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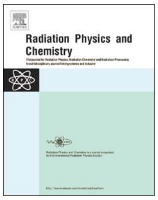

Evaluation of equivalent and effective dose by KAP for patient and orthopedic surgeon in vertebral compression fracture surgery

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ABSTRACT

Clinical scenarios were virtually modeled to estimate both the equivalent and effective doses normalized by KAP (**K**erma **A**rea **P**roduct) to vertebra compression fracture surgery in patient and surgeon. This surgery is known as kyphoplasty and involves the use of X-ray equipment, the C-arm, which provides real-time images to assist the surgeon in conducting instruments inserted into the patient and in the delivery of surgical cement into the fractured vertebra. The radiation transport code used was MCNPX (**M**onte **C**arlo **N**-**P**article e**X**tended) and a pair of UFHADM (**U**niversity of **F**lorida **H**ybrid **AD**ult **M**ale) virtual phantoms. The developed scenarios allowed us to calculate a set of equivalent dose (H_T) and effective dose (E) for patients and surgeons. In additional, the same scenario was calculated KAP in the tube output and was used for calculating conversion coefficients (E/KAP and H_T/KAP). From the knowledge of the experimental values of KAP and the results presented in this study, it is possible to estimate absolute values of effective doses for different exposure conditions. In this work, we developed scenarios with and without the surgical table with the purpose of comparison with the existing data in the literature. The absence of the bed in the scenario promoted a percentage absolute difference of 56% in the patient effective doses in relation to scenarios calculated with a bed. Regarding the surgeon, the use of the personal protective equipment (PPE) reduces between 75% and 79% the effective dose and the use of the under table shield (UTS) reduces the effective dose of between 3% and 7%. All these variations emphasize the importance of the elaboration of virtual scenarios that approach the actual clinical conditions generating E/KAP and H_T/KAP closer to the actual values.

1. Introduction

The vertebral compression fractures (VCF) may occasionally occur by walking, sports or traffic accidents, but particularly in older individuals suffering from osteoporosis (Riggs and Melton, 1995; Edidin et al., 2013). Osteoporosis generates a weakening of the bones increasing the risk of breakage. The injured vertebrae provide much discomfort to the individual, and thus the best indication for pain relief is a surgical procedure (Lieberman et al., 2001; Gangi et al., 2003; Ledlie and Renfro, 2003).

The surgery used to correct the vertebral compression fracture is known as kyphoplasty and vertebroplasty. Both techniques inject surgical cement in the vertebra of the patient aiming at filling the porous part, and thus, strengthening the vertebra and relief of pain (Ledlie and Renfro, 2003). This surgery is minimally invasive and is usually done with two incisions. Throughout the process, the surgeon uses X-ray imaging equipment (C-arm) for guiding the delivery of cement through the real-time radiographic images. Although the benefits are large, the use of X-ray equipment to obtain real-time images always brings a concern regarding the dose to the patient and medical staff. Studies involving kyphoplasty and vertebroplasty in computational and experimental scopes have been developed in order to quantify the radiation dose related to this practice (Perisinakis et al., 2004; Harstall et al., 2005; Mroz et al., 2006; Ortiz et al., 2006; Boszczyk et al., 2006; Schneider et al., 2014; Panizza et al., 2014; Lonjon, et al., 2016).

Seibert (2004) did an editorial with a short literature review and found that few studies involving the theme vertebroplasty and kyphoplasty bring a relevant discussion on radiation doses. He emphasizes that the majority of papers published in this area are not in radiology journals and thus there is a great possibility of the procedures being not properly developed.

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Panizza et al. (2014) develop a work evaluating 20 patients who underwent kyphoplasty procedure. In their work, a KAP (**K**erma **A**rea **P**roduct) meter and a computer software was used to provide the effective dose based on the experimental values. They evaluated two surgical cement delivery techniques: one performed manually and another done through a cement delivery system (CDS). Due to differences in exposure time for the projections used, the difference in effective doses for the patients, with the techniques used was 90%.

Schils et al. (2013) evaluated the radiation dose for surgeons who use the CDS. It was observed that the radiation doses in the finger, wrist, and leg were reduced to over 80% for surgeons who use CDS thus allowing the orthopedic surgeon to work far below his annual limit.

The Monte Carlo method has been used in the diagnostic radiology area to assess radiation doses for both primary beam and scattered radiation (Mah et al., 2011; Chan and Doi, 1983). Recently, real computational scenarios were developed to represent the characteristics of the practice being studied and better estimate the scattering radiation doses (Santos et al., 2014, 2015, 2016).

This study aimed at calculating conversion coefficients expressed as equivalent dose (H_T) and effective dose (E) normalized by kerma-area product (KAP) for patients and orthopedic surgeons during procedures for vertebral compression fracture surgery. Through the elaborated scenarios, it is possible to measure the equivalent dose and effective dose for a large number of radiographic techniques and surgical setups. For this purpose, virtual anthropomorphic phantoms and a radiation transport code were used to model the real medical scenarios.

2. Materials and methods

For the simulations performed in this study, a pair of male anthropomorphic phantoms (UFHADM – **U**niversity of **F**lorida **H**ybrid **AD**ult **M**ale) was used for patient and surgeon, respectively (Lee et al., 2010). The computer code used was MCNPX (**M**onte **C**arlo **N**-**P**article e**X**tended) which simulated radiation transport (Pelowitz, 2011).

The MCNPX is a software heavily used in radiation dosimetry based on the Monte Carlo method. This code allows the transport of several particles in a wide range of energies, and also the 3D modeling of complex radiation scenarios. The UFHADM is a male adult phantom weighting 73.39 kg and measuring 1.76 m in height. The masses of their organs were based on ICRP 89 (ICRP, 2002).

In order to use a pair of virtual phantoms in the MCNPX input file, the identification numbers of each phantom were reduced. This simplification was necessary because the duplication, without the simplification process, would exceed the maximum number of characters allowed (255). Simplification and duplication were made using software ImageJ (ImageJDisclaimer, 2015).

The original phantom has the arms normally connected to the body, and this prevents the direct beam reaching the desired location on the latero-lateral projection. During the kyphoplasty, the patient's arms remain raised. Thus, it was necessary to remove the patient's arms to achieve the conversion coefficients close to the actual values.

The elaborated scenarios have two projections, AP (Antero-Posterior) and LL (Latero-Lateral) (Fig. 1(A) and (B)). The spectra were generated by SRS 78 (**S**pectrum of **X**-**Ray** **S**ource) software (Cranley et al., 1997) considering a filtration of 4.0 mmAl +0.1 mmCu, an anode angle of 10°, and the distance from the focus to the detector of 100 cm. Seven X-ray spectra were generated from 60 to 120 kVp in steps of 10 kVp. The radiographic parameters used and the spatial dimensions of the equipment are based on the X-ray equipment model Philips, BV Pulsera version 2.3.

In order to simulate an irradiation scenario as real as possible, objects inside the room were modeled to evaluate the scattering radiation doses generated by this surgery procedure. A scenario that has a greater realism can better simulate the radiation transport and its effects, such as scattering, absorption, and production of secondary particles. The main objects were the bed, X-ray equipment, the PPE (**P**rotection **P**ersonal **E**quipment), and the UTS (**U**nder **T**able **S**hield). In this work, scenarios were created with and without a bed, the PPE, and the UTS. The bed is composed of carbon fiber with density (d) of 1.17 g/cm^3, (composition H (5.7%), C (67.9%), N (26.4%)), and a polyurethane foam (d=0.021 g/cm^3, composition H (4.1%), C (54.4%), N (12.1%), O (29.4%)). The equipment was built from stainless steel 304 (d=8.0 g/cm^3, composition C (0.04%), Si (0.50%), P (0.02), S (0.02%) Cr (19.00%), Mn (1.00%), Fe (70.17%), Ni (9.25%)), and the box of the X-ray tube is coated with laminated lead on the inside (11.35d=g/cm^3, composition Pb (100%)) (McConn et al., 2011). PPE

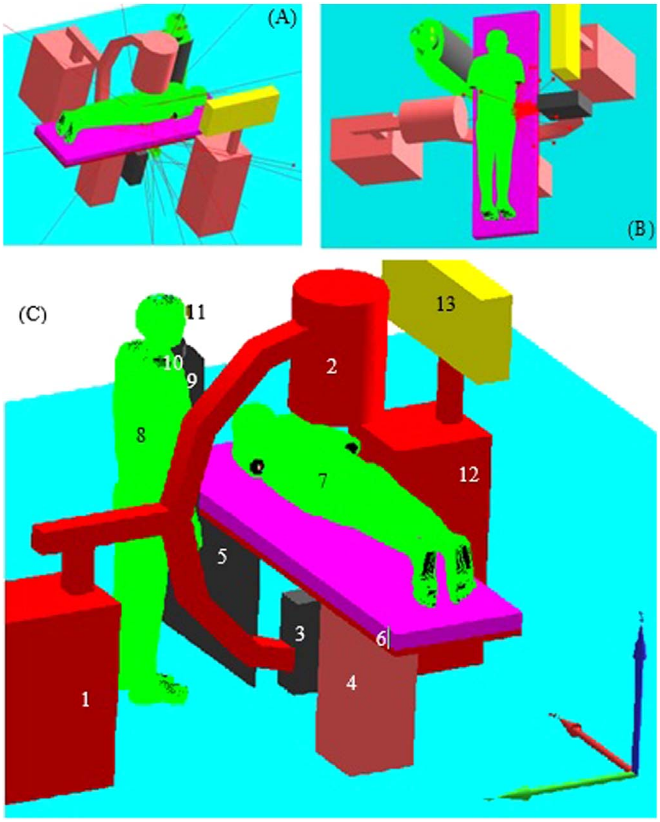

Fig. 1. (A) Antero-Posterior projection (B) Latero-Lateral Projection, (C) 1 - equipment support, 2 - image intensifier, 3 - X-ray tube, 4 - table support, 5 - under table shield, 6 - bed, 7 - patient, 8 - surgeon, 9 - full-body protector, 10 - thyroid shield, 11 – leaded glasses, 12 - support video monitors, 13 - video monitors.

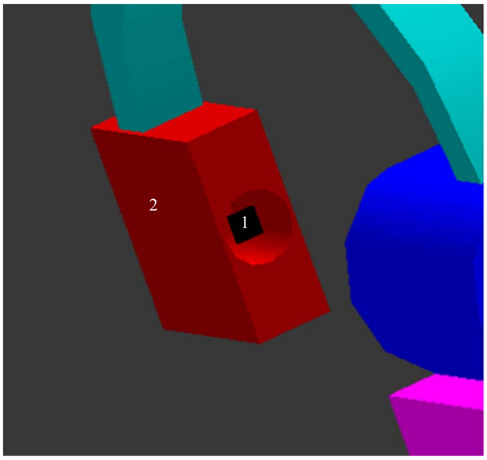

Fig. 2. Scheme of the X-Ray tube and the air cell used to calculate KAP. 1 – Air cell, 2 – X-ray tube. For the best view of the figure, the scene was loaded without the bed and without the patient.

