chances of survival (Kalra et al., 2015). They avoid the reoccurrence of the diseases in most cases even if there have been reports of the disease reoccurring. Even though the radiation process provides a significant amount of benefits in these circumstances, it also exposes the patients to risks (Fresh et al., 2013). There are different types of radiation exposure that affect the body and are the main causes of failures seen in the medical professions. In general, exposures to radiation can have a massive impact on the genetic makeup of the patients. Carcinogenesis is induced by the radiations that take place through the process of stochastic, and it increases randomly with the dosage increase (Albert, 2013). Moreover, these risks include a high level of toxicity, such as the cardiac toxicity, pulmonary modification and lymphedema (McCullough et al., 2012). Another serious risk is the development of secondary malignancy. Nonetheless, the radiation treatment has been advancing and evolving through more flexible treatment schedules so that the process can be more effective. It is due to these benefits that professionals seem to believe the benefits outweigh risks.

Results

i. *Analysis of techniques such as reduction of radiation doses, shielding, and regular maintenance in enhancing patient safety during CT scans*

Demaio et al. (2014) reflected that 0.35mm thick shields were more effective than 0.25mm shields or 1mm shields. Demaio et al, (2014) further revealed that a 0.35 mm thick, double-layered shield, similar to 0.70 mm shield the best protective layer and achieved the maximum patient safety and comfort. Hence, the 0.35m –thick lead shields and bismuth shields for radiation protection were considered for comparison (Fig 1).

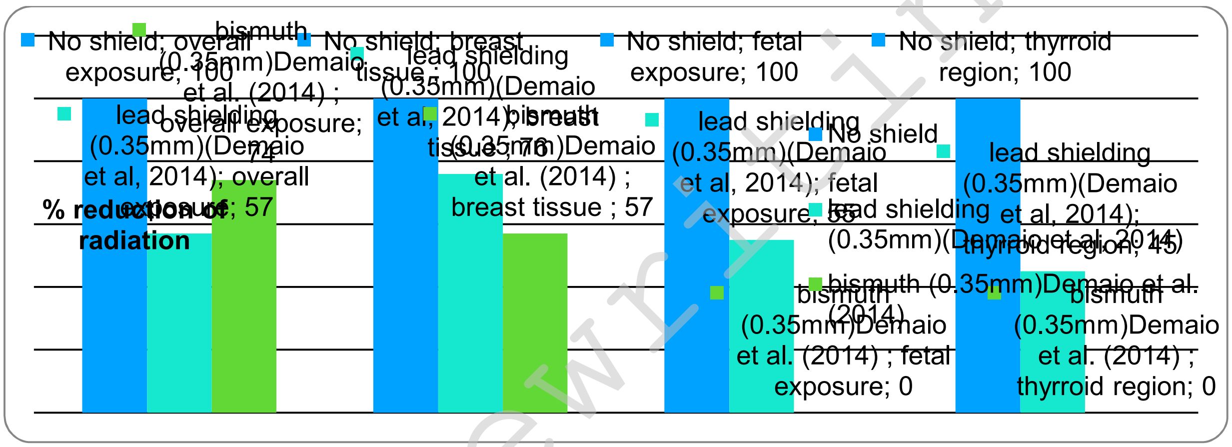


Fig 1: Comparison of radiation exposure between the 0.35m –thick lead shields and bismuth shields

Fig 1 reflects that techniques such as shielding can be certainly used to enhance patient safety management during CT scans. However, the Demaio et al. (2014) showed that the overall exposure to radiation was more minimized by bismuth shields compared to lead shields (74% versus 57%). However, lead shields offered higher protection in radiation exposure to the breast tissues compared to their bismuth counterparts (76% versus 57%).

ii. *Role of selecting appropriate radiation doses in minimizing radiation exposure*

Boone .et al (2012) highlighted that information should be sufficient to guide intervention approaches and to enhance the prescription of accurate dosages. The authors further suggested that scanner factors, size of the patient, and clinical history of a patient should be evaluated before selecting the appropriate radiation dose. Bell (2016) and Chintapalli et al. (2012) emphasized that existing protocols for radiation safety should be appropriately complied. Such findings suggest that adherence to radiation safety protocols could protect patients from the harmful effects of ionizing radiations.

iii. Improvement in technological interventions could reduce radiation exposure

McCullough et al. (2012) highlighted that detectors, sensors, noise reduction approaches, image reconstruction (iterative reconstruction), and algorithms for post-processing could minimize radiation exposure in at-risk individuals. The use of beam-shaping filters, angular modulation, voltage selection, optimization of tube potential, and automatic exposure control could enhance patient safety during CT scanning (Ramah et al., 2013, and Trattner, 2014). These findings suggest that both regulatory and technological modulations are necessary to mitigate the harmful effects of radiation exposure across at-risk individuals.

iv. To suggest the best and comprehensive procedure that covers CT dose protocols

The evidence reflects that it is necessary to define the best and comprehensive procedure for CT. This is because studies suggest that radiation doses can be harmful either in stochastic doses (threshold doses) or in non-stochastic doses (zero threshold doses). Stochastic doses reflect that radiations impose harm in a dose-dependent manner, while non-stochastic doses reflect that radiations impose harm in a non dose-dependent manner. Albert et al. (2013) and McCullough et al. (2012) reported that both stochastic and non-stochastic effects of ionizing radiations could increase the risk of carcinogenesis.

Conclusion

The present study was based on a systematic review and it appropriately highlighted the necessity of implementing regulatory guidelines and protective measures in reducing the risk of radiation exposure across at-risk individuals. The study further elucidated and compared the material factsheets of different radiation shields based on their efficacy across clinical settings. The systematic review reflected that radiation shields should be specific to a patient or to the tissues those are exposed to radio imaging. This study also implicated that healthcare professionals should exhibit appropriate knowledge while selecting radiation doses and protective shields before implementing CT scans. Hence, protocol-based and technology-based modulations are necessary to reduce the harmful effects of ionizing radiations in healthy volunteers and patients. Non-compliance with regulatory guidelines on radiation exposure and a failure to select appropriate protective shields or radiation doses could increase the risk of carcinogenesis in at-risk individuals.

Although this study was based on a systematic review, the number of studies that was considered for the analysis was too small. Future analysis on radiation safety during CT should include more studies. Moreover, the review did not include randomized controlled trials (RCT) studies. RCT trials reduce the chances of experimental and subjective bias. Hence, the authors of the respective studies failed to identify or report the effects of confounding variables on their findings. Such issues could have reduced the viability and reproducibility of their findings. Moreover, the chances of selection or experimental bias cannot be ruled out in this review too. Future studies should include a meta-analysis approach with different studies. Such study design could help to identify the odds of patient safety based on radiation exposure with the types of protective shields and the regulatory guidelines governing the selection of radiation doses.

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