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Research Article

Examining Practitioners' Assessments of Perceived Aesthetic and Diagnostic Quality of High kVp–Low mAs Pelvis, Chest, Skull, and Hand Phantom Radiographs

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ABSTRACT

This study investigated the usefulness of the dose optimization strategy of increased tube voltage (kVp) and decreased tube current-exposure time product (mAs) (or high kVp–low mAs) by examining practitioners' assessments of perceived aesthetic and diagnostic quality of direct digital radiographs acquired using this strategy. Ninety-one practitioners (radiologists, radiology residents, radiographers, and radiography students) from eight clinical sites in Ontario examined three types of radiographs (''standard'' image, +20 kVp image, and +30 kVp image) for anthropomorphic pelvis, chest, skull, and hand phantoms and rated (on a five-point scale) each image in regard to its perceived aesthetic quality, perceived diagnostic quality, and visualization of anatomic structures. Our primary findings are that for the pelvis, skull, and hand–although not the chest–images acquired using standard technical factors were rated significantly higher in diagnostic and aesthetic quality than those acquired using the high kVp–low mAs strategy. Despite this, both standard and dose-optimized images of the pelvis, skull, and hand were rated to be of acceptable diagnostic quality for clinical use. In conclusion, for the pelvis, skull, and hand, an increase of 20 kVp was an effective strategy to reduce dose while still acquiring images of diagnostic quality.

RESUMÈ

Cette étude évalue l'utilité de la stratégie d'optimisation de la dose fondée sur l'augmentation de la tension du tube (kVp) et de la diminution du produit tube de courant/temps d'exposition (mAs) (ou kVp élevé–mAs faible) en examinant l'évaluation que font les praticiens de la qualité esthétique et diagnostique perçue des radiographies numériques directes prises à l'aide de cette stratégie. Quatre-vingt onze praticiens (radiologistes, résidents en radiologie, radiographes et étudiants en radiographie) de huit sites cliniques en Ontario ont examiné trois types de radiographies (image « standard », image à +20 kVp, image à +30 kVp) de fantômes anthropomorphiques du pelvis, de la poitrine, du crâne et de la main et les ont cotées (sur une échelle de 1 à 5) selon (a) qualité esthétique perçue, (b) leur qualité diagnostique perçue et (c) la visualisation des structures anatomiques. Nos constatations initiales montrent que, dans le cas des images du pelvis, du crâne et de la main, mais non celles de la poitrine, les images prises avec les facteurs techniques standard ont reçu une note significativement plus élevée pour la qualité esthétique et diagnostique que celles prises en utilisant la technique kVp élevé–mAs faible. Cependant, les images standard et à dose optimisée du pelvis, du crâne et de la main ont été jugées de qualité diagnostique acceptable pour un usage clinique. En conclusion, pour le pelvis, le crâne et la main, une augmentation de +20 kVp est une stratégie efficace pour réduire la dose tout en produisant quand même des images de qualité diagnostique.

Keywords: Anthropomorphic phantom; chest; direct digital radiography; dose optimization; hand; high kVp-low mAs; multiple anatomic areas; practitioner assessments; pelvis; perceived diagnostic image quality; perceived aesthetic image quality; skull

Introduction

The importance of regularly investigating dose optimization strategies for general radiographic examinations is critical to ensure that practitioners are delivering a dose to patients that is ''as low as reasonably achievable'' (ALARA) [1]. Hence, much research has been conducted to investigate strategies that can reduce the dose delivered to patients while still producing images of diagnostic quality [2]. From this research, a variety of dose optimization strategies have been identified that reduce dose by a considerable percentage without

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significant effect on the quality of the images for diagnosis [3]. In particular, the strategy of increasing the tube voltage (kVp) and decreasing the tube current-exposure time product (mAs) shows particular promise [4]. When this strategy is used, the photons in the radiation beam have a higher energy and are more penetrating. Thus, instead of being absorbed into the patient as a lower kVp radiation beam would, more of the beam is able to penetrate and exit the patient's tissues, resulting in a lesser dose delivered to patients [5, 6].

Many previous studies have investigated the use of this particular dose optimization strategy by examining qualified observers' perceptions of resultant image quality using a variety of different methods [7–11]. However, more robust and comprehensive work is still needed, particularly in terms of the number and type of participants providing assessments of perceived image quality and the number of anatomic areas examined in a single study. With respect to the number and type of participants, many of the similar existent studies have used very small sample sizes. The smallest study reviewed included only two radiographers [12], and the largest study reviewed included six radiographers and one radiologist [9]. This, of course, lessens the external validity, or the generalizability, of the results. With respect to the number of anatomic areas examined, many of the similar existent studies reviewed have only used one anatomic area [4, 7, 9–11]. This limited focus is problematic because different anatomic areas vary in thickness and require that images be acquired with differing technical factors that in turn affect image quality and dose delivered to the patient.

Furthermore, despite the Canadian Association of Medical Radiation Technologists' clearly outlined ALARA mandate and the wealth of evidence regarding dose optimization strategies, there is evidence that these strategies, including the high kVp–low mAs strategy, are not being fully realized within radiology departments [13]. Is it that practitioners do not find high kVp–low mAs images to be aesthetically pleasing? Do they not find these high kVp–low mAs images to be of acceptable diagnostic quality? Are they unable to visualize the relevant anatomic structures on these high kVp–low mAs images? In particular, the question of practitioners' aesthetic preferences does not appear to have been explicitly investigated in similar existent studies.

Thus, the present study aimed to investigate the usefulness of the dose optimization strategy of high kVp–low mAs radiography by examining practitioners' assessments of aesthetic and diagnostic quality of images acquired using this strategy. The objective was to conduct a robust and comprehensive study by including a large number of participant assessors, incorporating multiple anatomic areas, and explicitly investigating practitioners' aesthetic preferences. The study included 91 practitioners (radiologists, radiology residents, radiographers, and radiography students) from eight clinical sites in Southwestern Ontario who examined three types of direct digital radiographic images (a "standard" image, a +20 kVp image, and a +30 kVp image) of anthropomorphic pelvis, chest, skull, and hand phantoms and rated (on a five-point scale) each image in regard to its perceived aesthetic quality, perceived diagnostic quality, and visualization of anatomic structures.

