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Dose Creep: Is It Real or Imagined?

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By

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ABSTRACT

Two types of patient-centered care in the radiology profession are service and safety. Service relates to the technologist being a patient advocate by effectively communicating, building relationships, and providing care. Two types of safety in the radiologic sciences profession relate to contrast media and radiation safety. The focus of this study was on radiation safety. The project was designed to evaluate exposure indicator values from radiographic procedures performed by junior and senior radiography students during the month of March 2013. The mean exposure indicator values for radiographic procedures were evaluated by all students and then by student rank (juniors and seniors). The type of procedure and student rank (junior and seniors) had an impact on exposure indicator values. The results revealed that dose creep occurred during radiographic procedures performed by student radiographers. It was determined that there is a need for additional education for student radiographers regarding selection of appropriate exposure factors to minimize dose creep.

Radiologic technology is one of many professions within the health care industry that emphasizes patient-centered care. Patient-centered care requires that health care providers, including radiographers, focus on two major categories: service and safety. Service involves focusing on patient needs and satisfaction. Radiographers become patient advocates by effectively communicating, building relationships and providing care. Two types of safety in the radiologic sciences profession relate to contrast media and radiation safety.[1]

When radiographers perform and then submit images to radiologists to be diagnosed, optimal images are required and radiation protection measures must be used to ensure patient safety. The American Society of Radiologic Technologists and American Registry of Radiologic Technologists provide standards by which radiographers can practice safety. The Code of Ethics for radiologic technologists includes a statement that radiologic technologists use expertise to minimize patient dose.[2] Furthermore, a goal of the radiology community is to incorporate the as low as reasonably achievable (ALARA) philosophy into practice. The ALARA concept is one in which radiologic technologists use all known methods to minimize radiation exposure.

Methods to minimize exposure include the three cardinal principles of radiation safety: time, distance, and shielding. Time should be minimized, distance from the radiation source must be maximized and shielding needs be employed whenever possible.[3] Additional factors to minimize patient dose include, but are not limited to, the radiographer restricting the x-ray beam to the area of interest and using optimal exposure factors.

Despite emphasis on radiation protection, technological advancements have increased patient exposure. This can be attributed to an increase in the number of medical imaging procedures ordered and performed in the United States on an annual basis. The National Council on Radiation Protection reported in 2006 that the number of medical imaging procedures has increased significantly during the past twenty years. The exposure received from imaging procedures to the American population on a yearly basis has increased nearly 600% since 1990.[3]

In addition to an increased number of procedures ordered, incidents of overexposure have also raised awareness of the risks of radiation in the United States. Consequently, legislation was introduced in the U.S. House of Representatives to increase training and documentation of exposure in patient medical records. Furthermore, the International Council on Radiation on Radiological Protection drafted a report in support of increased education regarding radiation protection.[4]

Another cause of increased dose may be attributed to the radiology profession transitioning from film-screen to digital radiography. Film-screen radiography involved a process in which exposure factors (mAs and kVp) were selected. After the exposure, chemical processing produced an image with an amount of darkness directly proportional to the amount of radiation striking the image receptor. Underexposure was obvious as the image appeared light, referred to as low image density; and overexposure was recognized as being too dark or possessing high image density.[5] Image density was one of the reliable indicators of proper selection of exposure factors with film-screen radiography. Since the level of density could not be manipulated after the film was processed, exposure latitude or the ability to make errors in selection of mAs and kVp was narrow.

The advent of digital radiography in the 1980s[6] modified the workflow in radiology department by eliminating the need for film and chemical processing. The process of selecting exposure factors and taking an exposure remained the same, but the image was electronic and displayed on a computer monitor. Incident exposure to the image receptor did not affect image density. In fact, a digital process referred to as automatic rescaling compensated for incorrect exposure factors selected by the radiographer prior to the exposure to produce a diagnostic quality image. With digital radiography, exposure factors may be significantly different from optimal values before the quality of the image is affected. Underexposure in digital imaging may result in image noise which appears grainy, and overexposure can create a high quality image with minimal noise.[4]

Current literature confirms the phenomenon of dose or exposure factor creep in which technologists have found it prudent to overexpose patients in an effort to prevent noise appearing on images. The major advantage of digital radiography is a wide dynamic range.[7] A wide dynamic range refers to the image receptor detecting a wide range of radiation intensities in the exit beam and will digitize the image to be viewed on a monitor.

