EFFECTIVE DOSE PER UNIT KERMA-AREA PRODUCT CONVERSION FACTORS IN ADULTS UNDERGOING MODIFIED BARIUM SWALLOW STUDIES

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*Received 27 September 2016; revised 4 January 2017; editorial decision 6 January 2017;
accepted 16 January 2017*

This study presents an investigation of adult effective dose (E) per unit Kerma-Area Product (KAP) in Modified Barium Swallow Study (MBSS) examinations. PC program for X-ray Monte Carlo (version 2.0.1) was used to calculate patient organ doses during MBSS examinations, which used combined to generate effective dose. Normalized patient doses were obtained by dividing the effective dose (mSv) by the incident KAP ($\text{Gy}\cdot\text{cm}^2$). Five standard projections were studied and the importance of X-ray beam size and in patient size (body mass index) were investigated. Lateral projections had an average E/KAP conversion factor of $0.19 \pm 0.04 \text{ mSv/Gy}\cdot\text{cm}^2$. The average E/KAP was highest for upper gastrointestinal (GI) anterior–posterior projections ($0.27 \pm 0.04 \text{ mSv/Gy}\cdot\text{cm}^2$) and lowest for upper GI posterior–anterior projections ($0.09 \pm 0.03 \text{ mSv/Gy}\cdot\text{cm}^2$). E/KAP always increased with increasing filtration and/or X-ray tube voltage. Reducing the X-ray beam cross-sectional area increased the E/KAP conversion factors. Small patients have the E/KAP conversion factors that are twice those of a standard adult. Conversion factors for effective dose of adult patients undergoing MBSS examinations must account for X-ray beam projection, beam quality (kV and filtration), image size and patient size.

INTRODUCTION

Swallowing impairment, termed dysphagia, results from an underlying pathology of neurogenic, oncologic, structural, surgical, congenital or iatrogenic origin⁽¹⁾. If untreated, dysphagia may result in serious medical complications such as malnutrition and aspiration pneumonia. The prevalence of dysphagia is estimated to be up to 22% in persons 50 years and older⁽²⁾ with 10 million Americans evaluated for swallowing dysfunction each year⁽³⁾. In the USA, it has been estimated that oropharyngeal dysphagia occurs in ~10% of all acute hospital inpatients⁽⁴⁾, 30% of patients in rehabilitation centers and half of all patients in nursing home facilities⁽⁵⁾. The modified barium swallowing study (MBSS), a videofluoroscopic examination of swallowing function, is the primary diagnostic test used to discover abnormalities in oropharyngeal swallowing function and detect the presence and etiology of aspiration⁽⁶⁾. Most importantly, MBSSs are used to identify the physiologic targets of

treatments and to test the effectiveness of these targets prior to making treatment recommendations (diet modifications, compensatory strategies and restorative exercises to improve swallowing function)⁽⁷⁾.

While MBSSs are essential for acquiring the diagnostic information required by Speech Language Pathologists (SLPs), they do expose patients to ionizing radiation. Therefore, it is important to understand the amount of radiation a patient receives in any given MBSS procedure. Specifically, knowing the radiation associated with MBSSs: (1) allows clinicians to accurately weigh the risk/benefit of the MBSS and determine if it is in the best interest of the patient to undergo the examination; (2) provides a baseline for evaluating the impact of changing technical parameters of the X-ray unit on radiation dose; (3) provides a standard of comparison for an institution to use to determine if their equipment is optimally functioning and (4) allows for a comparison with radiation levels associated with natural

background radiation as well as current regulatory dose limits for occupationally exposed workers and members of the public.

On most modern equipment, the amount of radiation that is incident on the patient (quantity) can be readily measured, or calculated, by the vendor. Information on the amount of radiation that is used for an MBSS examination may be directly displayed to the operator, or stored in the DICOM header. The quality of radiation being used can be gained from knowing the tube voltage used (kV) and the total amount of filtration of the X-ray beam. However, converting the incident radiation quantity and quality into a meaningful patient dose metric (e.g. effective dose) generally requires special medical physics expertise that is not generally available in most clinical departments. The purpose of this paper was to generate conversion factors that permit any SLP or radiologists/technologist to use the information provided by the fluoroscopy unit for a given MBSS study and convert it into a corresponding patient effective dose.