Materials and Methods

Participant Sample and Recruitment

Following the granting of ethical clearance by an institutional research ethics board (file number: 14-01-13-1; date of approval: January 29, 2014), all radiologists, radiology residents, radiographers, and student radiographers from eight clinical sites within a Local Health Integration Network (LHIN) in Southwestern Ontario were invited to participate in the study. One hundred individuals participated in the study out of a potential pool of approximately 200 individuals; however, the data from nine participants were excluded because these individuals did not complete all portions of the informed consent form. Of the 91 participants, six were radiologists, four were radiology residents, 48 were radiographers, 31 were student radiographers, and two identified their professional role as "other" and specified their position to be Picture Archiving and Communication System (PACS) administrators. The participants had a range of 0.5 to 38 years of experience, or an average of 11.44 years (standard deviation [*SD*] = 11.29), and a total of 1,030 years. All participants provided informed consent after reading the letter of informed consent enclosed in the study package. The inclusion criteria required that participants were members of one of the aforementioned professional groups at a clinical site within the LHIN and that they regularly reviewed or acquired radiographic images; there were no exclusion criteria.

Anthropomorphic Phantoms

Radiographic images of anthropomorphic phantoms (all from The Phantom Laboratory) were acquired, which is common in dose optimization and/or image quality studies [7, 9, 10, 12, 13]. These phantoms are tissue equivalent to an adult male of average size and consist of real bone. Specifically, a phantom pelvis (SK250 Torso), chest (SK200 Thorax), skull (SK100 Skull), and hand (XA231 R Hand) were used. These particular anatomic areas were purposefully selected for the following reasons. The pelvis was selected because it is one of the most common radiographic examinations performed [12, 14] and appears to be the second most commonly used anatomic area for studies examining dose optimization and/or image quality [9, 12, 14]. The chest was selected because it is also one of the most common radiographic examinations performed in typical clinical practice [8, 15, 16] and appears to be the most commonly used anatomic area for studies examining dose optimization and/or image quality [4, 7, 8, 10, 11, 14, 17, 18]. The skull was selected because, although it is not a common radiographic examination in developed countries, it is still frequently performed in developing countries because of the prohibitive costs of computed tomography [19]; it is an area for which high-quality examinations are required for diagnosis, especially in the event of nonaccidental injury and for which radiographs are generally of poor quality [20, 21]; and it has been used in other studies examining dose optimization and/or image quality [13, 21]. The hand was selected because it is a much thinner anatomic area than the other areas used in this study, and thus, changes in technical factors may affect image quality more prominently; also, this anatomic area does not appear to have been used in previous studies examining dose optimization and/or image quality and was included for novelty. Lastly, these anatomic areas (with the exception of the hand) were purposefully selected because there are existing image quality criteria for them, specifically the *European Guidelines on Quality Criteria for Diagnostic Radiographic Images* [22], which have been used in several dose optimization and/or image quality studies [4, 7, 10, 11, 13, 21].

Radiographic Equipment

All images were obtained using a Carestream DR X Revolution Mobile X-ray system at University Hospital–London Health Sciences Centre in London, Ontario, Canada. This system had undergone Healing Arts and Radiation Protection Act of Ontario quality control and assurance testing, as well as the quality control and assurance testing required by the Radiation Emitting Devices Act of Canada.

Radiographic Technique: Image Acquisition and Selection

The images were obtained using 50-inch source-to-image detector distance, which is the vendor's recommended distance. There was no object-to-image distance because phantoms were placed directly on the detector. The degree of collimation was the size of the detector and remained consistent for all anatomic areas imaged. The pelvis and chest were imaged using a 6:1 linear grid, whereas the skull and hand were imaged without a grid as per the standard practice at the clinical site. The images were obtained by a radiographer with 33 years of experience and were confirmed by a third-party radiographer with 25 years of experience.

For each of the four anatomic areas, the following process was used to obtain a set of three images including one "standard" image and two dose optimized images (Figure 1). "Standard" images were obtained using the technical factors already programmed into the system at this particular clinical site. It is important to note that the research group confirmed that this clinical site's technical factors were representative of the "standard" technical factors programmed into other direct digital imaging systems at each clinical site included in the study (Table 1). The first set of dose optimized images was obtained by increasing the tube voltage by 20 kVp and decreasing the tube current-exposure time product by one mAs system setting. After this image was acquired, the exposure index and dose area product were recorded from the user interface of the system. If the exposure index was within the vendor's acceptable limit for the system (which was between 1,300 and 1,500, ±150) another image was acquired at the same tube voltage (kVp) but with the tube current-exposure time product again decreased by one mAs system setting. This was repeated until an image was acquired that had an exposure index that was beyond the acceptable vendor-specified limit. From this series of images, the image selected for inclusion in this study had the most similar exposure index to that of the first image taken with the "standard" technical factors (Table 1). Exposure index was used as the selection factor because it is a numeric value that represents the intensity of radiation exposure that the detector has received and, thus, verifies that a digital radiographic image of acceptable quality has been obtained [23]. Therefore, it was important to select an image that had a similar exposure index number to the "standard" image to ensure that assessments of images would be done using images of comparable quality, despite being acquired with different technical factors. Similarly, the second set of dose-optimized images were obtained by increasing the tube voltage by 30 kVp from the technical factors used for the "standard" image and repeating the aforementioned process (Table 1).

In sum, three images for each of the four anatomic areas were obtained (for a total of 12 images): (1) one "standard" image acquired with the preprogrammed technical factors used at the clinical sites; (2) one dose optimized image acquired by increasing the tube voltage by 20 kVp and decreasing the tube current-exposure time product (mAs) as needed to achieve an exposure index similar to the "standard" image; and (3) another dose-optimized image acquired by increasing the tube voltage by 30 kVp and decreasing the tube current-exposure time product (mAs) as needed to achieve an exposure index similar to the "standard" image.

Preparing the Images for Participant Viewing

For each anatomic area, the order of the three images was randomized so that participants did not necessarily view the images in the order that they were acquired (ie, 1: "standard" image, 2: +20 kVp image, and 3: +30 kVp image) (Figure 1). The research group made a record of the image order, and then each of the 12 images were stripped of all visible identifying information (ie, clinical site, examination number, and technical factors). Thus, the "type" (ie, "standard", +20 kVp, and +30 kVp) of image the participants viewed was not made known to them. This was done to ensure the authenticity of the participants' ratings because they could not simply rate an image based on any biases they may hold regarding the technical factors or dose optimization strategy.