Digital radiography drastically reduced the number of repeat radiographs due to incorrect selection of exposure factors. Since over and underexposed images will be displayed with the same brightness, the visual indicator of using the appropriate exposure factors with film-screen radiography has been eliminated. The exposure indicator value, which indicates the amount of radiation received by the image receptor, may be reviewed to evaluate under and overexposure.[6]

Unfortunately, the exposure indicator varies from one vendor to another. For example, Fuji, Philips, and Konica use a sensitivity or S number to represent exposure to the image receptor. With these vendors, the relationship between the exposure indicator and radiation exposure is inversely proportional. Therefore, the exposure to the image receptor is lower when the S number is higher. On the other hand, Agfa developed a logarithm of the mean exposure (lgM) for its exposure indicator. With this system, the lgM number is directly proportional to the exposure received by the image receptor.[8]

The new standard in exposure indicators originated from a meeting in 2004 but was adopted at the 2010 Image Gently Pediatric Digital Radiography Summit.[9] The International Electrotechnical Commission (IEC) published its standard and adopted the universal term exposure indicator (EI) to be used by manufacturers to provide immediate feedback regarding exposure to the image receptor.[6]

When purchasing new radiographic equipment, hospitals and imaging clinics may elect to use the new universal exposure indicator values; however, older equipment in the same departments may still provide S, lgM, or other values. Once universal EI values are applied in all radiology departments, the confusion regarding exposure indicator values specific to vendors will finally subside.

Since there are no federally mandated dose limits for patients, the radiology profession must internally address the issues of overusage and overexposure to decrease patient dose.[3] The unfortunate consequence is that excessive exposure factors may be selected by the radiographer which results in overexposure. The literature confirms the need for quality assurance monitoring of exposure indicator values to prevent dose creep. This study evaluated exposure indicator values from radiographic procedures performed by student radiographers in northeast Tennessee. It also determined if there is a need to further enhance the radiography curriculum to select appropriate exposure factors to minimize patient dose.

Literature Review

Radiologic technologists are responsible for incorporating principles of radiation protection while performing diagnostic procedures.[10] There are many factors that may be used to decrease patient dose during procedures. These factors include but are not limited to shielding, minimizing repeats, using beam restriction devices, selecting proper exposure factors, using a longer source-to-image receptor distance and minimizing dose creep.

Shielding, one of the three cardinal principles of radiation, is used to decrease exposure to a patient who is potentially reproductive. This can be accomplished by placing barrier material, usually lead, over the reproductive organs of the patient when the gonads are within four to five centimeters of the primary beam.[11] Shielding is not limited to patients of reproductive age since individuals in all age groups should be protected from ionizing radiation.

When a projection or entire radiologic procedure must be performed a second time due to technologist or equipment error, it is referred to as a repeat. Unfortunately, a repeat radiograph doubles patient dose. Consequently, it is the duty of the technologist to decrease the probability of repeats during radiographic procedures. Many factors, such as effective communication, immobilization techniques, proper positioning, optimal exposure factors, appropriate beam limitation and shielding, proper use of ancillary equipment, and accuracy while archiving images will help reduce the number of repeats. Efforts are made by departments to reduce repeats due to equipment errors by scheduling routine preventative maintenance on radiographic and ancillary equipment.[12]

Beam limiting devices can be used to reduce the size of the x-ray beam. These devices include aperture diaphragms, cones, cylinders, and collimators. Although collimators are most commonly used in radiology departments, all of these devices serve to protect the patient from excessive radiation exposure. Beam limitation devices should be used to restrict the beam to the area of clinical interest and will decrease patient exposure if used properly. Automatic collimation, also referred to as positive beam limitation, is used in radiologic departments to further decrease patient dose. Technologists shouldn't rely on automatic collimation and must provide appropriate beam restriction manually by adjusting the collimation to the anatomy of interest.

The appropriate use of exposure factors, kVp and mAs, serve to decrease radiation dose. The exposure factor kVp controls the quality of the x-ray beam and is used to provide penetration through the body part. Higher kVp increases beam penetration. On the other hand, mAs controls the quantity of the x-ray and determines the number of x-rays that will be produced. It includes both milliamperage (mA) and the length of the exposure (s or time). Higher mAs increases the number of x-rays in the useful beam that interact with electrons in the patient's body.