METHODS

Modified barium swallow studies

A MBSS is generally performed in fluoroscopy suites within radiology departments in hospitals. MBSSs are conducted by a SLP in conjunction with radiologists. During a MBSS, the SLP administers barium boluses or barium-coated boluses of different sizes and consistencies to assess swallowing function. When the SLP identifies impairment, they often attempt a physiologically relevant compensatory strategy to provide evidence for implementing the strategy during management of the patient's dysphagia. The MBSS is typically recorded and saved as a movie for reviewing and scoring, off-line by the SLP, and to track patient change in swallowing function over time. MBSS recordings can be saved in a variety of standard formats (e.g. .avi) as well as proprietary formats that are specific to a given vendor. Additional images may be acquired for review by a radiologist when these are clinically indicated. The present study focuses on the radiation associated with the MBSS procedures that relate to the diagnostic imaging aspects of interest to the SLP rather than images related only to radiology practice.

A typical MBSS is conducted mainly in the lateral view, which generally accounts for 85% of the patient swallows examined. The lateral view of the MBSS spans the patient from the lips at the anterior, the posterior wall of the pharynx at the posterior, the nasal cavity at the superior and the esophagus at the inferior. The lateral view shows lip closure, tongue/bolus movement in the oral cavity, movement of the velum, the initiation of pharyngeal swallow with

hyoid movement, tongue base retraction, movement of the epiglottis and larynx, movement of the pharyngeal wall as well as the pharyngeal esophageal segment opening. These features are all necessary for evaluating swallowing physiology. A few swallows are assessed in the posterior–anterior (PA) view. In the PA view, swallows are typically followed through from the oral cavity through the pharynx and to the distal esophagus to assess esophageal clearance in the upright position. The use of the PA view allows clinicians to visualize asymmetry in pharyngeal bolus flow, pouching and esophageal clearance not visible in the lateral view. From a radiological imaging perspective, an anterior–posterior (AP) projection would provide essentially the same physiological information as the PA view, and has been included in this study for completeness.

The intensity of the X-ray beam incident on the patient is known as the entrance air Kerma (K_{air}) and can be used to determine the skin radiation dose. In radiology, the skin dose is used to predict the likelihood of radiation burns (deterministic risks) that only occur at doses in excess of 2 Gy. Skin burns normally do not occur in *any* radiographic or fluoroscopy guided procedures (e.g. MBSS) because skin doses are well below the threshold dose (2 Gy) for producing these types of effect. However, there have been rare cases that have resulted in significant skin burns and epilation^(8, 9). Further, entrance K_{air} is independent of the X-ray beam cross-sectional area and, therefore, not the ideal measure for evaluating patient dose. Since deterministic risks are not a concern with MBSS, it is preferable to use the Kerma-Area Product (KAP) when estimating patient radiation doses. The KAP is the product of the entrance K_{air} and the corresponding X-ray beam area, expressed in terms of $\text{Gy}\cdot\text{cm}^2$, which can be used to estimate organ doses associated with any radiographic examination. Organ doses can be used to quantify stochastic risks (e.g. carcinogenesis) when patient demographic characteristics (e.g. age and gender) are taken into account⁽¹⁰⁾, and may also be combined with tissue weighting factors developed by the International Commission on Radiological Protection (ICRP)⁽¹¹⁾ to obtain an effective dose.