All images were uploaded, with permission, to a standard PACS within the LHIN. PACS monitors are calibrated by an installed program that constantly monitors the gray scale display function specification of the Digital Imaging and Communications in Medicine (DICOM) standard. All the participants in this study are familiar with this system and use it in their daily work.

Image Quality Assessment Tool

The research group developed a tool for participants to assess the images in regard to perceived aesthetic quality, perceived diagnostic quality, and visualization of anatomic structures. The tool included three questions for each of the

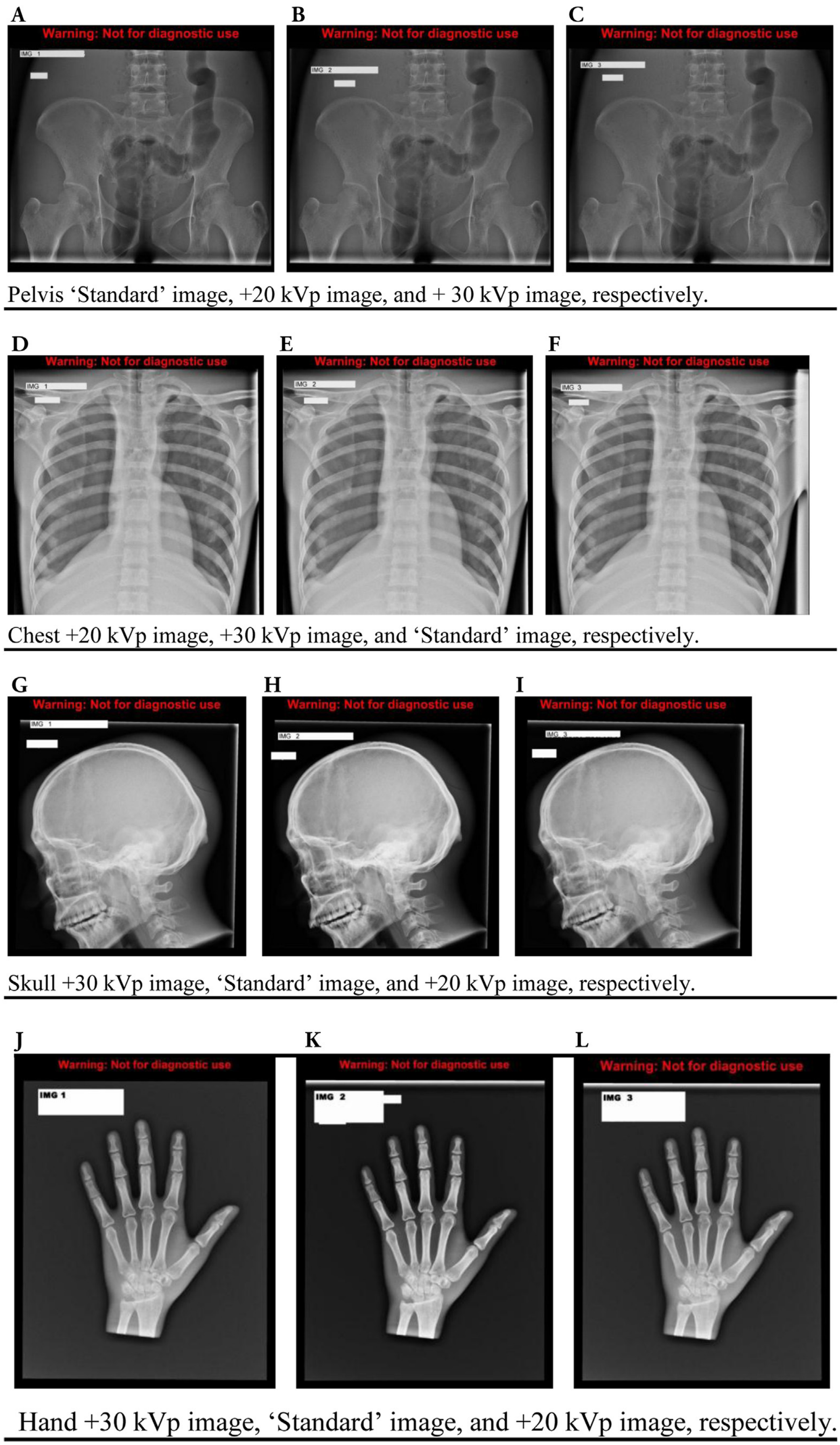

Figure 1. Radiographs used in study. Pelvis (A) "standard" image, (B) +20 kVp image, and (C) +30 kVp image. Chest (D) +20 kVp image, (E) +30 kVp image, and (F) "standard" image. Skull (G) +30 kVp image, (H) "standard" image, and (I) +20 kVp image. Hand (J) +30 kVp image, (K) "standard" image, and (L) +20 kVp image.

Table 1
Technical Factors Used in the Acquisition of Study Radiographs

Radiograph	Tube Voltage (kVp)	Tube Current Exposure Time Product (mAs)	Exposure Index Number	Dose Area Product ($dGycm^2$)
Pelvis "standard"	85	10	1406	3.7
Pelvis +20 kVp	105	4	1449	2.1
Pelvis +30 kVp	115	3.7	1472	2.0
Chest "standard"	120	0.7	1543	1.1
Chest +20 kVp	140	0.9	1529	0.8
Chest +30 kVp	150	0.7	1552	0.8
Skull "standard"	75	7.1	1395	1.1
Skull +20 kVp	95	2.5	1414	0.6
Skull +30 kVp	105	1.7	1397	0.4
Hand "standard"	52	1.2	1239	0.1
Hand +20 kVp	72	0.28	1249	0.06
Hand +30 kVp	82	0.22	1330	0.06