Both theory and research supports the use of higher kVp and lower mAs to decrease patient dose. A research study evaluated digital exposure techniques during pelvic imaging on patient dose, exposure indicator values and image quality. The study confirmed that high kVp and low mAs exposure techniques used during digital radiographic procedures decrease radiation exposure.[13]

Another method to reduce patient dose is adjusting the source-to-image receptor distance (SID). By placing the x-ray tube farther away from the patient, radiation intensity is decreased since there is less entrance surface dose that can be absorbed by the patient. Therefore, SID is an effective tool to reduce radiation dose and produce an optimal image.

Another research project was conducted to assess the effect of SID on radiation exposure and image quality. The results confirmed that by increasing SID, both entrance surface dose and effective dose decrease. As a result, the study provided substantive evidence supporting the theory that a longer SID reduces patient dose.[14]

A different method technologists should use to decrease radiation dose is to avoid exposure creep. Digital radiography allows technologists to perform radiographs with a very high amount of radiation exposure. When this occurs, automatic rescaling corrects for high exposure factors used causing patients to be crudely overexposed.[15]

A research project evaluated the use of a wide range of mAs values on the overall quality of images using a computed radiography (CR) reader. The results confirmed the literature that overexposure and underexposure of the image receptor produces an image of diagnostic quality.[7] The concept of overexposing patients in digital radiography is referred to as exposure or dose creep.

Exposure creep violates the ALARA principle and places the patient at increased risk. Technologists must use exposure factors that provide the appropriate image needed by the radiologist and decrease patient dose. Since Computed Radiography (CR) readers provide an exposure indicator number that indicates the exposure to the image receptor and the amount of radiation received by the patients, departments could monitor exposure indicator numbers for each technologist. This enables departments to maintain accountability in an effort to avoid dose creep and maintain exposure indicator numbers in the optimal range.[16]

A report was published regarding the use of appropriate exposure indicators for pediatric digital radiography that expressed concern about excessive radiation exposure during diagnostic medical procedures. Because of new technological advances in radiology, these researchers stressed the need for re-education of technologists to prevent unnecessary radiation exposure. This concept is especially important concerning pediatric patients because they are more susceptible to radiation effects than adults. The researchers determined that technologists should also be provided feedback on the appropriateness of chosen radiographic technique for each digital radiograph. For this reason, continuing education for technologists should serve to decrease patient dose.[6]

Another study was conducted to provide data from CR readers that would allow radiology administrators to monitor and analyze exposures for quality control purposes. The study used 11 Kodak CR readers in a radiology department, where data from procedures performed by technologists was collected monthly from the readers. After reporting all exposure data into a single table, the authors analyzed trends in exposure indicator values. Depending on the results, administrators provided continuing education based on average exposure indicator values for each radiographer. If a technologist consistently demonstrated a higher exposure indicator average, additional training was required. This quality control plan served to decrease radiation exposure to patient and alert radiographers of the dangers of dose creep.[4]

A study was conducted to evaluate attitudes and radiation protection practices among radiologic technologists. The researchers concluded that while technologists were aware of exposure increases, there was a lack of continuing education within facilities. Even though commonly recognized and acceptable methods of radiation protection were used to decrease exposure, radiographers must routinely use factors to lower radiation exposure in the United States.[17]

Methods to minimize patient exposure in radiologic technology include shielding, minimizing repeats, beam restriction devices, proper exposure factors, longer source-to-image receptor distance and minimizing dose creep. This research study will determine if student radiographers in northeast Tennessee select exposure factors in digital radiography that minimize patient dose.

During the educational experience in a radiography program, students learn concepts dealing with digital radiography that include methods to decrease radiation exposure to patients and prevent dose creep. Additional didactic education includes learning proper positioning for exams, radiographic equipment and safety, image production and evaluation, radiation biology and protection, and radiographic pathology. This study examined if students applied concepts related to digital radiography taught in the didactic component of the program to the clinical environment.

Methods

The research study used an experimental design to investigate whether appropriate exposure factors and indicator numbers were used by radiography students when performing radiographic procedures. A comparison group design was used to distinguish between data logged by student rank. The documentation of exposure indicator values involved voluntary participation.