Table 1
E/KAP calculated values (mSv/Gy cm^2) to patient.

Tube voltage (kVp)	Complete AP	Without Bed AP	Diference[a]	Complete LL	Without Bed LL	Diference[a]
60	7.20E−02	1.18E−01	64%	5.26E−02	5.15E−02	2%
70	8.99E−02	1.44E−01	60%	6.96E−02	6.82E−02	2%
80	1.07E−01	1.69E−01	58%	8.69E−02	8.51E−02	2%
90	1.22E−01	1.90E−01	56%	1.02E−01	9.98E−02	2%
100	1.33E−01	2.06E−01	55%	1.14E−01	1.12E−01	2%
110	1.43E−01	2.19E−01	53%	1.25E−01	1.22E−01	2%
120	1.51E−01	2.30E−01	52%	1.34E−01	1.31E−01	2%
Average value	1.17E−01	1.82E−01	56%	9.79E−02	9.57E−02	2%

[a] The analysis was performed by percentage absolutes differences.

Table 2
H_T/KAP calculated values (mSv/Gy cm^2) to patient in complete scenario.

Tube voltage (kVp)	Lung			Breast			Testicles			Liver		
	AP	LL	Difference[a]	AP	LL	Difference[a]	AP	LL	Difference[a]	AP	LL	Difference[a]
60	1.50E−03	4.51E−04	70%	1.62E−02	2.08E−03	87%	1.43E−01	3.16E−02	78%	1.25E−02	3.00E−03	76%
70	2.28E−03	7.87E−04	65%	1.92E−02	2.80E−03	85%	1.72E−01	4.62E−02	73%	1.79E−02	5.23E−03	71%
80	3.13E−03	1.22E−03	61%	2.18E−02	3.59E−03	84%	1.99E−01	6.14E−02	69%	2.35E−02	7.97E−03	66%
90	3.92E−03	1.64E−03	58%	2.38E−02	4.33E−03	82%	2.21E−01	7.52E−02	66%	2.85E−02	1.06E−02	63%
100	4.60E−03	2.04E−03	56%	2.55E−02	4.84E−03	81%	2.38E−01	8.67E−02	64%	3.28E−02	1.31E−02	60%
110	5.20E−03	2.40E−03	54%	2.68E−02	5.31E−03	80%	2.51E−01	9.69E−02	61%	3.63E−02	1.52E−02	58%
120	5.72E−03	2.74E−03	52%	2.77E−02	5.71E−03	79%	2.62E−01	1.06E−01	60%	3.93E−02	1.72E−02	56%
Average Value	3.76E−03	1.61E−03	57%	2.30E−02	4.10E−03	82%	2.12E−01	7.19E−02	66%	2.72E−02	1.03E−02	62%

[a] The analysis was performed by percentage absolutes differences.

Table 3
E/KAP calculated in patients undergoing kyphoplasty compared to the results obtained by Panizza et al. (2014).

Projection (tube voltage)	Analyzed scenarios	E/KAP (mSv/Gy cm^2)	Difference[a]
AP (60–80 kVp)	Panizza Study	1.65E−01	
	Complete scenario	8.96E−02	84%
	Withou Bed scenario	1.44E−01	15%
LL (60–90 kVp)	Panizza Study	7.29E−02	
	Complete scenario	7.78E−02	6%
	Withou Bed scenario	7.62E−02	4%

[a] The analysis was performed by percentage absolutes differences based on the Panizza average value.

was modeled for the virtual phantom representing the surgeon. The PPE is composed of full-body protector, thyroid shielding, and lead glasses with 0.75 mm thick. The full-body protector and thyroid shielding is made of lead; and the leaded glasses (d=6.22 g/cm^3) is composed by O (15.64%), C (8.09%), Ti (0.01%), As (0.003%), Pb (75.19%)). The UTS is made of lead with 0.5 mm wide. All modeled objects are described in Fig. 1(C).

Conversion coefficients (CC) calculated in this study relate the equivalent dose (H_T) and the effective dose (E) to the kerma-area product (KAP), which allows the conversion of measurements of KAP to the equivalent and effective doses. All procedures for the effective dose calculation were based on ICRP 103 (ICRP, 2007).

For the calculation of KAP, an air cell of 5×5×1 cm^3 was created in the tube output (Fig. 2). This cell can cover all the photons leaving the tube to simulate the KAP meter that is inside the X-ray tube. The KAP was calculated using the MCNPX tally f6, which provides the energy deposited by mass in air cell (MeV/g) in electronic equilibrium conditions, as in a real situation.

In the Monte Carlo method, the number of histories in which the scenarios were processed is essential to evaluate the uncertainty level. In this work, the scenarios were processed with a hundred billion histories (10^9). The absorbed dose in each organ and tissue of the UFHADM phantom was determined using tally *F8 (in MeV) of MCNPX, code version 2.7.0 (Pelowitz, 2011). These doses are the same as.

the equivalent doses of organs (in mSv) as w_R=1 for photons and electrons. In this study, the equivalent dose (H_T) of 26 organs with dosimetric importance were evaluated, as well the effective dose (E), as described ICRP 116 (ICRP, 2010). The effective dose calculated in this study was normalized by KAP (Gy cm^2).

Table 4
E/KAP (μSv/Gy cm^2) to surgeon in the AP projection.

Tube voltage (kVp)	PPE with UTS	without PPE with UTS	Difference[a]	PPE and without UTS	without PPE and without UTS	Difference[a]
60	2.30E−01	1.16E+00	80%	2.54E−01	1.21E+00	79%
70	3.25E−01	1.53E+00	79%	3.54E−01	1.59E+00	78%
80	4.27E−01	1.90E+00	77%	4.61E−01	1.97E+00	77%
90	5.25E−01	2.22E+00	76%	5.63E−01	2.30E+00	76%
100	6.26E−01	2.49E+00	75%	6.66E−01	2.58E+00	74%
110	6.97E−01	2.70E+00	74%	7.40E−01	2.79E+00	73%
120	7.65E−01	2.88E+00	73%	8.11E−01	2.98E+00	73%
Average value	5.14E−01	2.13E+00	76%	5.50E−01	2.20E+00	75%

[a] The analysis was performed by percentage absolutes differences.

Table 5
E/KAP (µSv/Gy cm^2) to surgeon in the LL projection.

Tube voltage (kVp)	PPE with UTS	without PPE with UTS	Difference[a]	PPE and without UTS	without PPE and without UTS	Difference[a]
60	2.34E−02	1.48E−01	84%	2.57E−02	1.54E−01	83%
70	4.23E−02	2.37E−01	82%	4.55E−02	2.45E−01	82%
80	6.70E−02	3.35E−01	80%	7.15E−02	3.46E−01	79%
90	9.04E−02	4.31E−01	79%	9.56E−02	4.44E−01	78%
100	1.18E−01	5.21E−01	77%	1.23E−01	5.38E−01	77%
110	1.44E−01	6.06E−01	76%	1.51E−01	6.24E−01	76%
120	1.65E−01	6.78E−01	76%	1.73E−01	6.97E−01	75%
Average value	8.07E−02	3.80E−01	79%	8.53E−02	3.92E−01	78%

[a] The analysis was performed by percentage absolutes differences.

3. Results and discussion

The values of the equivalent dose conversion coefficients for an organ depend on several factors. First, increasing the tube voltage, the CC for all organs increases. Second, the size and distribution of the organs in the phantom are of especial importance for the patient's doses. They are located within the field of view (small intestine, large intestine, stomach, etc) and receive larger CC values in comparison to the parts located outside the beam range (thyroid, brain, heart, etc).

The most critical situation for the orthopedic surgeon was in the AP projection. In this projection, the most radiosensitive organs of the orthopedic surgeon are located closer to the scattered radiation center, which covers much of the surgeon body. As expected, in all situations the patients had higher CC values than the orthopedic surgeon.

Table 1 presents a summary of the results and an average value of the calculated conversion coefficients to the patient. It was observed that the average values of E/KAP with the bed have a difference of 56% in relation to projection AP scenarios without the bed. This was expected because the bed attenuates part of the photons of the direct beam. For LL projection, a slight difference of 2% was observed in the CC calculated for the complete scenario. This increase is attributed to the backscattering provided by the surgical bed. Although the surgical bed in this projection does not intersect the beam, the photons can be scattered by the bed and deposit their energy in patient's body.

For complete scenario, the difference between AP and LL projection was 16% and scenarios without the bed difference between the projections was 48%. These differences are justified by different irradiation area. The percentage difference between the projections is larger for scenario without bed, again because the absence of bed provides higher CC values and consequently major differences. In AP projection, most radiosensitive organs are affected and thus higher conversion coefficients are calculated. Analyzing the H_T/KAP values for organs with greater radiosensitivity, such as lung, breast, testicles, and liver, one can justify the effective dose increase in AP projection in relation to LL projection. For the complete scenario, the percentage absolute difference for these organs were 57%, 82%, 66%, 62%, respectively, as can be seen in Table 2. Another important point for the reduction of CC in LL projection is the fat layer on the side of the phantom, creating a barrier to the most radiosensitive organs.

Panizza et al. (2014) developed a study evaluating the effective dose in patients undergoing kyphoplasty. A KAP meter measured the KAP values and the effective dose was calculated from the experimental values using the PCXMC 2.0 (**P**rogram **C**alculating **X**-ray **M**onte **C**arlo). They studied two situations, A and B. In the study A, they measured the effective dose in patients undergoing manual injection of surgical cement, while, in the study B, the orthopedic surgeon uses a cement delivery system (CDS). We made an average of their E/KAP and compared them to the average values calculated in this study considering the same tube voltage intervals, as shown in Table 3. The percentage absolute differences between the Panizza et al. (2014) work and this study are 15% and 4% for the scenario without the bed in AP and LL projections, respectively. Considering the bed, the percentage difference of E/KAP in the AP projection increased to 84%. In LL projection, the bed does not attenuate the beam direct as in the AP projection. Then, the bed only contributes to increase slight the dose due to backscattered radiation.

A surgical bed is essential to kyphoplasty procedures, therefore the dose values specific to the realistic scenarios calculated in this work might be useful to the better estimation of the effective dose in the patients.

Considering the long simulation time and the nature of the problem, in general, the accuracy of the results was satisfactory. The uncertainties are shown in Appendix A and B. The results for H_T and E were normalized by the kerma-area product (KAP) and presented in the format of conversion coefficient (CC).

All conversion coefficients (equivalent (H_T) and effective dose (E) normalized by KAP) calculated for the patient and surgeon in this study are shown in Appendices A and B, respectively.

Tables 4 and 5 present the average value of the calculated E/KAP to the surgeon considering different protective materials and different projection. Analyzing the percentage difference among the average acquired values of E/KAP, it was observed that the use of PPE reduces on average for the two projection from 75% to 79% the values of CC. The addition of UTS, as expected, decreases still further the values of E/KAP up to 7%.