12 images. The first question asked participants "Do you find Image # _ aesthetically pleasing (ie, 'pretty')?" Participants were asked to circle their answer on a scale of 1 to 5. A rating of 1 represented "No, definitely not;" 3 represented "Neutral;" and 5 represented "Yes, definitely." The second question asked participants "How do you rate the overall diagnostic quality of Image #_?" Participants were asked to circle their answer on a scale of 1 to 5. A rating of 1 represented "Very dissatisfied (inadequate for diagnosis, definite loss of information, the image should be rejected);" 3 represented "Neither satisfied nor dissatisfied (acceptable for interpretation, bordering on loss of information);" and 5 represented "Very satisfied (optimal for evaluating the appropriate category of information)." Participants were also given the option of selecting an "I cannot judge" box and were asked to explain why they selected this option in the box provided. This scale was modified from Gallet (2010) [24]. The third question provided participants with a list of image scoring criteria specific to the anatomic landmarks of that particular anatomic area, and were adapted from the *European Guidelines on Quality Criteria for Diagnostic Radiographic Images* [22] for the pelvis, chest, and skull and from textbooks of radiographic positioning and anatomy for the hand [23, 25] (Table 2). Participants were asked "How satisfied are you that Image #_ offers a visually sharp reproduction of" these anatomic landmarks. Participants were asked to circle their response on the same 5-point scale used in the second question. For reference purposes, all participants were provided with schematics of each anatomic area that included labels of all the structures included in the criteria list.

Justification for the development of this tool's elements is as follows. In regard to the question about image aesthetics, this feature was included to investigate aesthetic quality as distinct from diagnostic quality. As indicated by Joyce et al (2013) [13], it is possible that some practitioners may conflate aesthetic quality with diagnostic quality. This conflation is problematic because although a practitioner may not find an image aesthetically pleasing, if they can accurately view the anatomic landmarks, the image would still be of acceptable diagnostic quality. In regard to the question about overall perceived image quality, this feature was included to be consistent with other dose optimization and/or image quality studies [9, 17]. In regard to the question about the appearance of anatomic landmarks and the use of modified *European Guidelines on Quality Criteria for Diagnostic Radiographic Images* [22], these features were, again, included to be consistent with other dose optimization and/or image quality studies [4, 11, 16, 21].

Table 2
Modified *European Guidelines* [22] Criteria Used for Question #3 of the Image Quality Assessment Tool

Anatomic Area	Modified Criteria
Pelvis	A. A visually sharp reproduction of the sacrum and its intervertebral foramina?
	B. A visually sharp reproduction of the pubic and ischial rami?
	C. A visually sharp reproduction of the sacroiliac joints?
	D. A visually sharp reproduction of the necks of the femora?
	E. A visually sharp reproduction of the trabecular bone of the trochanters?
Chest	A. A visually sharp reproduction of the trachea and proximal bronchi?
	B. A visually sharp reproduction of the borders of the heart and aorta?
	C. A visually sharp reproduction of the diaphragm and lateral costophrenic angles?
	D. A visually sharp reproduction of the retrocardiac lung and the mediastinum?
	E. A visualization of the spine through the heart shadow?
Skull	A. A visually sharp reproduction of the outer and inner lamina of the cranial vault?
	B. A visually sharp reproduction of the floor of the sella?
	C. A visually sharp reproduction of the apex of the petrous temporal bone?
	D. A visually sharp reproduction of the vertex of the skull?
	E. A visually sharp reproduction of the trabecular structure of the cranium?
Hand	A. A visually sharp reproduction of the bony trabecular markings?
	B. Adequate contrast and density to demonstrate soft tissue?
	C. A visually sharp reproduction of the cortical outlines of the anatomic structures?

Participants' Image Viewing Environment

All individuals participated during their regular work hours (which was permitted by the clinical sites' administration). Participants completed the study independently in a private room at their clinical site with no time restrictions. To ensure the study images were viewed appropriately, the private rooms had low ambient light and were equipped with PACS-quality reporting flat-panel display monitors with viewing software that enabled the participant to zoom, pan, and simultaneously display image pairs for direct comparison, all of which are standard in radiologist reporting rooms.

Data Analysis

Where appropriate, the mean and standard deviations were calculated for participants' ratings. The ratings of perceived aesthetic quality and diagnostic quality were compared with one-way analysis of variance (ANOVA) with the Tukey post hoc test (significance determined at $p = .05$). Diagnostic quality ratings by professional groups were also compared with two-way ANOVA with the Tukey post hoc test. These parametric statistical tests were used because, due to the large sample size of this study, the data follow a normal distribution. The number of participants who passed (ie, rated an image ≥ 3 out of 5 in perceived diagnostic quality) and failed (ie, rated an image ≤ 3 out of 5 in perceived diagnostic quality) each image were counted and calculated into percentages. All statistics were performed in PRISM 6 (GraphPad Software, Inc, La Jolla, CA).

Results

Pelvis

Ratings of Perceived Aesthetic Quality

One-way ANOVA using data from all professional groups with image type (standard, +20 kVp, and +30 kVp) as the factor revealed significant differences (F (2, 255) = 12.7, $p < .001$). Tukey post hoc analysis revealed that the standard image (mean [M] = 3.76, SD = 0.91) was rated significantly higher in aesthetic quality than the other two images (+20 kVp image, M = 3.15 and SD = 0.91; +30 kVp image, M = 3.11 and SD = 0.89) (Figure 2).

Ratings of Perceived Diagnostic Quality

One-way ANOVA using data from all professional groups with image type (standard, +20 kVp, and +30 kVp) as the factor revealed significant differences (F (2, 254) = 12.24, $p < .001$ therefore $p < .05$). Tukey post hoc analysis revealed that the standard image (M = 3.86 and SD = 0.98) was rated significantly higher in perceived diagnostic quality than the other two images (+20 kVp image, M = 3.28, SD = 0.93; +30 kVp image, M = 3.21, SD = 0.89) (Figure 2).

Two-way ANOVA was then performed with image type (standard, +20 kVp, and +30 kVp) as one factor but also with two groups as another factor. The two groups were participants separated by professional position: radiologists and radiology residents (RRRs) and radiographers and radiography students (RRSs). Results revealed no interaction by position ($F(1, 240) = 0.1031$, $p = .7484$ therefore $p > .05$) (ie, profession did not impact ratings of perceived diagnostic quality) but did reveal a significant effect ($F(2, 240) = 7.756$, $p = .0005$) based on the type of image. The standard image (RRRs: M = 4.13, SD = 0.641; RRSs: M = 3.91, SD = 0.903) was rated significantly higher than the +20 kVp image (RRRs: M = 3.33, SD = 0.50; RRSs: M = 3.34, SD = 0.87) and +30 kVp image (RRRs: M = 3.22, SD = 0.667; RRSs: M = 3.26, SD = 0.839).