In January 2013, radiography students were asked to document exposure indicator numbers in addition to procedure names and exposure factors they logged into an electronic management system, E*Value, for the spring semester of 2013. The benefit in logging the information was to ensure students were aware of the exposure factors and indicator values they used during radiographic procedures and to ensure they compared these values to the ideal factors.

Study Design

The research project began with an extensive review of the literature to better understand the methods used to decrease patient exposure and focused on dose creep. Prior to conducting the study, permission to conduct research was obtained from the Institutional Review Board (IRB) at East Tennessee State University (ETSU). It was determined that the research project met neither FDA nor DHHS definition of research involving human subjects and did not require ETSU/VA IRB approval. Data was gathered to address four research questions:

- Do exposure indicator values differ between radiographic procedures performed by radiography students?
- Do exposure indicator values differ between junior and senior radiography students?
- Are exposure indicator values within the acceptable lgM range?

- Is there a need for additional education for student radiographers regarding selection of appropriate exposure factors to minimize dose creep?

To address these questions, data from radiographic procedures logged from March 1, 2013 to March 31, 2013 by students from a radiography program in northeast Tennessee were downloaded from the E*Value system. The data were transferred to a Microsoft Excel spreadsheet.

To comply with Health Insurance Portability and Accountability Act (HIPAA) regulations, no patient identification information was logged in the E*Value System. Therefore, the data did not include names, social security numbers, exam dates, medical record numbers, postal addresses, health plan numbers, phone numbers, account numbers, email addresses, or any other unique identifier.

To comply with Family Educational Rights and Privacy Act (FERPA) and assure privacy of analyzing and reporting results, no student identifying information was downloaded from the E*Value system. Information downloaded and subsequently analyzed included procedure name, clinical affiliate at which the procedure was performed, student rank (junior or senior), exposure factors, and exposure indicator values.

Upon review of the exposure indicator values, it was noted that a wide variation in exposure indicator units existed at the clinical affiliates. One affiliate used three different units within their own facility. After extensive review, it was determined that the most common unit among the clinical sites was lgM, a proprietary unit for Agfa. Therefore, the only exposure indicator values used for this study were lgM.

The Statistical Package for the Social Sciences (SPSS), Version 20 was used for all statistical analysis in this study. Exposure indicator numbers were analyzed by radiographic procedure and student rank.

Study Assumptions

The following assumptions were part of this study:

- Student radiographers applied information learned from didactic and clinical educational experiences to select exposure factors for diagnostic procedures performed.
- Exposure factors for particular radiographic procedures were standardized from facility to facility.
- The images from logged radiographic procedures were approved by registered radiologic technologists and were of diagnostic quality.
- The exposure factors and indicator numbers logged in e-Value were true and accurate.

Results

Of the 1808 total performed procedures logged from March 1, 2013 to March 31, 2013, exposure indicators values were not logged for 723 of the exams. Of the remaining 1,085 procedures, 600 were removed from the study since the exposure indicators were not lgM values. Therefore, 483 procedures were included in the study. Since many of the procedures were performed with more than one projection and had different lgM values, there were 710 exposure indicator values analyzed for the purpose of this research study.

Table 1 represents the mean exposure indicator values for each of the procedure groups. Mean exposure indicator values for each procedure group were compared by information logged by junior and senior radiography students as well as the mean lgM values for the entire group for the month of March 2013.

Table 1
Summary Exposure Indicator Values

Procedure	Mean Junior lgM values	Mean Senior lgM values	Mean Total lgM values
Abdomen			
Abdomen - Acute Series	2.18	2.36	2.29
Abdomen - KUB	2.14	1.94	2.03
Abdomen - Portable	2.06	1.96	2.04
Abdomen - Other	2.1	2.15	2.11
Chest			
Chest - Portable	2.10	2.11	2.11
Chest - Routine (PA/Lateral)	2.14	2.12	2.13
Chest - Wheelchair or stretcher	2.24	2.35	2.26
Chest - Other	2.07	2.03	2.05
Lower Extremity			
Knee	2.24	2.20	2.21
Other – Foot, Ankle, Hip, etc.	2.09	2.42	2.16
Spine			
Lumbar Spine	2.37	2.25	2.33
Other – Cervical, Thoracic, Etc.	2.1	2.03	2.07
Upper Extremities			
Hand, Wrist, Forearm, Elbow, Humerus, Shoulder	2.13	2.03	2.08
Miscellaneous			
Pelvis, Trauma, Graduate Competencies, Pediatric Portables, etc.	2.13	2.09	2.09