The calculation of the effective dose normalized by KAP, considering the protective equipment, is very useful in hospitals that do not comply with the basic guidelines for radiation protection. This occurs mainly in countries where radiation protection is poor. Thus, it is possible to estimate the effective dose for various realities through of E/KAP and H_T/KAP for surgeons who perform kyphoplasty. E/KAP and H_T/KAP for the surgeon were calculated and are shown in Tables B.1 to B.8 in Appendix B.

4. Conclusion

The construction of a virtual scenario for kyphoplasty procedures allowed the calculation of equivalent and effective doses normalized to KAP. Considering an average over the clinically relevant kVp range of values, the E/KAP was reduced by 56% in AP projection when we compare the complete scenario and the scenarios without the bed. For surgeons, the use of PPE reduces the effective dose on average for the two projection from 75% to 79% and the additional use of the UTS reduces the effective dose up to 7%. This work provides results that show the importance of building real scenarios in computational contexts. When we approximate the real situations by the computational simulations, the calculation of effective dose become closer to the experimentally measured values. The CC provided in this study may be applied for estimating the equivalent and effective doses to surgeon and to patient during kyphoplasty procedures, since the KAP in the radiation beam is known.

Acknowledgements

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Appendix A

See Tables A.1–A.4.

Table A.1
HT/KAP and E/KAP in mSv/Gy cm^2 to patient in complete scenario in anterior-posterior (AP) projection and the statistical uncertainties (%).

Tube voltage (kVp)	60		70		80		90		100		110		120	
Bone Marrow	3.50E−02	0.02%	5.05E−02	0.02%	6.72E−02	0.02%	8.23E−02	0.01%	9.54E−02	0.01%	1.07E−01	0.01%	1.17E−01	0.01%
Colon	2.36E−01	0.03%	2.85E−01	0.03%	3.30E−01	0.03%	3.67E−01	0.03%	3.96E−01	0.03%	4.20E−01	0.03%	4.39E−01	0.03%
Lung	1.50E−03	0.19%	2.28E−03	0.17%	3.13E−03	0.15%	3.92E−03	0.14%	4.60E−03	0.13%	5.20E−03	0.13%	5.72E−03	0.12%
Stomach	1.65E−02	0.21%	2.35E−02	0.19%	3.06E−02	0.17%	3.71E−02	0.16%	4.24E−02	0.15%	4.67E−02	0.15%	5.03E−02	0.14%
Breast	1.62E−02	0.48%	1.92E−02	0.47%	2.18E−02	0.46%	2.38E−02	0.45%	2.55E−02	0.44%	2.68E−02	0.44%	2.77E−02	0.43%
Testicles	1.43E−01	0.15%	1.72E−01	0.14%	1.99E−01	0.14%	2.21E−01	0.14%	2.38E−01	0.13%	2.51E−01	0.13%	2.62E−01	0.13%
Bladder	4.18E−01	0.07%	5.34E−01	0.07%	6.44E−01	0.07%	7.35E−01	0.06%	8.08E−01	0.06%	8.68E−01	0.06%	9.17E−01	0.06%
Oesophagus	1.32E−03	1.41%	2.21E−03	1.16%	3.22E−03	1.01%	4.25E−03	0.90%	5.24E−03	0.83%	6.02E−03	0.78%	6.85E−03	0.74%
Liver	1.25E−02	0.07%	1.79E−02	0.06%	2.35E−02	0.06%	2.85E−02	0.06%	3.28E−02	0.05%	3.63E−02	0.05%	3.93E−02	0.05%
Thyroid	1.75E−03	1.72%	2.30E−03	1.61%	2.97E−03	1.49%	3.31E−03	1.46%	3.68E−03	1.42%	4.09E−03	1.36%	4.39E−03	1.34%
Bone Surface	2.76E−02	0.02%	4.03E−02	0.02%	5.38E−02	0.02%	6.58E−02	0.01%	7.58E−02	0.01%	8.42E−02	0.01%	9.13E−02	0.01%
Brain	1.60E−04	0.72%	2.63E−04	0.61%	3.80E−04	0.53%	4.84E−04	0.49%	5.84E−04	0.46%	6.68E−04	0.44%	7.42E−04	0.42%
Salivary Glands	4.05E−03	0.55%	4.84E−03	0.54%	5.52E−03	0.53%	6.00E−03	0.53%	6.40E−03	0.52%	6.70E−03	0.51%	6.99E−03	0.51%
Skin	6.33E−02	0.02%	6.95E−02	0.02%	7.51E−02	0.02%	7.95E−02	0.02%	8.29E−02	0.02%	8.56E−02	0.02%	8.78E−02	0.02%
Adrenals	7.88E−03	0.98%	1.26E−02	0.82%	1.82E−02	0.72%	2.31E−02	0.65%	2.78E−02	0.61%	3.19E−02	0.57%	3.51E−02	0.55%
Extrathoracic (ET) region	1.46E−03	1.40%	1.99E−03	1.29%	2.47E−03	1.22%	2.85E−03	1.18%	3.21E−03	1.13%	3.43E−03	1.11%	3.60E−03	1.09%
Gall bladder	2.36E−02	0.64%	3.50E−02	0.57%	4.62E−02	0.51%	5.72E−02	0.48%	6.58E−02	0.45%	7.34E−02	0.43%	7.96E−02	0.42%
Heart	4.12E−03	0.28%	5.94E−03	0.25%	7.88E−03	0.23%	9.62E−03	0.21%	1.11E−02	0.20%	1.23E−02	0.20%	1.34E−02	0.19%
Kidneys	2.39E−02	0.12%	3.61E−02	0.11%	4.94E−02	0.10%	6.13E−02	0.09%	7.16E−02	0.08%	8.04E−02	0.08%	8.82E−02	0.08%
Muscle	7.21E−02	0.01%	8.80E−02	0.01%	1.03E−01	0.01%	1.16E−01	0.01%	1.26E−01	0.01%	1.34E−01	0.01%	1.41E−01	0.01%
Oral Mucosa	4.42E−03	0.57%	5.34E−03	0.56%	6.10E−03	0.55%	6.77E−03	0.54%	7.19E−03	0.53%	7.55E−03	0.53%	7.87E−03	0.52%
Pancreas	2.94E−02	0.16%	4.31E−02	0.14%	5.80E−02	0.13%	7.08E−02	0.12%	8.17E−02	0.12%	9.07E−02	0.11%	9.84E−02	0.11%
Protate	2.50E−02	0.13%	3.33E−02	0.12%	4.15E−02	0.11%	4.86E−02	0.10%	5.45E−02	0.10%	5.95E−02	0.10%	6.37E−02	0.09%
Small intestine	3.63E−01	0.02%	4.49E−01	0.02%	5.29E−01	0.02%	5.95E−01	0.02%	6.47E−01	0.02%	6.89E−01	0.02%	7.23E−01	0.02%
Spleen	3.20E−03	1.53%	5.39E−03	1.27%	7.96E−03	1.09%	1.03E−02	1.00%	1.26E−02	0.92%	1.47E−02	0.86%	1.63E−02	0.82%
Thymus	9.28E−04	2.11%	1.42E−03	1.82%	2.01E−03	1.61%	2.52E−03	1.48%	3.03E−03	1.38%	3.27E−03	1.33%	3.68E−03	1.28%
E/KAP	7.20E−02	0.60%	8.99E−02	0.60%	1.07E−01	0.60%	1.22E−01	0.56%	1.33E−01	0.55%	1.43E−01	0.55%	1.51E−01	0.55%

Table A.2
HT/KAP and E/KAP in mSv/Gy cm^2 to patient in complete scenario in latero-lateral (LL) projection and the statistical uncertainties (%).

Tube voltage (kVp)	60		70		80		90		100		110		120	
Bone Marrow	8.31E−02	0.01%	1.10E−01	0.01%	1.39E−01	0.01%	1.64E−01	0.01%	1.85E−01	0.01%	2.03E−01	0.01%	2.18E−01	0.01%
Colon	2.14E−01	0.04%	2.72E−01	0.03%	3.28E−01	0.03%	3.75E−01	0.03%	4.13E−01	0.03%	4.43E−01	0.03%	4.69E−01	0.03%
Lung	4.51E−04	0.34%	7.87E−04	0.28%	1.22E−03	0.24%	1.64E−03	0.21%	2.04E−03	0.20%	2.40E−03	0.18%	2.74E−03	0.17%
Stomach	1.05E−02	0.26%	1.66E−02	0.22%	2.34E−02	0.20%	2.96E−02	0.18%	3.51E−02	0.17%	3.94E−02	0.16%	4.34E−02	0.15%
Breast	2.08E−03	1.33%	2.80E−03	1.22%	3.59E−03	1.13%	4.33E−03	1.06%	4.84E−03	1.02%	5.31E−03	0.98%	5.71E−03	0.95%
Testicles	3.16E−02	0.31%	4.62E−02	0.28%	6.14E−02	0.25%	7.52E−02	0.24%	8.67E−02	0.22%	9.69E−02	0.21%	1.06E−01	0.21%
Bladder	1.57E−01	0.12%	2.30E−01	0.11%	3.08E−01	0.10%	3.77E−01	0.09%	4.34E−01	0.08%	4.82E−01	0.08%	5.24E−01	0.08%
Oesophagus	5.99E−04	2.09%	1.21E−03	1.57%	1.90E−03	1.31%	2.61E−03	1.15%	3.30E−03	1.05%	3.91E−03	0.97%	4.46E−03	0.91%
Liver	3.00E−03	0.15%	5.23E−03	0.12%	7.97E−03	0.10%	1.06E−02	0.09%	1.31E−02	0.09%	1.52E−02	0.08%	1.72E−02	0.08%
Thyroid	5.71E−04	2.98%	8.16E−04	2.67%	1.02E−03	2.52%	1.24E−03	2.37%	1.38E−03	2.29%	1.61E−03	2.18%	1.67E−03	2.14%
Bone Surface	7.17E−02	0.01%	9.60E−02	0.01%	1.21E−01	0.01%	1.41E−01	0.01%	1.58E−01	0.01%	1.72E−01	0.01%	1.83E−01	0.01%
Brain	4.12E−05	1.37%	7.27E−05	1.12%	1.11E−04	0.97%	1.45E−04	0.88%	1.81E−04	0.81%	2.10E−04	0.77%	2.37E−04	0.73%
Salivary Glands	4.99E−04	1.54%	6.74E−04	1.43%	8.52E−04	1.35%	1.01E−03	1.27%	1.12E−03	1.24%	1.19E−03	1.22%	1.28E−03	1.18%
Skin	1.17E−01	0.01%	1.24E−01	0.01%	1.30E−01	0.01%	1.34E−01	0.01%	1.38E−01	0.01%	1.41E−01	0.01%	1.43E−01	0.01%
Adrenals	5.52E−03	1.17%	9.55E−03	0.95%	1.43E−02	0.81%	1.93E−02	0.72%	2.35E−02	0.66%	2.70E−02	0.62%	3.06E−02	0.59%
Extrathoracic (ET) region	4.15E−04	2.60%	5.76E−04	2.36%	7.59E−04	2.19%	8.95E−04	2.07%	1.09E−03	1.94%	1.17E−03	1.89%	1.31E−03	1.81%
Gall bladder	8.52E−03	1.08%	1.42E−02	0.89%	2.12E−02	0.76%	2.77E−02	0.69%	3.32E−02	0.64%	3.87E−02	0.60%	4.30E−02	0.57%
Heart	1.03E−03	0.56%	1.81E−03	0.45%	2.76E−03	0.38%	3.69E−03	0.34%	4.59E−03	0.32%	5.35E−03	0.30%	6.06E−03	0.28%
Kidneys	2.62E−02	0.12%	3.99E−02	0.10%	5.51E−02	0.09%	6.88E−02	0.08%	8.04E−02	0.08%	9.03E−02	0.08%	9.89E−02	0.07%
Muscle	1.25E−01	0.00%	1.47E−01	0.00%	1.67E−01	0.00%	1.84E−01	0.00%	1.98E−01	0.00%	2.08E−01	0.00%	2.17E−01	0.00%
Oral Mucosa	5.50E−04	1.59%	7.50E−04	1.46%	9.83E−04	1.35%	1.15E−03	1.29%	1.31E−03	1.24%	1.42E−03	1.21%	1.50E−03	1.18%
Pancreas	3.75E−02	0.14%	5.61E−02	0.13%	7.59E−02	0.11%	9.33E−02	0.11%	1.08E−01	0.10%	1.20E−01	0.10%	1.30E−01	0.09%
Protate	8.93E−03	0.21%	1.36E−02	0.18%	1.86E−02	0.16%	2.32E−02	0.15%	2.72E−02	0.14%	3.06E−02	0.13%	3.36E−02	0.13%
Small intestine	2.35E−01	0.03%	3.03E−01	0.03%	3.70E−01	0.02%	4.26E−01	0.02%	4.72E−01	0.02%	5.10E−01	0.02%	5.42E−01	0.02%
Spleen	4.64E−03	1.27%	7.92E−03	1.04%	1.16E−02	0.91%	1.51E−02	0.82%	1.84E−02	0.76%	2.11E−02	0.72%	2.34E−02	0.69%
Thymus	2.38E−04	4.14%	3.82E−04	3.47%	5.74E−04	2.99%	8.30E−04	2.60%	9.52E−04	2.45%	1.14E−03	2.27%	1.28E−03	2.15%
E/KAP	5.26E−02	0.54%	6.96E−02	0.53%	8.69E−02	0.52%	1.02E−01	0.50%	1.14E−01	0.48%	1.25E−01	0.48%	1.34E−01	0.48%