The standard image was passed (ie, rated ≥ 3 out of 5 in perceived diagnostic quality) by 100% of RRRs and 92.2% of RRSs. The +20 kVp image was passed by 100% of RRRs and 82.6% of RRSs. The +30 kVp image was passed by 88.8% of RRRs and 81.0% of RRSs.

Ratings by Modified European Guideline Criteria

One-way ANOVA using data from all professional groups with image type (standard, +20 kVp, and +30 kVp) as the factor revealed that for each modified European Guideline criterion the standard image was rated significantly higher than the dose-optimized images (Appendix 1).

Chest

Ratings of Perceived Aesthetic Quality

One-way ANOVA using data from all professional groups with image type (standard, +20 kVp, and +30 kVp) as the factor revealed no significant differences ($F(2, 252) = 2.61$, $p = .08$, $p > .05$). The standard image (M = 3.68, SD = 1.05) was rated equal in aesthetic quality to the other two images (+20 kVp image, M = 3.34 and SD = 1.13; +30 kVp image, M = 3.36 and SD = 1.06) (Figure 2).

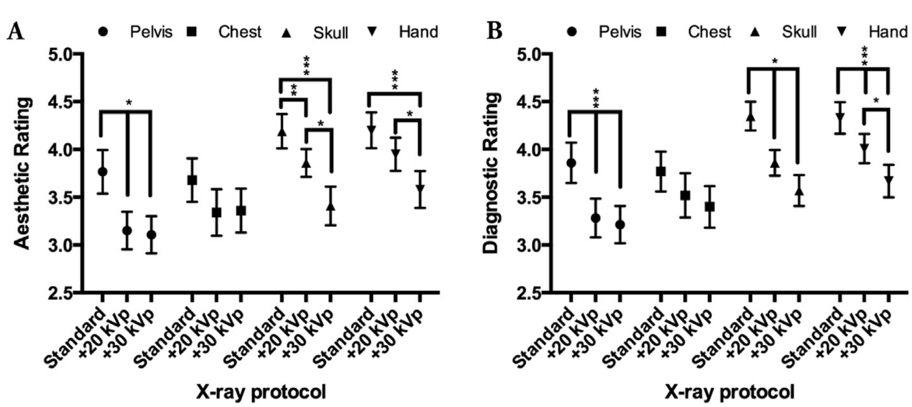

Figure 2. Average (A) aesthetic and (B) diagnostic quality of radiographic images acquired using either standard or dose-optimized X-ray protocols. Radiographs were acquired using previously detailed protocols and blindly rated by practitioners on the basis of either (A) aesthetic quality or (B) diagnostic quality. Significant differences between ratings on the basis of X-ray acquisition protocol are indicated by *($p \leq .05$), **($p \leq .01$), or ***($p \leq .0001$).

Ratings of Perceived Diagnostic Quality

One-way ANOVA using data from all professional groups with image type (standard, +20 kVp, and +30 kVp) as the factor revealed no significant differences (F (2, 259) = 1.82, p = .17 therefore p > .05). Tukey post hoc analysis revealed that the standard image (M = 3.77 and SD = 0.97) was rated equal in perceived diagnostic quality to the other two images (+20 kVp image, M = 3.52, SD = 1.08; +30 kVp image, M = 3.40, SD = 1.01) (Figure 2).

Two-way ANOVA was then performed with image type (standard, +20 kVp, and +30 kVp) as one factor but also with two groups separated by professional position as the other factor (RRRs and RRSs). Results revealed significant interaction by position (F (1, 248) = 18.63, p < .0001 therefore p < .05) (ie, profession impacted ratings of perceived diagnostic quality) but did not reveal a significant effect ($F_{2,248}$ = 0.5856, P = .5575) based on the type of image. The standard image (RRRs: M = 2.78, SD = 1.09; RRSs: M = 3.88, SD = 0.91) was rated equal to the +20 kVp image (RRRs: M = 2.90, SD = 1.2; RRSs: M = 3.59, SD = 1.05) and +30 kVp image (RRRs: M = 2.67, SD = 1.00; RRSs: M = 3.47, SD = 0.99).

The standard image was passed (ie, rated ≥3 out of 5 in perceived diagnostic quality) by 55.5% of RRRs and 91% of RRSs. The +20 kVp image was passed by 60% of RRRs and 85.7% of RRSs. The +30 kVp image was passed by 55.5% of RRRs and 83.1% of RRSs.

Ratings by Modified European Guideline Criteria

One-way ANOVA using data from all professional groups with image type (standard, +20 kVp, and +30 kVp) as the factor revealed that for each modified European Guideline criterion the standard image was rated significantly higher than the dose-optimized images, except for criteria C (ie, visually sharp reproduction of the diaphragm and lateral costophrenic angles) and D (ie, visually sharp reproduction of the retrocardiac lung and the mediastinum) where the +30 kVp image was rated equal to both the standard and +20 kVp image (Appendix 1).

Skull

Ratings of Perceived Aesthetic Quality

One-way ANOVA using data from all professional groups with image type (standard, +20 kVp, and +30 kVp) as the factor revealed significant differences (F (2, 252) = 19.7, p < .0001). Tukey post hoc analysis revealed that the standard image (M = 4.19, SD = 0.818) was rated significantly higher in aesthetic quality than the other two images (+20 kVp image, M = 3.86 and SD = 0.675; +30 kVp image, M = 3.41 and SD = 0.818) (Figure 2).

Ratings of Perceived Diagnostic Quality

One-way ANOVA using data from all professional groups with image type (standard, +20 kVp, and +30 kVp) as the factor revealed significant differences (F (2, 257) = 27.8, p < .0001 therefore p < .05). Tukey post hoc analysis revealed the standard image (M = 4.35 and SD = 0.685) was rated significantly higher in perceived diagnostic quality than the other two images (+20 kVp image, M = 3.86, SD = 0.632; +30 kVp image, M = 3.57, SD = 0.760) (Figure 2).