A two-way analysis of variance (ANOVA) was performed to evaluate the exposure indicator values between radiographic procedures performed by all radiography students and by student rank (juniors and seniors). The alpha was set at .05. The means and standard deviations are reported in *Table 2.* The ANOVA indicated significant interaction between procedure and student rank, $F(13, 679) = 2.08$, $p = .01$, partial $\eta^2 = .04$, a significant effect for procedures, F(13,

679) = 4.67, p = .00, partial η^2 = .08, and a nonsignificant effect for rank, $F(1, 679)$ = .01, p = .95, partial η^2 = .01. *See Table 3.*

Table 2
Mean Exposure Indicator Values

Procedure	Student Rank	Mean lgM values	Standard Deviations	N
Abdomen - Acute Series	Junior	2.18	.26	4
	Senior	2.36	.27	7
	Total	2.29	.27	11
Abdomen - KUB	Junior	2.14	.11	7
	Senior	1.94	.11	10
	Total	2.03	.15	17
Abdomen - Portable	Junior	2.06	.42	16
	Senior	1.96	.18	4
	Total	2.04	.38	20
Abdomen - Other	Junior	2.10	.13	12
	Senior	2.15	.05	5
	Total	2.11	.11	17
Chest - Portable	Junior	2.10	.18	127
	Senior	2.11	.14	94
	Total	2.11	.16	221
Chest – Routine (PA/Lateral)	Junior	2.13	.16	93
	Senior	2.12	.16	62
	Total	2.13	.16	155
Chest - Wheelchair or stretcher	Junior	2.24	.43	19
	Senior	2.35	.17	4
	Total	2.26	.39	23
Chest - Other	Junior	2.07	.32	4
	Senior	2.03	.12	3
	Total	2.05	.23	7
Lower Extremity - Knee	Junior	2.24	.21	22
	Senior	2.20	.21	30
	Total	2.21	.21	52
Lower Extremity - Other (Foot, Ankle, Hip, etc.)	Junior	2.09	.38	31
	Senior	2.42	.59	8
	Total	2.16	.44	39
Lumbar Spine	Junior	2.37	.14	18
	Senior	2.25	.12	8
	Total	2.33	.14	26

Table 2 **Mean Exposure Indicator Values (cont.)**				
Procedure	**Student Rank**	**Mean IgM values**	**Standard Deviations**	**N**
Spine Other – Cervical, Thoracic, etc.	Junior	2.10	.25	16
	Senior	2.03	.16	10
	Total	2.07	.22	26
Upper Extremity	Junior	2.13	.24	43
	Senior	2.03	.20	31
	Total	2.08	.23	74
Miscellaneous	Junior	2.13	.29	4
	Senior	2.09	.13	15
	Total	2.09	.17	19
Total	Junior	2.13	.24	416
	Senior	2.12	.20	291
	Total	2.13	.23	707