Table A.3
HT/KAP and E/KAP in mSv/Gy cm^2 to patient in scenario without bed in anterior-posterior (AP) projection and the statistical uncertainties (%).

Tube voltage (kVp)	60		70		80		90		100		110		120	
Bone Marrow	6.76E−02	0.01%	9.43E−02	0.01%	1.22E−01	0.01%	1.48E−01	0.01%	1.69E−01	0.01%	1.87E−01	0.01%	2.03E−01	0.01%
Colon	4.20E−01	0.03%	4.90E−01	0.03%	5.54E−01	0.03%	6.05E−01	0.03%	6.46E−01	0.02%	6.77E−01	0.02%	7.02E−01	0.02%
Lung	3.29E−04	0.41%	6.31E−04	0.32%	1.02E−03	0.26%	1.44E−03	0.23%	1.83E−03	0.21%	2.18E−03	0.19%	2.52E−03	0.18%
Stomach	1.19E−02	0.24%	1.84E−02	0.21%	2.54E−02	0.19%	3.18E−02	0.17%	3.72E−02	0.16%	4.17E−02	0.16%	4.55E−02	0.15%
Breast	6.93E−04	2.32%	1.07E−03	2.02%	1.37E−03	1.83%	1.78E−03	1.66%	2.10E−03	1.54%	2.44E−03	1.45%	2.79E−03	1.36%
Testicles	1.49E−01	0.14%	1.86E−01	0.14%	2.21E−01	0.13%	2.49E−01	0.13%	2.70E−01	0.13%	2.87E−01	0.12%	3.01E−01	0.12%
Bladder	8.53E−01	0.05%	1.05E+00	0.05%	1.24E+00	0.05%	1.38E+00	0.05%	1.50E+00	0.05%	1.59E+00	0.04%	1.67E+00	0.04%
Oesophagus	8.80E−04	1.74%	1.54E−03	1.39%	2.43E−03	1.17%	3.30E−03	1.02%	4.07E−03	0.94%	4.89E−03	0.87%	5.54E−03	0.82%
Liver	8.09E−03	0.09%	1.28E−02	0.08%	1.80E−02	0.07%	2.29E−02	0.06%	2.70E−02	0.06%	3.06E−02	0.06%	3.36E−02	0.06%
Thyroid	1.39E−04	6.12%	1.92E−04	5.49%	2.43E−04	5.24%	3.08E−04	4.74%	3.72E−04	4.47%	4.18E−04	4.25%	4.72E−04	4.11%
Bone Surface	5.21E−02	0.01%	7.37E−02	0.01%	9.60E−02	0.01%	1.15E−01	0.01%	1.31E−01	0.01%	1.44E−01	0.01%	1.55E−01	0.01%
Brain	1.22E−05	2.56%	2.14E−05	2.09%	3.26E−05	1.79%	4.44E−05	1.60%	5.70E−05	1.45%	6.77E−05	1.36%	7.81E−05	1.28%
Salivary Glands	1.24E−04	3.13%	1.47E−04	3.07%	1.86E−04	2.90%	2.14E−04	2.80%	2.44E−04	2.67%	2.56E−04	2.62%	2.95E−04	2.48%
Skin	1.03E−01	0.01%	1.09E−01	0.01%	1.14E−01	0.01%	1.19E−01	0.01%	1.22E−01	0.01%	1.24E−01	0.01%	1.26E−01	0.01%
Adrenals	9.78E−03	0.88%	1.60E−02	0.73%	2.33E−02	0.63%	3.00E−02	0.58%	3.54E−02	0.54%	4.07E−02	0.51%	4.51E−02	0.49%
Extrathoracic (ET) region	1.05E−04	5.20%	1.44E−04	4.78%	1.90E−04	4.44%	2.52E−04	4.02%	3.13E−04	3.66%	3.48E−04	3.53%	3.65E−04	3.49%
Gall bladder	2.79E−02	0.59%	4.19E−02	0.52%	5.69E−02	0.46%	7.01E−02	0.43%	8.01E−02	0.41%	8.94E−02	0.39%	9.65E−02	0.38%
Heart	8.61E−04	0.62%	1.60E−03	0.49%	2.48E−03	0.41%	3.40E−03	0.36%	4.24E−03	0.33%	5.02E−03	0.31%	5.71E−03	0.29%
Kidneys	4.22E−02	0.09%	6.20E−02	0.08%	8.29E−02	0.07%	1.01E−01	0.07%	1.17E−01	0.07%	1.30E−01	0.06%	1.41E−01	0.06%
Muscle	1.33E−01	0.00%	1.57E−01	0.00%	1.79E−01	0.00%	1.97E−01	0.00%	2.11E−01	0.00%	2.23E−01	0.00%	2.32E−01	0.00%
Oral Mucosa	1.29E−04	3.30%	1.62E−04	3.16%	2.18E−04	2.90%	2.28E−04	2.92%	2.68E−04	2.76%	2.84E−04	2.70%	3.15E−04	2.62%
Pancreas	4.17E−02	0.14%	6.10E−02	0.12%	8.11E−02	0.11%	9.88E−02	0.10%	1.14E−01	0.10%	1.26E−01	0.09%	1.36E−01	0.09%
Protate	4.34E−02	0.10%	5.63E−02	0.09%	6.88E−02	0.08%	7.97E−02	0.08%	8.84E−02	0.08%	9.56E−02	0.08%	1.02E−01	0.07%
Small intestine	7.12E−01	0.02%	8.50E−01	0.01%	9.75E−01	0.01%	1.08E+00	0.01%	1.15E+00	0.01%	1.21E+00	0.01%	1.26E+00	0.01%
Spleen	3.18E−03	0.49%	5.58E−03	0.39%	8.52E−03	0.34%	1.13E−02	0.30%	1.39E−02	0.28%	1.61E−02	0.26%	1.81E−02	0.25%
Thymus	8.57E−05	6.96%	1.60E−04	5.44%	2.58E−04	4.55%	3.85E−04	3.77%	5.17E−04	3.36%	6.48E−04	3.03%	7.43E−04	2.87%
E/KAP	1.18E−01	0.47%	1.44E−01	0.46%	1.69E−01	0.46%	1.90E−01	0.46%	2.06E−01	0.46%	2.19E−01	0.40%	2.30E−01	0.40%

Table A.4
HT/KAP and E/KAP in mSv/Gy cm^2 to patient in scenario without bed in latero-lateral (LL) projection and the statistical uncertainties (%).