Two-way ANOVA was then performed with image type (standard, +20 kVp, and +30 kVp) as one factor but also with two groups separated by professional position as the other factor (RRRs and RRSs). Results revealed no interaction by position (F (1, 245) = .008923, p = .9248 therefore p > .05) (ie, profession did not impact ratings of perceived diagnostic quality) but did reveal a significant effect (F (2, 245) = 10.13, p < .0001 therefore p > .05) based on the type of image. The standard image (RRRs: M = 4.33, SD = 0.71; RRSs: M = 4.35, SD = 0.69) was rated significantly higher than the +20 kVp image (RRRs: M = 3.80, SD = 0.79; RRSs: M = 3.87, SD = 0.62) and +30 kVp image (RRRs: M = 3.60, SD = 0.70; RRSs: M = 3.55, SD = 0.78).

The standard image was passed (ie, rated ≥3 out of 5 in perceived diagnostic quality) by 100% of RRRs and 98.68% of RRSs. The +20 kVp image was passed by 100% of RRRs and 98.70% of RRSs. The +30 kVp image was passed by 100% of RRRs and 92.10% of RRSs.

Ratings by Modified European Guideline Criteria

One-way ANOVA using data from all professional groups with image type (standard, +20 kVp, and +30 kVp) as the factor revealed that for each modified European Guideline criterion the standard image was rated significantly higher than the dose-optimized images, except in criterion E (ie, a visually sharp reproduction of the trabecular structure of the cranium) where the +20 kVp image was rated significantly higher than the standard and +30 kVp images (Appendix 1).

Hand

Ratings of Perceived Aesthetic Quality

One-way ANOVA using data from all professional groups with image type (standard, +20 kVp, and +30 kVp) as the factor revealed significant differences (F (2, 257) = 11.20, p < .0001). Tukey post hoc analysis revealed that the standard image (M = 4.20, SD = 0.865) was rated significantly higher in aesthetic quality than the other two images (+20 kVp image, M = 3.95 and SD = 0.810; +30 kVp image, M = 3.58 and SD = 0.901) (Figure 2).

Ratings of Perceived Diagnostic Quality

One-way ANOVA using data from all professional groups with image type (standard, +20 kVp, and +30 kVp) as the factor revealed significant differences (F(2, 259) = 16.6, p < .0001 therefore p < .05). Tukey post hoc analysis revealed that the standard image (M = 4.33 and SD = 0.773) was rated significantly higher in perceived diagnostic quality than the other two images (+20 kVp image, M = 4.01, SD = 0.711; +30 kVp image, M = 3.67, SD = 0.802) (Figure 2).

Two-way ANOVA was then performed with image type (standard, +20 kVp, and +30 kVp) as one factor but also with two groups separated by professional position as the other factor (RRRs and RRSs). Results revealed no interaction by position ($F(1, 248) = 2.344$, $p = .1270$ therefore $p > .05$) (ie, profession did not impact ratings of perceived diagnostic quality) but did reveal a significant effect ($F(2, 248) = 10.35$, $p < .0001$ therefore $p > .05$) based on type of image. The standard image (RRRs: $M = 4.40$, $SD = 0.70$; RRSs: $M = 4.32$, $SD = 0.79$) was rated significantly higher than the +20 kVp image (RRRs: $M = 3.56$, $SD = 0.53$; RRSs: $M = 4.05$, $SD = 0.72$) and +30 kVp image (RRRs: $M = 3.40$, $SD = 0.70$; RRSs: $M = 3.68$, $SD = 0.81$).

The standard image was passed (ie, rated ≥ 3 out of 5 in perceived diagnostic quality) by 100% of RRRs and 97.4% of RRSs. The +20 kVp image was passed by 100% of RRRs and 97.40% of RRSs. The +30 kVp image was passed by 90% of RRRs and 93.40% of RRSs.

Ratings by Modified European Guideline Criteria

One-way ANOVA using data from all professional groups with image type (standard, +20 kVp, and +30 kVp) as the factor revealed that for each modified European Guideline criterion the standard image was rated significantly higher than the dose-optimized images, except in criterion B (ie, adequate contrast to density to show soft tissue) where no significant differences were noted (Appendix 1).

Discussion/Conclusion

Diagnostic Quality

The primary finding of this study is that for the pelvis, skull, and hand significant statistical differences in practitioners' ratings of diagnostic quality were noted based on image type (ie, images acquired using standard technical factors were rated significantly higher in diagnostic quality than those acquired using the dose optimization strategy of increased tube voltage [kVp] and decreased tube current-exposure time product [mAs]). Furthermore, there were no significant differences noted by image type based on professional group for these phantoms (pelvis, skull, and hand) (ie, RRRs rated the images no different than RRSs).

Although practitioners were able to note a significant difference between images of different acquisition protocols, it is important to note that all pelvis, skull, and hand images were "passed" (ie, rated on average as a three or above in diagnostic quality) regardless of their acquisition protocol, meaning that they were deemed to be of acceptable diagnostic quality. In other words, although these images were found to be appreciably different in diagnostic quality, they were also all found to be of acceptable diagnostic quality for clinical use, which is the relevant issue at hand. In fact, 100% of RRRs passed the +20 kVp pelvis, skull, and hand images. This is an important finding because it suggests that this amount of kVp increase (ie, +20 kVp) appears to be a highly effective dose optimization strategy for clinical practice. However, although the vast majority of RRSs (82.6%, 98.7%, and 97.3% for pelvis, skull, and hand, respectively) also passed the +20 kVp images, the fact that not all of them did so suggests there may still be personnel issues associated with the implementation of this dose optimization strategy in clinical practice. For example, this result suggests that if the +20 kVp strategy is used it may result in RRSs repeating image acquisitions to achieve "better" images, thus potentially resulting in a greater effective dose than if the strategy was not implemented at all. Even more interestingly, RRSs did not pass the image acquired with standard protocols 100% of the time either. This result is perplexing because these standard images were taken using the technical factors typically implemented at their clinical site and were acquired by an experienced radiographer and confirmed by a second experienced radiographer. Perhaps this could be related to Yielder and Davis' (2009) argument [26] that the entrenchment of a "hierarchy with strong medical dominance" and the resultant subordination and conforming workplace culture that radiographers experience breeds "reluctance to question and challenge, [and] also gives rise to low . . . confidence and the reduced capacity for motivation for learning" (p. 384). They go on to suggest that the "protocol-driven" work that occurs within radiology departments encourages "'followers' not 'thinkers' and discourage(s) innovation and the use of initiative" (p. 384).