PC program for X-ray Monte Carlo methodology

PC program for X-ray Monte Carlo (PCXMC) (version 2.0.1.4) is a software program for calculating patients' organ doses and effective doses during medical X-ray examinations⁽¹²⁾. The program combines patient anatomical data in the form of mathematical hermaphrodite phantom models with Monte Carlo techniques⁽¹²⁾. All key X-ray beam characteristics that impact patient doses are operator selectable. In this study, a fixed X-ray tube anode angle of 14° was used as this is representative of current X-ray tubes. The X-ray beam quality (i.e.

penetrating power) is varied by selecting X-ray tube voltages as well as the amount of X-ray beam filtration. The two filter materials (Al and/or Cu) typically used in MBSSs are selectable in PCXMC and can be combined to offer the range of beam qualities that are achievable in current fluoroscopy systems. The lowest beam quality that is likely to be encountered clinically would employ an X-ray tube voltage of 60 kV, and 3 mm Al filtration. The highest beam quality that might be used clinically would employ an X-ray tube voltage of 110 kV with a total filtration of 3 mm Al and 0.2 mm Cu. The program provides calculated values of effective dose using ICRP Publication 103 tissue weighting factors⁽¹¹⁾.

PCXMC calculations are dependent on X-ray irradiation geometry, which includes image receptor dimensions, as well as the source to image receptor distance and the corresponding air gap. The center of the X-ray beam is specified by three coordinates (*X*, *Y* and *Z*) and is located directly inferior to the mandible within the phantom. The projection angle defines the orientation of the X-ray beam direction relative to the patient. A projection angle of 0° corresponds to a lateral orientation, a projection angle of 90° corresponds to a PA with the beam entering the patient at the rear, and a projection angle of 270° corresponds to an AP orientation with the beam entering the patient at the front. In this study, the cranio-caudal orientation constant was kept at 0°. For this study, the typical adult patient has a body mass index (BMI) of 24 kg/m² with a weight of 78 kg and a height of 1.80 m.

PCXMC permits the operator to specify the total incident radiation beam in terms of the KAP (Gy·cm²). The KAP obtained with no patient backscatter radiation (i.e. free in air) is independent of the measurement location. As the measurement location approaches the patient, the reduction in K_{air} as a result of the inverse square law is exactly offset by a corresponding increase in X-ray beam area. For any given exposure, the normalized patient dose is expressed in terms of mSv/Gy·cm², obtained by dividing the effective dose (mSv) by the incident KAP (Gy·cm²).

Projections, image sizes and patient sizes

Five projections were investigated which cover the whole range of MBSS examinations in normal sized adults: lateral, upper gastrointestinal (GI) AP, upper GI PA, middle GI PA and lower GI PA. While MBSSs are not typically acquired in the AP projection, this projection was included for the upper GI to ascertain the difference between using PA versus AP projections. In the lateral projection (Figure 1A), the beam area includes the lips anteriorly, the nasal cavity superiorly, the cervical spinal column posteriorly and the upper esophageal sphincter (UES)

inferiorly. In the upper GI PA (Figure 1B), the beam area includes the oral cavity superiorly, the lateral pharyngeal walls laterally and the pharyngo-esophageal segment and esophagus inferiorly. The upper GI AP projection covers the same patient anatomy as the upper GI PA projection, but the X-ray beam enters the patient anteriorly (Figure 2). In the middle GI PA follow through projection (Figure 1C), the beam area includes the UES superiorly and the middle portion of the esophagus (imaging approximately the first seven ribs). In the lower GI PA follow through projection (Figure 1D), the beam area includes the middle and lower esophagus and the transition to the stomach, inferiorly.

Table 1 provides a summary of the image sizes, and corresponding central beam axis locations, that were used in radiation dosimetry computations for normal sized adults undergoing MBSS examinations. Of note, the origin of the coordinate system in PCXMC is located in the center of the bottom of the phantom's trunk. To investigate the influence of the X-ray beam size, the nominal sizes were adjusted as presented in Table 1 by 10% in each direction with appropriate collimation. To investigate the influence of adult patient size, a range of patient sizes were included as characterized by three BMI values (18, 24 and 30 kg/m²), presented in Table 2. These BMI values were selected to align to the upper value for underweight, normal weight and overweight BMIs, respectively. Data in Table 2 show the modified image receptor sizes, after appropriate collimation, that were used for determining the corresponding E/KAP conversion factors in these nonstandard sized adults.