Tube voltage (kVp)	60		70		80		90		100		110		120	
Bone Marrow	8.29E−02	0.01%	1.10E−01	0.01%	1.38E−01	0.01%	1.63E−01	0.01%	1.84E−01	0.01%	2.02E−01	0.01%	2.18E−01	0.01%
Colon	2.12E−01	0.04%	2.69E−01	0.04%	3.24E−01	0.03%	3.71E−01	0.03%	4.08E−01	0.03%	4.38E−01	0.03%	4.63E−01	0.03%
Lung	2.68E−04	0.45%	5.04E−04	0.36%	8.21E−04	0.29%	1.15E−03	0.26%	1.45E−03	0.23%	1.75E−03	0.22%	2.03E−03	0.20%
Stomach	9.68E−03	0.27%	1.54E−02	0.23%	2.18E−02	0.20%	2.77E−02	0.19%	3.28E−02	0.17%	3.69E−02	0.17%	4.08E−02	0.16%
Breast	3.12E−04	3.48%	5.45E−04	2.80%	8.37E−04	2.36%	1.11E−03	2.09%	1.37E−03	1.94%	1.62E−03	1.79%	1.87E−03	1.66%
Testicles	2.75E−02	0.34%	4.09E−02	0.30%	5.49E−02	0.27%	6.79E−02	0.25%	7.88E−02	0.24%	8.85E−02	0.22%	9.68E−02	0.22%
Bladder	1.56E−01	0.12%	2.29E−01	0.11%	3.06E−01	0.10%	3.75E−01	0.09%	4.31E−01	0.08%	4.79E−01	0.08%	5.21E−01	0.08%
Oesophagus	5.24E−04	2.24%	1.06E−03	1.68%	1.68E−03	1.40%	2.34E−03	1.22%	2.93E−03	1.11%	3.52E−03	1.02%	4.02E−03	0.96%
Liver	2.53E−03	0.16%	4.52E−03	0.13%	6.99E−03	0.11%	9.42E−03	0.10%	1.16E−02	0.09%	1.36E−02	0.09%	1.55E−02	0.08%
Thyroid	6.12E−05	9.06%	1.12E−04	7.31%	1.42E−04	6.83%	2.20E−04	5.73%	2.50E−04	5.53%	3.21E−04	4.98%	3.22E−04	4.91%
Bone Surface	7.15E−02	0.01%	9.57E−02	0.01%	1.20E−01	0.01%	1.41E−01	0.01%	1.58E−01	0.01%	1.71E−01	0.01%	1.82E−01	0.01%
Brain	1.33E−05	2.41%	2.33E−05	1.98%	3.68E−05	1.68%	4.96E−05	1.50%	6.31E−05	1.38%	7.52E−05	1.29%	8.93E−05	1.20%
Salivary Glands	4.92E−05	4.94%	6.77E−05	4.53%	8.87E−05	4.16%	1.18E−04	3.74%	1.47E−04	3.43%	1.71E−04	3.26%	1.93E−04	3.07%
Skin	1.16E−01	0.01%	1.22E−01	0.01%	1.28E−01	0.01%	1.32E−01	0.01%	1.36E−01	0.01%	1.38E−01	0.01%	1.41E−01	0.01%
Adrenals	5.40E−03	1.18%	9.34E−03	0.96%	1.40E−02	0.82%	1.88E−02	0.73%	2.30E−02	0.67%	2.64E−02	0.63%	2.99E−02	0.60%
Extrathoracic (ET) region	5.38E−05	7.31%	7.61E−05	6.55%	1.23E−04	5.47%	1.70E−04	4.88%	2.06E−04	4.55%	2.31E−04	4.26%	3.03E−04	3.84%
Gall bladder	8.17E−03	1.11%	1.36E−02	0.91%	2.03E−02	0.78%	2.67E−02	0.70%	3.19E−02	0.65%	3.72E−02	0.61%	4.14E−02	0.58%
Heart	6.18E−04	0.73%	1.18E−03	0.57%	1.92E−03	0.47%	2.63E−03	0.41%	3.36E−03	0.37%	3.99E−03	0.34%	4.59E−03	0.32%
Kidneys	2.61E−02	0.12%	3.97E−02	0.10%	5.48E−02	0.09%	6.84E−02	0.08%	7.99E−02	0.08%	8.97E−02	0.08%	9.82E−02	0.07%
Muscle	1.24E−01	0.00%	1.46E−01	0.00%	1.66E−01	0.00%	1.83E−01	0.00%	1.96E−01	0.00%	2.07E−01	0.00%	2.15E−01	0.00%
Oral Mucosa	4.17E−05	5.73%	7.03E−05	4.84%	9.57E−05	4.39%	1.11E−04	4.13%	1.43E−04	3.79%	1.71E−04	3.46%	1.97E−04	3.28%
Pancreas	3.71E−02	0.15%	5.55E−02	0.13%	7.49E−02	0.12%	9.22E−02	0.11%	1.06E−01	0.10%	1.18E−01	0.10%	1.28E−01	0.09%
Protate	8.43E−03	0.22%	1.29E−02	0.19%	1.77E−02	0.17%	2.21E−02	0.15%	2.60E−02	0.14%	2.93E−02	0.14%	3.22E−02	0.13%
Small intestine	2.34E−01	0.03%	3.01E−01	0.03%	3.67E−01	0.02%	4.23E−01	0.02%	4.69E−01	0.02%	5.06E−01	0.02%	5.38E−01	0.02%
Spleen	4.57E−03	0.40%	7.69E−03	0.33%	1.13E−02	0.29%	1.48E−02	0.26%	1.79E−02	0.24%	2.15E−02	0.23%	2.29E−02	0.22%
Thymus	5.60E−05	8.75%	1.12E−04	6.51%	1.91E−04	5.24%	3.34E−04	4.20%	3.75E−04	3.95%	5.20E−04	3.42%	5.86E−04	3.17%
E/KAP	5.15E−02	0.53%	6.82E−02	0.53%	8.51E−02	0.51%	9.98E−02	0.49%	1.12E−01	0.46%	1.22E−01	0.47%	1.31E−01	0.47%

Appendix B

See Tables B.1–B.8.

Table B.1

HT/KAP and E/KAP in μSv/Gy cm^2 to orthopedic surgeon in scenarios with PPE and UTS in anterior-posterior (AP) projection and the statistical uncertainties (%).

Tube voltage (kVp)	60		70		80		90		100		110		120	
Bone Marrow	1.70E−01	0.21%	2.44E−01	0.19%	3.28E−01	0.17%	4.08E−01	0.16%	4.81E−01	0.15%	5.47E−01	0.14%	6.03E−01	0.14%
Colon	3.61E−01	0.89%	4.97E−01	0.81%	6.50E−01	0.74%	7.83E−01	0.70%	9.15E−01	0.66%	1.02E+00	0.63%	1.10E+00	0.61%
Lung	3.43E−01	0.40%	4.73E−01	0.37%	6.04E−01	0.34%	7.17E−01	0.33%	8.22E−01	0.31%	9.11E−01	0.30%	9.85E−01	0.29%
Stomach	4.89E−01	1.20%	7.07E−01	1.07%	9.23E−01	0.98%	1.15E+00	0.91%	1.35E+00	0.85%	1.49E+00	0.82%	1.64E+00	0.79%
Breast	7.18E−02	7.33%	9.59E−02	6.69%	1.22E−01	6.18%	1.67E−01	5.42%	2.47E−01	4.59%	2.49E−01	4.47%	2.91E−01	4.17%
Testicles	7.20E−02	6.43%	1.03E−01	5.71%	1.66E−01	4.84%	2.25E−01	4.29%	3.02E−01	3.76%	3.49E−01	3.53%	4.08E−01	3.30%
Bladder	3.19E−02	8.10%	7.24E−02	5.87%	1.25E−01	4.75%	1.69E−01	4.15%	2.39E−01	3.50%	2.90E−01	3.28%	3.47E−01	3.02%
Oesophagus	4.13E−02	7.89%	9.27E−02	5.73%	1.34E−01	4.98%	1.66E−01	4.52%	2.27E−01	3.97%	2.95E−01	3.55%	3.13E−01	3.42%
Liver	1.82E−02	1.86%	3.47E−02	1.46%	5.70E−02	1.22%	8.63E−02	1.04%	1.15E−01	0.92%	1.42E−01	0.85%	1.65E−01	0.79%
Thyroid	3.12E−02	13.10%	5.54E−02	10.76%	7.59E−02	9.66%	1.06E−01	8.50%	1.49E−01	7.11%	1.54E−01	6.86%	2.03E−01	6.27%
Bone Surface	3.04E−01	0.16%	4.34E−01	0.14%	5.77E−01	0.13%	7.07E−01	0.12%	8.20E−01	0.11%	9.17E−01	0.11%	1.00E+00	0.11%
Brain	6.92E−02	1.10%	1.17E−01	0.92%	1.75E−01	0.79%	2.36E−01	0.71%	2.92E−01	0.66%	3.44E−01	0.61%	3.87E−01	0.59%
Salivary Glands	8.72E−02	3.72%	1.24E−01	3.37%	1.69E−01	3.02%	2.06E−01	2.82%	2.35E−01	2.69%	2.82E−01	2.51%	3.19E−01	2.38%
Skin	1.00E+00	0.14%	1.19E+00	0.14%	1.36E+00	0.13%	1.51E+00	0.13%	1.62E+00	0.13%	1.72E+00	0.13%	1.80E+00	0.13%
Adrenals	1.36E−01	7.39%	2.22E−01	6.18%	2.95E−01	5.67%	3.76E−01	5.12%	5.32E−01	4.60%	5.40E−01	4.46%	6.01E−01	4.27%
Extrathoracic (ET) region	4.74E−02	7.86%	8.02E−02	6.57%	1.22E−01	5.51%	1.62E−01	4.83%	2.11E−01	4.41%	2.38E−01	4.19%	2.79E−01	3.85%
Gall bladder	1.75E−02	23.15%	4.08E−02	16.93%	7.66E−02	12.33%	7.40E−02	12.12%	1.31E−01	10.02%	1.61E−01	8.96%	1.65E−01	8.99%
Heart	1.33E−01	1.56%	2.06E−01	1.34%	2.94E−01	1.18%	3.92E−01	1.06%	4.72E−01	0.98%	5.49E−01	0.93%	6.03E−01	0.89%
Kidneys	1.94E−01	1.36%	2.88E−01	1.20%	4.03E−01	1.07%	5.09E−01	0.98%	5.99E−01	0.92%	6.92E−01	0.87%	7.62E−01	0.84%
Muscle	5.71E−01	0.07%	7.28E−01	0.07%	8.87E−01	0.06%	1.03E+00	0.06%	1.14E+00	0.06%	1.24E+00	0.06%	1.32E+00	0.06%
Oral Mucosa	3.37E−02	6.48%	5.95E−02	5.30%	7.84E−02	4.86%	1.07E−01	4.26%	1.47E−01	3.81%	1.64E−01	3.60%	1.95E−01	3.38%
Pancreas	4.62E−01	1.29%	6.58E−01	1.16%	8.88E−01	1.05%	1.08E+00	0.98%	1.28E+00	0.92%	1.43E+00	0.88%	1.53E+00	0.86%
Protate	7.92E−01	0.68%	1.01E+00	0.65%	1.21E+00	0.62%	1.37E+00	0.60%	1.53E+00	0.58%	1.65E+00	0.57%	1.74E+00	0.55%
Small intestine	9.74E−02	1.29%	1.50E−01	1.12%	2.28E−01	0.96%	3.04E−01	0.86%	3.92E−01	0.77%	4.70E−01	0.72%	5.22E−01	0.68%
Spleen	7.29E−01	1.01%	1.06E+00	0.90%	1.36E+00	0.84%	1.66E+00	0.78%	1.88E+00	0.75%	2.12E+00	0.72%	2.28E+00	0.70%
Thymus	4.01E−02	10.02%	6.99E−02	8.32%	1.13E−01	6.72%	1.34E−01	6.33%	1.94E−01	5.44%	2.07E−01	5.34%	2.50E−01	4.87%
E/KAP	2.30E−01	8.99%	3.25E−01	8.59%	4.27E−01	8.10%	5.25E−01	7.50%	6.26E−01	7.54%	6.97E−01	7.10%	7.65E−01	6.91%

Table B.2

HT/KAP and E/KAP in μSv/Gy cm^2 to orthopedic surgeon in scenarios with PPE and with UTS in latero-lateral (LL) projection and the statistical uncertainties (%).