The practitioners' assessments of diagnostic quality for the chest images deviate from the situation described for the pelvis, skull, and hand. There were no significant statistical differences noted based on image type, meaning that practitioners rated the diagnostic quality of the image acquired with standard technical factors to be equal to that of the dose-optimized images. Furthermore, there were significant statistical differences noted by image type based on professional group as RRRs rated the standard and dose-optimized images significantly lower than RRSs. To be specific, on average, RRRs rated the diagnostic quality of each chest image, regardless of technical factors, as a "fail" (ie, below a three out of five), meaning that the image was not deemed to be of acceptable diagnostic quality. Contrastingly, on average, RRSs rated all the chest images as a "pass." This is troubling as it is yet another example of the difference between these two professional groups who work together on the important task of acquiring and reporting on radiographs for diagnosis. This discrepancy was likely amplified in the case of the chest because of the complexity of this anatomic area. Whatever the reason for this discrepancy, this finding is disconcerting because the chest radiograph is one of the most common radiographic examinations.

The deviation of the diagnostic quality ratings of the chest radiographs from pelvis, skull, and hand radiograph ratings may be explained by a variety of factors. First, as mentioned previously, the complexity of this anatomic region presents unique barriers to the implementation of dose optimization strategies, as it has been observed elsewhere that "dose reduction in the mediastinum, upper abdomen and retrocardiac areas appears to directly deteriorate diagnosis'' (p. 209) [3]. This is consistent with the results of the practitioners' ratings of the modified European Guidelines in which criteria C (ie, a visually sharp reproduction of the diaphragm and lateral costophrenic angles) and D (ie, a visually sharp reproduction of the retrocardiac lung and the mediastinum) were rated significantly higher in the image acquired with standard technical factors compared with the dose-optimized images. Second, it appears that the standard technical factors programmed into the x-ray system for chest radiographs in this particular LHIN were already ''dose optimized.'' This was ascertained by comparing our acquisition protocols to those described in some existent dose optimization studies of the chest. For example, the standard chest imaging protocol of 120 kVp that was used in this study was already double the kVp used for standard chest images in one study reviewed [10] and was higher than the kVp used for the most dose-optimized chest images in another study reviewed [4]. Lastly, the use of anthropomorphic phantoms may have influenced the results because over 5% of participants (one radiologist and four radiographers) indicated that interpretation of the images was confounded by the use of a phantom as opposed to a radiograph of an actual patient. It has been noted elsewhere that anthropomorphic chest phantoms do have some limitations in terms of diagnostic applications [3]. However, the feasibility of our study design required the use of phantoms because we did not have access to such images of humans, and we obviously could not and would not expose research participants to such unnecessary radiographic examinations and the resulting dose.

Aesthetic Quality

Practitioners' assessments of aesthetic image quality revealed significant statistical differences based on image type for the pelvis, skull, and hand (ie, practitioners found the images acquired with standard technical factors to be more aesthetically pleasing than the dose-optimized images). It is important to note that although practitioners may have preferred the standard image over the dose-optimized images, as indicated earlier, they still deemed the dose-optimized images to be of acceptable diagnostic quality for clinical practice. Thus, this reinforces the importance of not conflating the frivolous question of aesthetic quality with the relevant clinical question of diagnostic quality [13]. In contrast to the other anatomic areas, no significant statistical differences in aesthetic quality were noted based on image type for the chest, meaning the standard image was considered statistically equal to the dose-optimized images. Again, this discrepancy may be explained by the use of anthropomorphic phantoms in our study, which some practitioners noted to be undesirable.

Dose Savings

A phenomenon of diminishing returns in dose savings was observed in this study (Figure 3). For each anatomic area, the +20 kVp image resulted in a reduction in dose (as measured by dose area project [$dGycm^2$]) of at least 54% (skull) and at most 72% (chest). However, for each anatomic area, the amount of dose reduction for the +30 kVp image essentially remained constant (ie, between 0% and 2% further dose reduction), with the exception of the skull where an additional 18% of dose was reduced. Thus, increasing the tube voltage by 30 kVp does not appear to be an advisable dose optimization strategy for clinical practice because, for all anatomic areas other than the skull, the reduction in dose is either nonexistent or minimal compared with a 20 kVp increase. Thus, increasing tube voltage by 30 kVp does not appear to be worth the risk of acquiring an image of subdiagnostic quality that may then need to be repeated to answer the clinical question.

Strengths and Limitations

The major strength of this study is its large sample size that appears to be unparalleled in the existent literature of similar studies. This study had 10 times more participants than the largest comparable study reviewed. In the case in which the findings of this study support the results of existing literature, they add externally valid evidence to the claims that are based on much smaller sample sizes.

A limitation of this study was the relatively few number of radiologist participants (n = 6) compared with radiographer participants. Despite this, the present study was still among the largest pool of radiologists participating in similar existent studies [10, 21].

As mentioned previously, some participants indicated this study's use of anthropomorphic phantoms to be a limitation. Again, the research group felt the use of phantoms to be necessary to the design and feasibility of the study.

Lastly, it is a limitation that the research group neglected to further modify the European Guidelines to remove criteria related to the retrocardiac lung because it could not be visualized in the phantom.

Future Directions

The results of this study reinforce the need for future dose optimization studies to also include multiple anatomic areas. The distinctions noted between different anatomic areas' ratings of diagnostic and aesthetic image quality show that the conclusions regarding the dose optimization strategy of high kVp-low mAs are not always transferable between anatomic areas.

It may be fair to argue that future dose optimization research should not concern itself with increasing tube voltage by 30 kVp as it provided a negligible reduction of dose in this study. It would still be of much interest to investigate the upper kVp limit of dose savings for the skull as 100% of RRRs passed the +30 kVp image.