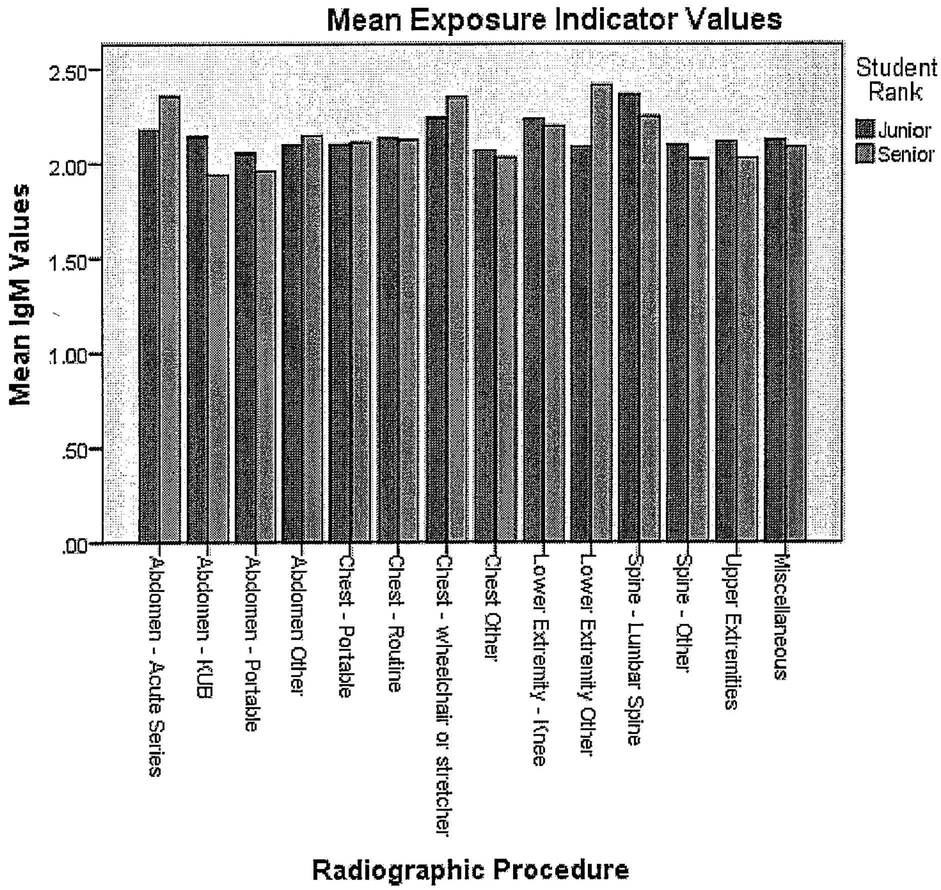

Figure 1.

Table 3 **ANOVA for Exposure Indicator Values by Procedure and Student Rank**					
Source	**Sum of Squares**	**df**	**Mean Squares**	**F**	**Sig.**
Procedure	2.86	13	0.22	4.67	0.00
Rank	0.00	1	0.00	0.00	951
Procedure and Rank	1.27	13	0.10	2.08	0.01
Total	3242.71	707			

Because the interaction between procedure and rank was significant, the differences in exposure indicator values for juniors and seniors were examined separately. To control for Type I error across the exposure indicator values, the alpha was set at .025. There were significant differences between exposure indicator numbers for junior students, $F(13, 679) = 2.944, p = .00$, and there were significant differences between exposure indicator numbers for senior students, $F(13, 679) = 3.972, p = .00$. *See Table 4.*

Table 4 **ANOVA for Student Rank Using Simple Main Effects Analysis**						
Student Rank	**Sum of Squares**	**df**	**Mean Squares**	**F**	**Sig.**	**η2**
Junior	1.80	13	.14	2.94	.00	.05
Senior	2.43	13	.19	3.97	.00	.07

Follow-up tests were conducted to evaluate the pairwise differences among the means for radiographic procedures. There was a significant difference in exposure indicator values for chest - portable, chest - routine, lower extremity - knee, and upper extremities for both junior and senior radiography students. Therefore, the type of radiographic procedure had an impact on exposure indicator values.

To evaluate the interaction between radiographic procedures performed by student rank, additional follow-up tests were conducted to evaluate the pairwise differences among the mean values. There was a significant difference in exposure indicator values for chest – wheelchair or stretcher, lower extremity - knee, lower extremity other, and lumbar spine procedures performed by junior students. On the other hand, there was a significant difference in exposure indicator values for abdomen - acute series, abdomen - KUB, abdomen – portable, chest – wheelchair or stretcher, lower extremity other, spine - other, and upper extremity procedures performed by senior students. Therefore, the type of procedure and student rank had an impact on exposure indicator values.

Discussion

Exposure indicator values indicate the exposure to the image receptor. The values provide feedback to the technologist about the technical factors selected. Underexposure and overexposure are indicated by values outside the appropriate range. The literature addressed the concern of increased radiation exposure due to dose creep.

The study evaluated exposure indicator values from radiographic procedures performed by student radiographers in northeast Tennessee. It also determined if there is a need to further enhance the radiography curriculum to select appropriate exposure factors to minimize patient dose. The study examined 4 research questions, and the following is a discussion of the findings:

- **Research Question 1: Do exposure indicator values differ between radiographic procedures performed by radiography students?** The study revealed that there was a significant difference in exposure indicator values based the type of procedure performed by radiography students. The greatest variation in lgM numbers were for chest - portable, chest - routine, lower extremity - knee, and upper extremity procedures.
- **Research Question 2: Do exposure indicator values differ between junior and senior radiography students?** There was a significant difference in exposure indicator values based on student rank. There was a significant difference in exposure indicator values for chest – wheelchair or stretcher, lower extremity - knee, lower extremity other, and lumbar

spine procedures performed by junior students. On the other hand, there was a significant difference in exposure indicator values for abdomen - acute series, abdomen - KUB, abdomen – portable, chest – wheelchair or stretcher, lower extremity other, spine - other, and upper extremity procedures performed by senior students.