RESULTS

Conversion factors

Figure 3A shows E/KAP as a function of X-ray beam quality (kV and X-ray beam filtration) for the lateral projections in normal sized adults. The average conversion factor ($\pm$ SD) for the 18 data points shown in Figure 3A was 0.19 ± 0.04 mSv/Gy·cm². Table 3 presents how the E/KAP conversion factor increases from 0.12 mSv/Gy·cm² at the lowest X-ray beam quality (60 kV and 3 mm Al) to more than double this value (0.25 mSv/Gy·cm²) at the highest X-ray beam quality (110 kV and 3 mm Al + 0.2 Cu).

Figure 3B–D shows the E/KAP conversion factors as a function of X-ray beam quality (kV and X-ray beam filtration) for normal sized adults for the PA projection for the upper, middle and lower GI, respectively. The average conversion factor ($\pm$ SD) for the 18 data points shown in Figure 3B was 0.09 ± 0.03 mSv/Gy·cm², in Figure 3C was 0.13 ± 0.04 mSv/Gy·cm², and in Figure 3D was 0.23 ± 0.07 mSv/Gy·cm². Table 3 presents how the E/KAP conversion factors for these body regions increased from a low of 0.06 mSv/Gy·cm²

Figure 1. Irradiation geometry for four projections in normal sized adults undergoing MBSS examinations. Color code: (A and B) white, skeleton; dark green, oral mucosa; dark blue, salivary glands; turquoise, pharynx/trachea/sinus; pink = thyroid. (C and D) white, skeleton; turquoise, lungs; red, heart; dark green, liver; dark blue, stomach; brown, pancreas; light green, kidneys; yellow, esophagus (left) and gall bladder (D, right).

for the middle GI at the lowest X-ray beam quality (60 kV and 3 mm Al) to nearly six times higher ($0.35 \text{ mSv/Gy}\cdot\text{cm}^2$) for the lower GI at the highest X-ray beam quality (110 kV and 3 mm Al + 0.2 Cu).

Figure 4 shows the comparison of E/KAP conversion factors for the upper GI for a PA and AP projection in a normal sized adult. The average conversion factor ($\pm$ SD) for the 18 AP data points shown in Figure 4 was $0.27 \pm 0.04 \text{ mSv/Gy}\cdot\text{cm}^2$, which is nearly three times higher than the corresponding values for PA projections. Table 3 presents how the E/KAP AP conversion factor increases from $0.19 \text{ mSv/Gy}\cdot\text{cm}^2$ at the lowest X-ray beam quality (60 kV and 3 mm Al) to nearly double this value ($0.34 \text{ mSv/Gy}\cdot\text{cm}^2$) at the highest X-ray beam quality (110 kV and 3 mm Al + 0.2 Cu). In contrast, the PA conversion factors are four times lower than the AP values at the lowest X-ray beam quality ($0.04 \text{ mSv/Gy}\cdot\text{cm}^2$), and more than two times lower at the highest X-ray beam quality ($0.14 \text{ mSv/Gy}\cdot\text{cm}^2$).

Beam area

Table 4 presents how changes in the X-ray beam area affects E/KAP conversion factors in normal sized adults undergoing a lateral upper GI projection most frequently used in MBSS examinations. Beam quality was set at 60 kV and 3 mm Al. Reducing the normal sized image ($22 \times 16 \text{ cm}^2$) both vertical and horizontal X-ray beam sizes by 10% ($19.8 \times 14.4 \text{ cm}^2$) increased the E/KAP conversion factor from 0.12 to $0.14 \text{ mSv/Gy}\cdot\text{cm}^2$ (i.e. 17%). Conversely, increasing both image dimensions by 10% ($24.2 \times 17.6 \text{ cm}^2$) reduced the E/KAP conversion factors from 0.12 to $0.11 \text{ mSv/Gy}\cdot\text{cm}^2$ (8%).