Lastly, the observed differences in ''pass'' rates between the RRRs group and the RRSs group need to be addressed further. This may be best observed through a qualitative research project that aims to gather a thick and rich

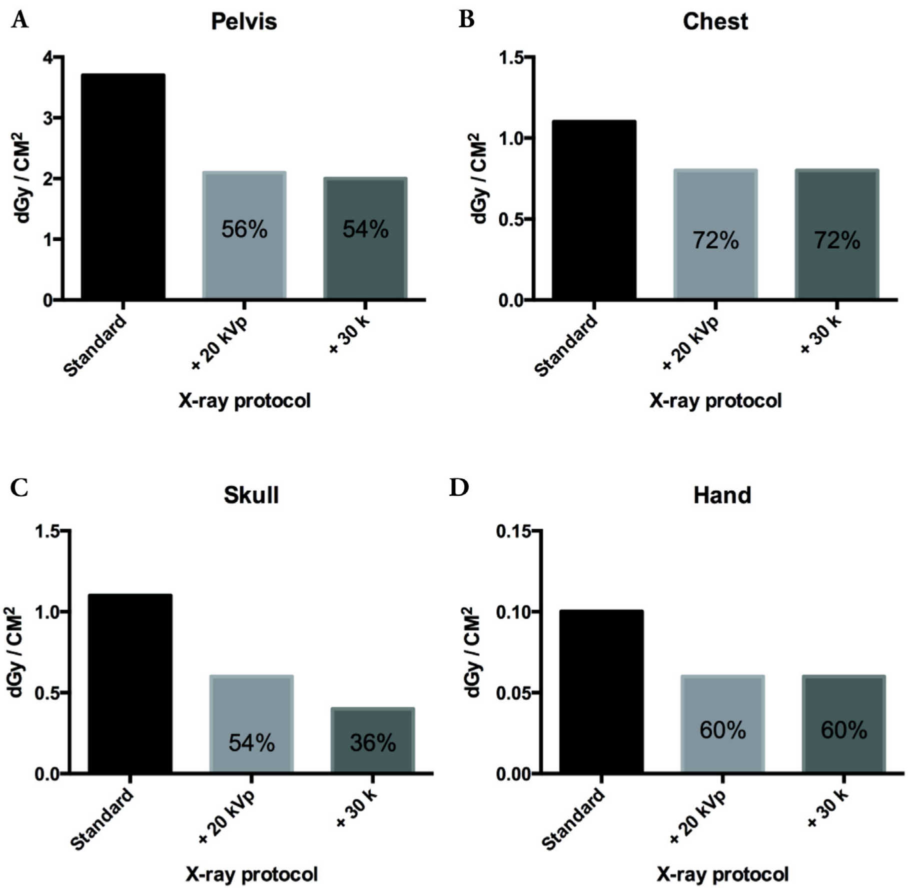

Figure 3. Delivered effective dose in the (A) pelvis, (B) chest, (C) skull, or (D) hand radiographic images acquired using either standard or dose-optimized X-ray protocol. Dose was determined via an equipment reading at the time of acquisition. Percentages indicate proportion of standard dose maintained in dose-optimized acquisitions.

description of RRRs' and RRSs' opinions, beliefs, perceptions, and values regarding this dose optimization strategy. Such a study may help to answer the important question of why ALARA mandates are not being fully realized within radiology departments.

Concluding Thoughts

We successfully polled and analyzed practitioners' perceptions of aesthetic and diagnostic quality in regard to the dose optimization strategy of increased tube voltage (kVp) and decreased tube current-exposure time product (mAs). The results of this research revealed that in most cases an increase of 20 kVp was an effective strategy to reduce dose while still acquiring images of diagnostic quality. Thus, if we were to accept the conclusions of this study, it may be said that in the case of the pelvis, skull, and hand the standard imaging protocol within this LHIN could be dose optimized using the high kVp–low mAs strategy to more closely adhere to the ALARA mandate.

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Appendix 1
Results of Question 3 (Modified European Guidelines) from the Image Quality Assessment Tool

Criteria	Standard Image	+20 kVp Image Mean Rating	+30 kVp Image Mean Rating
Pelvis A	M = 4.01	M = 3.04****	M = 3.06****
	SD = 0.88	SD = 0.90	SD = 0.92
Pelvis B	M = 3.94	M = 3.34***	M = 3.23****
	SD = 1.12	SD = 0.94	SD = 0.95
Pelvis C	M = 3.50	M = 2.76****	M = 2.86****
	SD = 1.02	SD = 0.95	SD = 0.87
Pelvis D	M = 4.34	M = 3.38****	M = 3.41****
	SD = 0.60	SD = 0.82	SD = 0.86
Pelvis E	M = 4.29	M = 3.38****	M = 3.30****
	SD = 0.78	SD = 0.86	SD = 0.92
Chest A	M = 3.89	M = 3.50*	M = 3.53*
	SD = 1.02	SD = 1.01	SD = 0.94
Chest B	M = 4.01	M = 3.68*	M = 3.72
	SD = 0.93	SD = 0.89	SD = 0.89
Chest C	M = 4.08	M = 3.73*	M = 3.80
	SD = 0.81	SD = 0.79	SD = 0.80
Chest D	M = 3.72	M = 3.30*	M = 3.38
	SD = 1.10	SD = 1.06	SD = 1.03
Chest E	M = 4.11	M = 3.74*	M = 3.62***
	SD = 0.77	SD = 0.87	SD = 0.89
Skull A	M = 4.26	M = 3.06****	M = 3.53****
	SD = 1.02	SD = 1.01	SD = 0.94
Skull B	M = 4.58	M = 3.84****	M = 3.29****
	SD = 0.54	SD = 0.69	SD = 0.84
Skull C	M = 4.09	M = 3.56****	M = 3.08****
	SD = 0.77	SD = 0.74	SD = 0.82
Skull D	M = 4.30	M = 3.93**	M = 3.70****
	SD = 0.66	SD = 0.70	SD = 0.74
Skull E	M = 4.31	M = 3.78***	M = 3.32****
	SD = 0.80	SD = 0.83	SD = 0.97
Hand A	M = 4.47	M = 3.88****	M = 3.46****
	SD = 0.78	SD = 0.79	SD = 0.82
Hand B	M = 3.93	M = 4.17	M = 4.01
	SD = 0.96	SD = 0.75	SD = 0.83
Hand C	M = 4.44	M = 3.83****	M = 3.54****
	SD = 0.74	SD = 0.72	SD = 0.85

Significance (as compared with mean) denoted by *($p \leq .05$), **($p \leq .01$), ***($p \leq .0001$), or ****($p \leq .00001$).