Tube voltage (kVp)	60		70		80		90		100		110		120	
Bone Marrow	2.12E−02	0.55%	3.79E−02	0.44%	6.07E−02	0.37%	8.44E−02	0.32%	1.09E−01	0.29%	1.32E−01	0.27%	1.55E−01	0.26%
Colon	2.82E−02	3.18%	4.87E−02	2.59%	7.50E−02	2.20%	9.91E−02	1.96%	1.28E−01	1.77%	1.53E−01	1.63%	1.80E−01	1.52%
Lung	2.55E−02	1.46%	4.75E−02	1.16%	7.70E−02	0.96%	1.07E−01	0.85%	1.38E−01	0.76%	1.66E−01	0.71%	1.95E−01	0.66%
Stomach	3.42E−02	4.48%	6.50E−02	3.50%	1.07E−01	2.90%	1.44E−01	2.56%	1.93E−01	2.26%	2.24E−01	2.14%	2.58E−01	1.97%
Breast	9.82E−03	19.68%	1.72E−02	15.63%	2.33E−02	13.94%	3.79E−02	11.21%	5.25E−02	10.07%	7.55E−02	8.29%	7.84E−02	7.87%
Testicles	1.53E−02	13.70%	3.10E−02	10.66%	5.78E−02	8.27%	7.27E−02	7.80%	9.20E−02	6.69%	1.20E−01	5.93%	1.24E−01	5.80%
Bladder	5.21E−03	20.89%	1.30E−02	14.43%	2.33E−02	10.97%	3.21E−02	9.57%	4.66E−02	8.03%	6.69E−02	6.95%	7.87E−02	6.23%
Oesophagus	5.83E−03	20.85%	1.46E−02	14.31%	2.07E−02	12.32%	3.55E−02	10.22%	4.24E−02	9.13%	6.22E−02	7.52%	7.13E−02	7.27%
Liver	2.02E−03	5.57%	4.25E−03	4.14%	8.39E−03	3.16%	1.34E−02	2.60%	2.00E−02	2.20%	2.65E−02	1.96%	3.53E−02	1.73%
Thyroid	1.78E−02	16.74%	2.87E−02	14.33%	5.92E−02	10.82%	6.26E−02	10.96%	9.83E−02	8.59%	1.31E−01	7.99%	1.53E−01	7.49%
Bone Surface	5.20E−02	0.39%	8.80E−02	0.32%	1.35E−01	0.27%	1.82E−01	0.24%	2.28E−01	0.22%	2.70E−01	0.21%	3.09E−01	0.19%
Brain	7.08E−02	1.09%	1.21E−01	0.91%	1.87E−01	0.77%	2.51E−01	0.69%	3.18E−01	0.63%	3.75E−01	0.59%	4.28E−01	0.56%
Salivary Glands	7.07E−02	4.18%	1.16E−01	3.56%	1.53E−01	3.18%	1.85E−01	3.01%	2.25E−01	2.78%	2.54E−01	2.65%	2.77E−01	2.58%
Skin	1.24E−01	0.40%	1.75E−01	0.36%	2.37E−01	0.32%	2.92E−01	0.30%	3.44E−01	0.28%	3.90E−01	0.27%	4.31E−01	0.26%
Adrenals	6.15E−03	33.49%	2.25E−02	18.69%	3.64E−02	15.70%	4.70E−02	14.13%	5.85E−02	12.30%	7.28E−02	11.86%	1.01E−01	10.36%
Extrathoracic (ET) region	6.09E−02	6.88%	1.15E−01	5.50%	1.47E−01	5.03%	2.01E−01	4.42%	2.37E−01	4.10%	2.85E−01	3.79%	3.16E−01	3.65%
Gall bladder	2.26E−03	65.81%	5.07E−03	45.15%	1.37E−02	30.06%	1.30E−02	29.80%	2.28E−02	23.72%	4.63E−02	18.17%	3.38E−02	19.80%
Heart	1.11E−02	5.30%	2.52E−02	3.84%	4.17E−02	3.16%	6.44E−02	2.62%	8.84E−02	2.28%	1.10E−01	2.06%	1.29E−01	1.91%
Kidneys	1.36E−02	5.14%	2.68E−02	3.91%	3.91E−02	3.39%	6.44E−02	2.75%	8.20E−02	2.50%	1.00E−01	2.29%	1.20E−01	2.11%
Muscle	6.14E−02	0.21%	9.60E−02	0.19%	1.39E−01	0.17%	1.81E−01	0.15%	2.19E−01	0.14%	2.56E−01	0.13%	2.89E−01	0.13%
Oral Mucosa	2.96E−02	7.02%	4.70E−02	6.08%	6.76E−02	5.19%	9.88E−02	4.50%	1.28E−01	4.08%	1.47E−01	3.79%	1.75E−01	3.50%
Pancreas	3.19E−02	4.90%	5.88E−02	3.88%	9.74E−02	3.16%	1.34E−01	2.79%	1.79E−01	2.50%	2.08E−01	2.31%	2.51E−01	2.13%
Protate	7.73E−02	2.20%	1.21E−01	1.87%	1.74E−01	1.64%	2.22E−01	1.50%	2.75E−01	1.37%	3.18E−01	1.29%	3.66E−01	1.21%
Small intestine	1.03E−02	3.93%	2.04E−02	3.06%	3.28E−02	2.54%	4.77E−02	2.18%	5.98E−02	1.97%	8.17E−02	1.73%	9.68E−02	1.60%
Spleen	4.11E−02	4.24%	8.39E−02	3.19%	1.38E−01	2.64%	1.95E−01	2.31%	2.42E−01	2.09%	2.93E−01	1.93%	3.34E−01	1.82%
Thymus	9.03E−03	21.44%	1.80E−02	16.40%	3.11E−02	12.58%	3.77E−02	11.44%	6.09E−02	9.64%	7.19E−02	9.35%	8.29E−02	8.33%
E/KAP	2.34E−02	36.71%	4.23E−02	30.68%	6.70E−02	25.58%	9.04E−02	22.19%	1.18E−01	19.76%	1.44E−01	18.99%	1.65E−01	17.57%

Table B.3
HT/KAP and E/KAP in μSv/Gy cm^2 to orthopedic surgeon in scenarios without PPE and with UTS in anterior-posterior (AP) projection and the statistical uncertainties (%).

Tube voltage (kVp)	60		70		80		90		100		110		120	
Bone Marrow	3.28E−01	0.16%	4.79E−01	0.14%	6.49E−01	0.13%	8.05E−01	0.12%	9.45E−01	0.11%	1.07E+00	0.11%	1.18E+00	0.10%
Colon	2.31E+00	0.35%	2.97E+00	0.33%	3.55E+00	0.32%	4.05E+00	0.31%	4.45E+00	0.30%	4.76E+00	0.29%	4.99E+00	0.29%
Lung	5.16E−01	0.33%	7.27E−01	0.30%	9.45E−01	0.27%	1.13E+00	0.26%	1.30E+00	0.25%	1.44E+00	0.24%	1.57E+00	0.23%
Stomach	2.02E+00	0.59%	2.70E+00	0.55%	3.37E+00	0.51%	3.97E+00	0.49%	4.46E+00	0.47%	4.80E+00	0.46%	5.14E+00	0.45%
Breast	1.35E+00	1.67%	1.69E+00	1.58%	2.02E+00	1.51%	2.37E+00	1.44%	2.61E+00	1.39%	2.80E+00	1.35%	3.02E+00	1.31%
Testicles	2.33E+00	1.13%	2.93E+00	1.08%	3.48E+00	1.05%	3.99E+00	1.01%	4.38E+00	0.98%	4.62E+00	0.97%	4.84E+00	0.95%
Bladder	6.62E−01	1.81%	9.83E−01	1.58%	1.32E+00	1.43%	1.63E+00	1.33%	1.89E+00	1.26%	2.09E+00	1.22%	2.30E+00	1.16%
Oesophagus	1.65E−01	3.98%	2.88E−01	3.22%	4.25E−01	2.77%	5.45E−01	2.52%	6.79E−01	2.30%	7.94E−01	2.15%	9.03E−01	2.03%
Liver	4.95E−01	0.36%	7.01E−01	0.33%	9.19E−01	0.30%	1.11E+00	0.29%	1.27E+00	0.27%	1.41E+00	0.27%	1.53E+00	0.26%
Thyroid	4.85E−01	3.32%	7.17E−01	2.96%	9.19E−01	2.75%	1.10E+00	2.59%	1.32E+00	2.42%	1.48E+00	2.30%	1.62E+00	2.23%
Bone Surface	4.42E−01	0.13%	6.45E−01	0.12%	8.68E−01	0.11%	1.07E+00	0.10%	1.25E+00	0.09%	1.40E+00	0.09%	1.52E+00	0.09%
Brain	1.48E−01	0.76%	2.38E−01	0.65%	3.44E−01	0.57%	4.48E−01	0.52%	5.39E−01	0.48%	6.27E−01	0.46%	7.01E−01	0.44%
Salivary Glands	9.32E−01	1.16%	1.17E+00	1.10%	1.43E+00	1.05%	1.63E+00	1.01%	1.81E+00	0.98%	1.99E+00	0.95%	2.13E+00	0.93%
Skin	1.75E+00	0.11%	2.07E+00	0.10%	2.37E+00	0.10%	2.62E+00	0.10%	2.81E+00	0.10%	2.96E+00	0.10%	3.08E+00	0.10%
Adrenals	3.43E−01	4.64%	5.53E−01	3.91%	7.76E−01	3.49%	9.49E−01	3.20%	1.19E+00	3.00%	1.31E+00	2.83%	1.43E+00	2.72%
Extrathoracic (ET) region	3.93E−01	2.77%	5.82E−01	2.45%	7.47E−01	2.25%	9.37E−01	2.08%	1.10E+00	1.98%	1.22E+00	1.89%	1.36E+00	1.81%
Gall bladder	4.03E−01	4.95%	6.13E−01	4.21%	8.11E−01	3.78%	1.01E+00	3.57%	1.20E+00	3.32%	1.36E+00	3.18%	1.48E+00	2.98%
Heart	6.75E−01	0.69%	9.66E−01	0.62%	1.29E+00	0.57%	1.60E+00	0.53%	1.82E+00	0.50%	2.03E+00	0.48%	2.21E+00	0.46%
Kidneys	3.56E−01	1.00%	5.43E−01	0.87%	7.72E−01	0.77%	9.63E−01	0.71%	1.13E+00	0.67%	1.29E+00	0.64%	1.43E+00	0.61%
Muscle	1.03E+00	0.05%	1.33E+00	0.05%	1.63E+00	0.05%	1.89E+00	0.05%	2.09E+00	0.05%	2.26E+00	0.04%	2.40E+00	0.04%
Oral Mucosa	9.15E−01	1.27%	1.19E+00	1.19%	1.45E+00	1.13%	1.70E+00	1.09%	1.93E+00	1.04%	2.10E+00	1.01%	2.23E+00	0.99%
Pancreas	1.21E+00	0.80%	1.69E+00	0.72%	2.25E+00	0.66%	2.67E+00	0.62%	3.09E+00	0.59%	3.39E+00	0.57%	3.63E+00	0.56%
Protate	9.86E−01	0.61%	1.28E+00	0.58%	1.56E+00	0.55%	1.79E+00	0.53%	2.00E+00	0.51%	2.17E+00	0.49%	2.30E+00	0.48%
Small intestine	1.40E+00	0.34%	1.89E+00	0.32%	2.40E+00	0.30%	2.82E+00	0.28%	3.15E+00	0.27%	3.46E+00	0.26%	3.69E+00	0.26%
Spleen	8.92E−01	0.91%	1.31E+00	0.81%	1.70E+00	0.75%	2.09E+00	0.70%	2.38E+00	0.67%	2.68E+00	0.64%	2.90E+00	0.62%
Thymus	2.19E−01	4.40%	3.18E−01	3.90%	4.85E−01	3.31%	6.16E−01	3.04%	7.63E−01	2.76%	8.53E−01	2.62%	9.81E−01	2.48%
E/KAP	1.16E+00	4.89%	1.53E+00	4.65%	1.90E+00	4.46%	2.22E+00	4.31%	2.49E+00	4.22%	2.70E+00	4.13%	2.88E+00	4.03%