Patient size

Table 5 presents how changes in patient size and height (BMI) affect E/KAP conversion factors for lateral upper GI projections with 60 kV and 3 mm Al filtration. For the shortest patients (150 cm) with the

Figure 2. Irradiation geometry for the upper GI comparing PA and AP projection in normal sized adults undergoing MBSS examinations. Color code: (A and B) white, skeleton; dark green, oral mucosa; dark blue, salivary glands; turquoise, pharynx/trachea/sinus; pink, thyroid; yellow, esophagus.

Table 1. Image sizes and centers used in radiation dosimetry computations for normal sized adults undergoing MBSS examinations.

View	Image dimension		Coordinate (cm)		
	Vertical (cm)	Horizontal (cm)	X	Y	Z
Lateral	22	16	7.57	-4.0	80
Upper GI PA	22	16	0	5.55	80
Middle GI PA	22	16	0	10.28	62
Lower GI PA	22	16	2.5	10.2	46

Table 2. Heights and weights (kg) of different sized individuals (adults) used in this study.

BMI (kg/m ²)	Height (m)		
	1.5	1.8	2.0
18	40 (18.5 × 12)	58 (22 × 16)	72 (24.5 × 16)
24	54 (18.5 × 14)	78 (22 × 16)	96 (25 × 17)
30	68 (18.5 × 16)	97 (22.5 × 17)	120 (25.4 × 19)

Image height and width (cm) in parentheses underweight (kg).

lowest BMI of 18 (40 kg), the E/KAP conversion factors nearly doubled to 0.23 mSv/Gy-cm² in comparison to a normal sized adult patient (180 cm) with a BMI 24 (78 kg) with a E/KAP conversion factor of 0.12 mSv/Gy-cm². For the tallest patients (200 cm) with a BMI of 30 (120 kg), the E/KAP conversion factors were reduced by ~33% to 0.08 mSv/Gy-cm². In all cases, when BMI is fixed the tallest patients have the lowest E/KAP conversion factors, and *vice versa*. When height is fixed patients with the highest

BMI have the lowest E/KAP conversion factors, and *vice versa*.

DISCUSSION

All radiological examinations involve exposures to nonuniform patterns of radiation where a wide range of organs and tissues receive varying amounts of radiation. Comparison of organ doses from different examinations is possible, but not practical or helpful for making informed clinical decisions. By using the effective dose quantity, the imaging community can obtain nominal direct inter-comparison of two types of radiological examinations⁽¹³⁾. A patient having an MBSS examination with an effective dose of 1 mSv likely has a detriment that is comparable to any another radiological exposure with an effective dose of 1 mSv in the same patient. Values of effective dose are currently accepted as being the best indicator available of the radiation received by patients undergoing radiological examination⁽¹⁴⁾. It is important to note that the ICRP explicitly recommends that effective doses are not used for radiation risk estimation because weighting factors are age/sex averages, and any risk estimates must always be based on organ doses combined with patient demographic data.

All of the E/KAP conversion factors obtained in this study increased with increasing X-ray beam quality. This was true when the tube voltage increased at a constant X-ray beam filtration, as well as when the beam filtration increased at an X-ray tube voltage. This finding is expected, because X-ray beam quality is a measure of the average energy of the photons in any X-ray beam, and increased photon energies are clearly more penetrating than low-energy photons. As photon energy increases, X-rays can penetrate further into the patient, thereby

Figure 3. Effective dose per unit KAP conversion factors for normal sized adults undergoing a (A) lateral, (B) PA upper GI, (C) PA middle GI and (D) lower GI projection in an MBSS examination.

increasing the doses to deeper lying organs and tissues. A recent study demonstrated that the energy imparted into patients increases substantially with increasing X-ray beam quality⁽¹⁵⁾. Effective doses will generally correlate very closely with energy imparted and the total patient stochastic radiation risk⁽¹⁶⁾.

Our data show that X-ray beam filtration has a very large effect on E/KAP conversion factors. The addition of 0.1 or 0.2 mm Cu increases E/KAP conversion factors more than increasing the tube voltage by 10–20 kV. The reason for this is that filtration

preferentially reduces the intensity of lower energy photons that impact on the incident air Kerma, but have only limited penetration into the patient.