- **Research Question 3: Are exposure indicator values within the acceptable lgM range?** The acceptable range of lgM values recommended by the clinical affiliates at which the radiographic procedures were performed was 2.0 to 2.3. As shown in *Fig. 2,* the total range of lgM values in this research study was .60 to 3.2. The data revealed that 19.3% of the radiographic procedures represented underexposure to the image receptors, and 14.5% were overexposed. Therefore, the exposure indicator values are not within the acceptable lgM range.

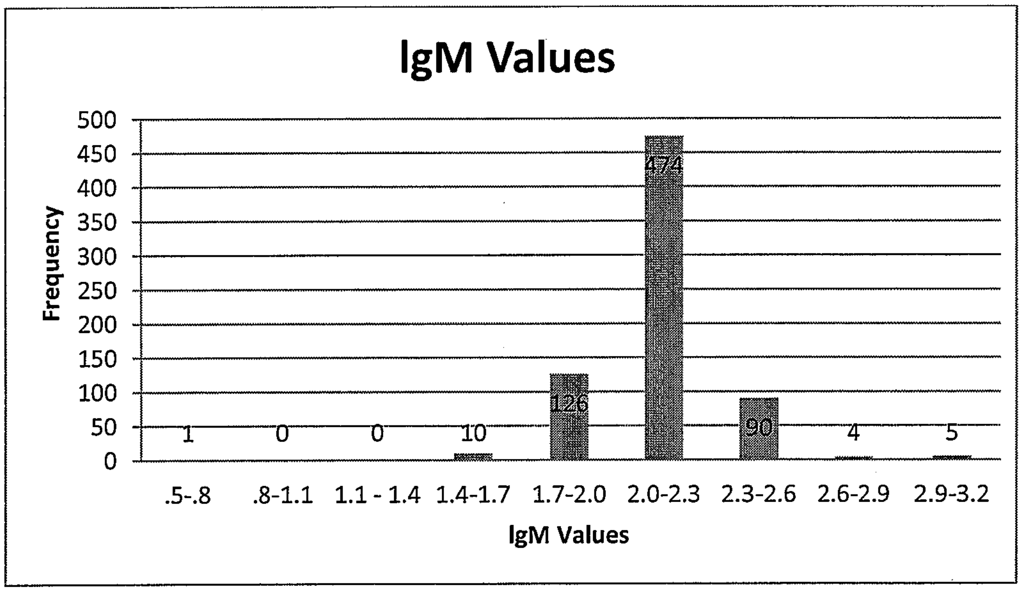

Figure 2.

- **Research Question 4: Is there a need for additional education for student radiographers regarding selection of appropriate exposure factors to minimize dose creep?** 12.6% of the procedures logged in *Fig. 2* had lgM values between 2.3 and 2.6 and represented image receptors that were double exposed. 0.56% of the procedures logged had lgM values between 2.6 and 2.9 and represented image receptors that were overexposed 300%. Finally, 7% of the procedures logged had lgM values between 2.9 and 3.2 and represented image receptors that were overexposed 400%. The results revealed that dose creep occurred during radiographic procedures performed by student radiographers. Clearly, there is a need for additional education for student radiographers regarding selection of appropriate exposure factors to minimize dose creep.

Conclusion

The project was designed to evaluate exposure indicator values from radiographic procedures performed by junior and senior radiography students during the month of March 2013. The mean exposure indicator values for radiographic procedures were evaluated by all students and then by student rank (juniors and seniors). The type of procedure and student rank (junior and seniors) had an impact on exposure indicator values.

The results revealed that dose creep occurred during radiographic procedures performed by student radiographers. It was determined that there is a need for additional education for student radiographers regarding selection of appropriate exposure factors to minimize dose creep.

The findings of this study added to the current literature regarding dose creep. Technologists and student radiographers need to acknowledge that dose creep exists and that it contributes toward the increase in patient dose in the radiology profession. Dose creep must be minimized since it violates the ALARA principle.

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