Table B.4
HT/KAP and E/KAP in μSv/Gy cm^2 to orthopedic surgeon in scenarios without PPE and with UTS in latero-lateral (LL) projection and the statistical uncertainties (%).

Tube voltage (kVp)	60		70		80		90		100		110		120	
Bone Marrow	4.72E−02	0.41%	8.36E−02	0.33%	1.31E−01	0.28%	1.79E−01	0.24%	2.27E−01	0.22%	2.73E−01	0.20%	3.17E−01	0.19%
Colon	2.22E−01	1.12%	3.29E−01	0.98%	4.52E−01	0.88%	5.70E−01	0.81%	6.67E−01	0.77%	7.61E−01	0.73%	8.48E−01	0.70%
Lung	6.12E−02	0.94%	1.10E−01	0.76%	1.72E−01	0.64%	2.32E−01	0.57%	2.93E−01	0.52%	3.51E−01	0.48%	4.05E−01	0.46%
Stomach	1.38E−01	2.23%	2.41E−01	1.82%	3.62E−01	1.56%	4.85E−01	1.39%	6.05E−01	1.27%	6.96E−01	1.20%	7.94E−01	1.13%
Breast	2.06E−01	4.20%	3.31E−01	3.61%	4.60E−01	3.20%	5.75E−01	2.91%	6.84E−01	2.72%	7.90E−01	2.53%	8.57E−01	2.46%
Testicles	3.81E−01	2.83%	5.73E−01	2.48%	7.46E−01	2.27%	9.20E−01	2.11%	1.05E+00	2.02%	1.23E+00	1.90%	1.36E+00	1.82%
Bladder	8.19E−02	5.11%	1.44E−01	4.12%	2.11E−01	3.55%	2.78E−01	3.22%	3.71E−01	2.84%	4.33E−01	2.66%	5.14E−01	2.48%
Oesophagus	2.88E−02	9.51%	5.91E−02	7.05%	1.01E−01	5.73%	1.39E−01	5.10%	1.85E−01	4.39%	2.20E−01	4.08%	2.51E−01	3.85%
Liver	4.34E−02	1.19%	7.39E−02	0.99%	1.16E−01	0.84%	1.57E−01	0.75%	1.97E−01	0.69%	2.34E−01	0.64%	2.69E−01	0.61%
Thyroid	2.81E−01	4.39%	4.33E−01	3.80%	5.98E−01	3.38%	7.66E−01	3.12%	9.21E−01	2.90%	1.07E+00	2.72%	1.14E+00	2.64%
Bone Surface	7.70E−02	0.32%	1.32E−01	0.26%	2.04E−01	0.22%	2.75E−01	0.20%	3.43E−01	0.18%	4.08E−01	0.17%	4.67E−01	0.16%
Brain	8.12E−02	1.02%	1.41E−01	0.84%	2.19E−01	0.71%	2.97E−01	0.63%	3.76E−01	0.58%	4.46E−01	0.54%	5.10E−01	0.51%
Salivary Glands	2.55E−01	2.23%	3.93E−01	1.93%	5.62E−01	1.69%	6.85E−01	1.57%	8.46E−01	1.45%	9.45E−01	1.38%	1.04E+00	1.32%
Skin	2.39E−01	0.28%	3.34E−01	0.26%	4.40E−01	0.24%	5.36E−01	0.22%	6.23E−01	0.21%	6.98E−01	0.20%	7.66E−01	0.19%
Adrenals	2.44E−02	17.16%	4.96E−02	12.59%	8.68E−02	10.35%	1.17E−01	9.05%	1.35E−01	8.45%	1.79E−01	7.37%	2.19E−01	7.08%
Extrathoracic (ET) region	2.32E−01	3.58%	4.12E−01	2.93%	5.17E−01	2.73%	6.49E−01	2.51%	8.19E−01	2.27%	9.43E−01	2.13%	1.05E+00	2.05%
Gall bladder	4.33E−02	15.01%	5.68E−02	13.39%	9.95E−02	10.90%	1.34E−01	9.97%	2.03E−01	8.07%	2.60E−01	7.47%	2.78E−01	7.18%
Heart	7.80E−02	2.03%	1.39E−01	1.63%	2.17E−01	1.38%	3.11E−01	1.19%	3.90E−01	1.08%	4.69E−01	1.00%	5.38E−01	0.94%
Kidneys	2.88E−02	3.50%	5.50E−02	2.73%	8.34E−02	2.32%	1.27E−01	1.95%	1.63E−01	1.76%	1.98E−01	1.62%	2.33E−01	1.51%
Muscle	1.29E−01	0.15%	1.99E−01	0.13%	2.83E−01	0.12%	3.63E−01	0.11%	4.34E−01	0.10%	5.00E−01	0.10%	5.61E−01	0.09%
Oral Mucosa	2.70E−01	2.34%	4.43E−01	1.97%	5.98E−01	1.78%	7.76E−01	1.61%	9.42E−01	1.49%	1.07E+00	1.41%	1.25E+00	1.32%
Pancreas	8.76E−02	2.94%	1.57E−01	2.36%	2.50E−01	1.97%	3.37E−01	1.75%	4.28E−01	1.60%	4.89E−01	1.50%	5.79E−01	1.40%
Protate	1.24E−01	1.74%	1.91E−01	1.49%	2.74E−01	1.31%	3.46E−01	1.20%	4.28E−01	1.10%	4.83E−01	1.04%	5.59E−01	0.98%
Small intestine	1.37E−01	1.09%	2.21E−01	0.92%	3.16E−01	0.81%	4.06E−01	0.74%	4.96E−01	0.69%	5.76E−01	0.64%	6.43E−01	0.61%
Spleen	5.65E−02	3.60%	1.15E−01	2.72%	1.89E−01	2.25%	2.67E−01	1.96%	3.35E−01	1.77%	4.01E−01	1.64%	4.58E−01	1.55%
Thymus	6.26E−02	8.09%	1.27E−01	6.15%	2.02E−01	5.13%	2.76E−01	4.48%	3.68E−01	3.98%	4.15E−01	3.77%	4.76E−01	3.57%
E/KAP	1.48E−01	17.00%	2.37E−01	14.49%	3.35E−01	12.78%	4.31E−01	11.65%	5.21E−01	10.90%	6.06E−01	10.28%	6.78E−01	9.78%

Table B.5
HT/KAP and E/KAP in μSv/Gy cm^2 to orthopedic surgeon in scenarios with PPE and without UTS in anterior-posterior (AP) projection and the statistical uncertainties (%).