Figure 4 shows that the doses associated with AP projections are about a factor of 3 higher than those associated with PA projections. This is expected as the AP projection will result in higher thyroid doses than a PA projection. However, the magnitude of the difference is surprising given that the thyroid only has a tissue weighting factor value of 0.04. The most likely explanation is that apart from the thyroid

Table 3. Selected E/KAP (mSv/Gy·cm²) values that are depicted in Figure 2 for normal sized adults undergoing MBSS examinations.

Body region	Projection	X-ray beam quality		
		60 kV (3 mm Al)	80 kV (2 mm Al + 0.1 mm Cu)	110 kV (3 mm Al + 0.2 mm Cu)
Upper GI	Lateral	0.124	0.191	0.254
	AP	0.191	0.267	0.336
	PA	0.043	0.087	0.141
Middle GI	PA	0.058	0.124	0.208
Lower GI	PA	0.109	0.217	0.349

Figure 4. Effective dose per unit KAP conversion factors for normal sized adults undergoing an upper GI PA projection in an MBSS examination.

gland, very few other radiosensitive organs are included in the field of view, which magnifies the relative importance of the thyroid gland when computing effective doses for projections used in MBSS examinations. It is therefore clear that operators should continue to use the PA projection given the very sizeable benefit gained in terms of patient exposures. The use of an AP projection would require a substantial increase in diagnostic information to compensate for the large increase in radiation dose, which is unlikely given that the information yields from PA and AP projections in any MBSS examination are expected to be comparable.

The lateral projection generally accounts for ~85% of the swallows examined in MBSSs, and our study shows that this has a relatively high E/KAP

conversion factor. The conversion factor for the lateral projection is higher than that for the PA by about a factor of 2, and is also higher than the middle adult GI projection. Only the lower GI projection has a higher E/KAP conversion factor (0.23 vs 0.19). For example, assuming that 15% of the radiation used in an MBSS examination is equally divided between upper, middle and lower PA GI projections, it is possible to generate the following nominal conversion factor in normal sized adults undergoing an MBSS examination. At the lowest X-ray beam quality investigated (60 kV + 3 mm Al), the projection weighted average conversion factor is 0.12 mSv/Gy·cm². At the highest X-ray beam quality (110 kV + 3 mm Al + 0.2 mm Cu), this increases to 0.25 mSv/Gy·cm². For an average X-ray beam quality of 80 kV, with 2 mm Al and 0.1 mm Cu filtration, an incident beam of 1 Gy·cm² will likely result in an effective dose in a normal sized adult of 0.18 mSv.

It is important to note that the use of higher X-ray beam qualities will actually reduce patient doses, despite the fact that the corresponding E/KAP factors increase (Table 3). The reason for this is that increasing beam quality will result in a more penetrating X-ray beam that requires much less incident radiation to achieve a given X-ray intensity at the image receptor. Virtually, all radiography and fluoroscopy being performed today makes use of Automatic Exposure Control systems that keep the radiation intensity at the image receptor fixed. In general, the reduction in radiation intensity at higher beam qualities will be larger than the corresponding increases in E/KAP conversion factors. Because increasing beam quality in MBSS examinations has the potential to reduce patient doses, this needs additional study. An analysis of the reductions in KAP that could be achieved using higher beam qualities should be investigated, together with the corresponding impact on diagnostic performance. Our data can be used to quantify how changes in both X-ray beam quantity and quality impact patient effective doses.

Data in Table 4 show how the X-ray beam cross-sectional area used in MBSS examinations affects the computed E/KAP conversion factors. In general,

Table 4. E/KAP conversion factors and normalized values of E/KAP conversion factors for normal sized adults irradiated in the lateral projection (60 kV, 3 mm Al) during MBSS examinations.

Image height	Image width		
	−10% (14.4 cm)	Normal (16 cm)	+10% (17.6 cm)
−10% (19.8 cm)	0.14 (117%)	0.13 (108%)	0.12 (100%)
Normal (22 cm)	0.13 (108%)	0.12 (100%)	0.11 (92%)
+10% (24.2 cm)	0.12 (100%)	0.12 (100%)	0.11 (92%)

Normalized E/KAP values are shown in parentheses and have been normalized to the normal sized image (100%).

Table 5. E/KAP conversion factors and normalized values of E/KAP conversion factors for varying sized adults irradiated in the lateral projection (60 kV, 3 mm Al) during MBSS examinations.

Patient BMI	Patient height		
	Short	Normal	Tall
Low	0.23 (192%)	0.13 (108%)	0.12 (100%)
Normal	0.18 (150%)	0.12 (100%)	0.10 (83%)
High	0.14 (117%)	0.11 (92%)	0.08 (67%)

Normalized E/KAP values are shown in parentheses and have been normalized to the normal sized patient (100%).

reducing the X-ray beam cross-sectional area increased the E/KAP conversion factors, and *vice versa*. This was true irrespective of whether the reduction in X-ray dimension was vertical or lateral. However, the magnitude of these changes is very modest, and was up to ~10% or so. Uncertainties in effective dose of the order of 10% are of little practical consequence and these are much smaller than changes in E/KAP conversion factors that are associated with changes in beam quality and patient size. For most clinical applications, the precise beam area is unlikely to require any special or explicit consideration.

Data in Table 5 reveal the effect of patient size (BMI) on the E/KAP conversion factors. In general, smaller patients have larger E/KAP conversion factors than larger patients. This finding can be understood by a consideration of the basic physics associated with X-ray beams irradiating any patient. Approximately two-thirds of the incident energy on a patient will be absorbed by the patient, and a third will be scattered out of the patient. The amount of radiation transmitted to the image receptor is always very low, and typically below 1% of the incident beam intensity. Additionally, modern fluoroscopy systems use automatic image adjustments and exposure control that may reduce this already low dose. Since ‘dose’ is energy divided by a corresponding

mass, when patient size increases, doses are always reduced because the energy imparted is essentially fixed at two-thirds of the incident beam. What is surprising is that the use of a single conversion factor computed for a standard sized individual (BMI 24 kg/m²) could result in errors of up to a factor of 2 in individuals with a low BMI.

For any given patient who undergoes the specified examination, the effective dose may be readily obtained by multiplication of the conversion factors provided in this paper with the corresponding values of KAP (Gy·cm²) that was used to perform an MBSS examination. Our computed conversion E/KAP coefficients should only be used for the specified beam and patient characteristics, together with defined X-ray beam irradiation geometry. When X-ray beam and/or patient characteristics other than the ones explicitly included in our investigation are employed, data in Tables 4 and 5 can be used to estimate the magnitude and direction of the errors associated with the differences in factors. KAP is generally provided explicitly on most modern imaging systems, and is also available in the DICOM header information that is now standard in radiological imaging. Tube voltage information is also readily available in any radiographic image DICOM header. X-ray tube filtration is generally available in reports issued by medical physicists who are required by regulations to test each radiographic unit that is used clinically.

CONCLUSION

The results of this study indicate that conversion factors for effective dose of adult patients undergoing MBSS examinations are significantly influenced by projection, beam quality (kV and filtration), image size and patient size. Given the conversion factors resulting from this study, an MBSS with an average X-ray beam quality of 80 kV, with 2 mm Al and 0.1 mm Cu filtration, an incident beam of 1 Gy·cm² will likely result in an effective dose in a normal sized adult of 0.18 mSv. The results provide 1) information regarding radiation doses associated with MBSSs and 2) clinicians with an algorithm for

computing effective dose for their patients. The results also revealed that effective dose is significantly increased by greater filtration and smaller patient size. Lastly, the results indicate that AP projections are associated with significantly higher effective doses than PA projections, which promotes the continued use of PA projections for MBSSs.

FUNDING

This work was supported by the National Institute of Diabetes and Digestive and Kidney Diseases at the National Institute of Health (GrantR01 DK098222: 'Impact of Pulse Rate on Swallowing Impairment Assessment and Radiation Exposure').

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