Tube voltage (kVp)	60		70		80		90		100		110		120	
Bone Marrow	1.71E−01	0.21%	2.45E−01	0.19%	3.30E−01	0.17%	4.10E−01	0.16%	4.85E−01	0.15%	5.51E−01	0.14%	6.08E−01	0.14%
Colon	3.62E−01	0.88%	4.99E−01	0.81%	6.53E−01	0.74%	7.87E−01	0.70%	9.19E−01	0.66%	1.03E+00	0.63%	1.11E+00	0.61%
Lung	3.44E−01	0.40%	4.73E−01	0.37%	6.05E−01	0.34%	7.19E−01	0.33%	8.24E−01	0.31%	9.13E−01	0.30%	9.89E−01	0.29%
Stomach	4.90E−01	1.20%	7.07E−01	1.07%	9.24E−01	0.98%	1.15E+00	0.91%	1.35E+00	0.85%	1.50E+00	0.82%	1.64E+00	0.79%
Breast	7.18E−02	7.33%	9.60E−02	6.69%	1.22E−01	6.16%	1.67E−01	5.41%	2.47E−01	4.58%	2.49E−01	4.47%	2.91E−01	4.17%
Testicles	9.23E−02	5.66%	1.34E−01	5.04%	2.06E−01	4.33%	2.74E−01	3.86%	3.51E−01	3.48%	4.07E−01	3.26%	4.70E−01	3.08%
Bladder	3.37E−02	7.91%	7.57E−02	5.73%	1.30E−01	4.66%	1.75E−01	4.06%	2.48E−01	3.44%	3.00E−01	3.23%	3.59E−01	2.97%
Oesophagus	4.15E−02	7.86%	9.30E−02	5.72%	1.35E−01	4.97%	1.67E−01	4.50%	2.28E−01	3.96%	2.96E−01	3.55%	3.14E−01	3.42%
Liver	1.85E−02	1.85%	3.53E−02	1.45%	5.81E−02	1.20%	8.76E−02	1.03%	1.16E−01	0.91%	1.44E−01	0.84%	1.67E−01	0.79%
Thyroid	3.12E−02	13.10%	5.55E−02	10.75%	7.59E−02	9.66%	1.06E−01	8.50%	1.50E−01	7.09%	1.55E−01	6.84%	2.04E−01	6.24%
Bone Surface	7.87E−01	0.12%	1.07E+00	0.11%	1.36E+00	0.10%	1.62E+00	0.10%	1.83E+00	0.09%	2.00E+00	0.09%	2.14E+00	0.09%
Brain	6.95E−02	1.10%	1.17E−01	0.91%	1.75E−01	0.79%	2.37E−01	0.71%	2.93E−01	0.66%	3.45E−01	0.61%	3.88E−01	0.59%
Salivary Glands	8.75E−02	3.71%	1.25E−01	3.36%	1.70E−01	3.01%	2.07E−01	2.81%	2.37E−01	2.68%	2.84E−01	2.50%	3.20E−01	2.38%
Skin	1.66E+00	0.11%	1.92E+00	0.11%	2.16E+00	0.11%	2.36E+00	0.11%	2.51E+00	0.10%	2.63E+00	0.10%	2.72E+00	0.10%
Adrenals	1.36E−01	7.39%	2.22E−01	6.18%	2.96E−01	5.66%	3.80E−01	5.09%	5.35E−01	4.59%	5.43E−01	4.45%	6.04E−01	4.25%
Extrathoracic (ET) region	4.76E−02	7.83%	8.06E−02	6.56%	1.23E−01	5.49%	1.62E−01	4.83%	2.11E−01	4.41%	2.38E−01	4.19%	2.80E−01	3.85%
Gall bladder	1.75E−02	23.15%	4.08E−02	16.93%	7.80E−02	12.24%	7.40E−02	12.12%	1.33E−01	9.95%	1.62E−01	8.93%	1.65E−01	8.98%
Heart	1.33E−01	1.56%	2.06E−01	1.34%	2.94E−01	1.18%	3.92E−01	1.06%	4.73E−01	0.98%	5.50E−01	0.93%	6.04E−01	0.89%
Kidneys	1.95E−01	1.36%	2.90E−01	1.19%	4.05E−01	1.06%	5.12E−01	0.98%	6.02E−01	0.92%	6.96E−01	0.87%	7.67E−01	0.83%
Muscle	9.03E−01	0.06%	1.12E+00	0.05%	1.33E+00	0.05%	1.51E+00	0.05%	1.66E+00	0.05%	1.78E+00	0.05%	1.88E+00	0.05%
Oral Mucosa	3.38E−02	6.46%	5.98E−02	5.28%	7.87E−02	4.85%	1.07E−01	4.25%	1.47E−01	3.81%	1.65E−01	3.59%	1.95E−01	3.38%
Pancreas	4.62E−01	1.29%	6.59E−01	1.16%	8.89E−01	1.05%	1.08E+00	0.98%	1.28E+00	0.92%	1.44E+00	0.88%	1.53E+00	0.86%
Protate	1.50E+00	0.49%	1.82E+00	0.48%	2.13E+00	0.47%	2.36E+00	0.46%	2.56E+00	0.45%	2.73E+00	0.44%	2.85E+00	0.43%
Small intestine	9.79E−02	1.29%	1.52E−01	1.11%	2.29E−01	0.95%	3.07E−01	0.86%	3.95E−01	0.77%	4.74E−01	0.72%	5.27E−01	0.68%
Spleen	7.30E−01	1.01%	1.06E+00	0.90%	1.37E+00	0.83%	1.66E+00	0.78%	1.89E+00	0.75%	2.12E+00	0.72%	2.28E+00	0.70%
Thymus	4.06E−02	9.97%	6.99E−02	8.32%	1.13E−01	6.72%	1.34E−01	6.33%	1.94E−01	5.44%	2.07E−01	5.34%	2.51E−01	4.86%
E/KAP	2.54E−01	8.46%	3.54E−01	8.13%	4.61E−01	7.71%	5.63E−01	7.17%	6.66E−01	7.22%	7.40E−01	6.82%	8.11E−01	6.64%

Table B.6
HT/KAP and E/KAP in μSv/Gy cm^2 to orthopedic surgeon in scenarios with PPE and without UTS in latero-lateral (LL) projection and the statistical uncertainties (%).

Tube voltage (kVp)	60		70		80		90		100		110		120	
Bone Marrow	2.13E−02	0.55%	3.81E−02	0.44%	6.11E−02	0.37%	8.49E−02	0.32%	1.10E−01	0.29%	1.33E−01	0.27%	1.56E−01	0.25%
Colon	2.83E−02	3.17%	4.91E−02	2.58%	7.55E−02	2.19%	9.97E−02	1.96%	1.29E−01	1.77%	1.55E−01	1.63%	1.82E−01	1.52%
Lung	2.56E−02	1.46%	4.77E−02	1.16%	7.73E−02	0.96%	1.07E−01	0.85%	1.39E−01	0.76%	1.67E−01	0.71%	1.95E−01	0.66%
Stomach	3.43E−02	4.48%	6.51E−02	3.49%	1.08E−01	2.89%	1.44E−01	2.56%	1.85E−01	2.44%	2.22E−01	2.19%	2.59E−01	1.97%
Breast	9.82E−03	19.68%	1.72E−02	15.63%	2.33E−02	13.94%	3.79E−02	11.21%	5.26E−02	10.06%	7.55E−02	8.29%	7.85E−02	7.86%
Testicles	1.66E−02	13.06%	3.35E−02	10.17%	6.42E−02	7.86%	7.69E−02	7.51%	1.01E−01	6.43%	1.28E−01	5.71%	1.35E−01	5.60%
Bladder	5.55E−03	20.05%	1.32E−02	14.27%	2.41E−02	10.71%	3.41E−02	9.27%	5.11E−02	7.71%	6.97E−02	6.80%	8.17E−02	6.12%
Oesophagus	5.83E−03	20.85%	1.46E−02	14.31%	2.11E−02	12.24%	3.55E−02	10.22%	4.24E−02	9.12%	6.24E−02	7.50%	7.15E−02	7.25%
Liver	2.05E−03	5.52%	4.30E−03	4.11%	8.52E−03	3.13%	1.36E−02	2.57%	2.04E−02	2.18%	2.68E−02	1.94%	3.57E−02	1.72%
Thyroid	1.78E−02	16.74%	2.87E−02	14.33%	5.92E−02	10.82%	6.26E−02	10.96%	9.83E−02	8.59%	1.31E−01	7.99%	1.53E−01	7.49%
Bone Surface	1.06E−01	0.31%	1.70E−01	0.26%	2.48E−01	0.22%	3.25E−01	0.20%	3.98E−01	0.19%	4.64E−01	0.17%	5.20E−01	0.17%
Brain	7.08E−02	1.09%	1.21E−01	0.91%	1.87E−01	0.77%	2.52E−01	0.69%	3.18E−01	0.63%	3.75E−01	0.59%	4.28E−01	0.56%
Salivary Glands	7.07E−02	4.18%	1.16E−01	3.56%	1.53E−01	3.18%	1.85E−01	3.01%	2.25E−01	2.78%	2.54E−01	2.65%	2.77E−01	2.58%
Skin	1.83E−01	0.33%	2.55E−01	0.30%	3.35E−01	0.27%	4.10E−01	0.25%	4.77E−01	0.24%	5.35E−01	0.23%	5.88E−01	0.22%
Adrenals	6.15E−03	33.49%	2.25E−02	18.68%	3.64E−02	15.70%	4.70E−02	14.13%	5.85E−02	12.29%	7.28E−02	11.86%	1.01E−01	10.35%
Extrathoracic (ET) region	6.09E−02	6.88%	1.15E−01	5.50%	1.47E−01	5.03%	2.01E−01	4.42%	2.37E−01	4.10%	2.85E−01	3.78%	3.16E−01	3.65%
Gall bladder	2.26E−03	65.81%	5.07E−03	45.15%	1.37E−02	30.06%	1.32E−02	29.46%	2.28E−02	23.72%	4.68E−02	18.00%	3.40E−02	19.68%
Heart	1.12E−02	5.29%	2.52E−02	3.83%	4.17E−02	3.16%	6.44E−02	2.62%	8.86E−02	2.28%	1.10E−01	2.06%	1.29E−01	1.91%
Kidneys	1.37E−02	5.13%	2.72E−02	3.88%	3.94E−02	3.38%	6.47E−02	2.74%	8.29E−02	2.49%	1.01E−01	2.29%	1.22E−01	2.10%
Muscle	9.25E−02	0.17%	1.39E−01	0.15%	1.94E−01	0.14%	2.48E−01	0.13%	2.97E−01	0.12%	3.42E−01	0.11%	3.83E−01	0.11%
Oral Mucosa	2.96E−02	7.02%	4.70E−02	6.08%	6.76E−02	5.18%	9.90E−02	4.50%	1.28E−01	4.08%	1.47E−01	3.79%	1.75E−01	3.50%
Pancreas	3.20E−02	4.90%	5.89E−02	3.88%	9.77E−02	3.16%	1.34E−01	2.79%	1.79E−01	2.50%	2.08E−01	2.30%	2.51E−01	2.13%
Protate	1.39E−01	1.64%	2.06E−01	1.44%	2.81E−01	1.29%	3.46E−01	1.20%	4.20E−01	1.11%	4.76E−01	1.05%	5.42E−01	0.99%
Small intestine	1.05E−02	3.90%	2.07E−02	3.04%	3.31E−02	2.53%	4.83E−02	2.17%	6.05E−02	1.96%	8.26E−02	1.72%	9.78E−02	1.59%
Spleen	4.11E−02	4.24%	8.46E−02	3.18%	1.39E−01	2.64%	1.96E−01	2.31%	2.43E−01	2.08%	2.94E−01	1.93%	3.35E−01	1.81%
Thymus	9.03E−03	21.44%	1.80E−02	16.40%	3.11E−02	12.58%	3.77E−02	11.44%	6.09E−02	9.64%	7.24E−02	9.31%	8.36E−02	8.31%
E/KAP	2.57E−02	34.17%	4.55E−02	28.95%	7.15E−02	24.32%	9.56E−02	21.22%	1.23E−01	21.93%	1.51E−01	20.57%	1.73E−01	16.94%

Table B.7
HT/KAP and E/KAP in μSv/Gy cm^2 to orthopedic surgeon in scenarios without PPE and without UTS in anterior-posterior (AP) projection and the statistical uncertainties (%).

Tube voltage (kVp)	60		70		80		90		100		110		120	
Bone Marrow	3.30E−01	0.16%	4.82E−01	0.14%	6.53E−01	0.13%	8.12E−01	0.12%	9.53E−01	0.11%	1.08E+00	0.11%	1.19E+00	0.10%
Colon	2.32E+00	0.35%	2.98E+00	0.33%	3.57E+00	0.32%	4.07E+00	0.31%	4.46E+00	0.30%	4.78E+00	0.29%	5.01E+00	0.29%
Lung	5.17E−01	0.33%	7.28E−01	0.30%	9.47E−01	0.27%	1.14E+00	0.26%	1.31E+00	0.25%	1.45E+00	0.24%	1.57E+00	0.23%
Stomach	2.02E+00	0.59%	2.70E+00	0.55%	3.37E+00	0.51%	3.97E+00	0.49%	4.47E+00	0.47%	4.80E+00	0.46%	5.14E+00	0.44%
Breast	1.36E+00	1.67%	1.69E+00	1.58%	2.02E+00	1.51%	2.37E+00	1.44%	2.61E+00	1.39%	2.81E+00	1.35%	3.03E+00	1.31%
Testicles	2.47E+00	1.10%	3.12E+00	1.05%	3.71E+00	1.01%	4.25E+00	0.98%	4.66E+00	0.95%	4.91E+00	0.94%	5.17E+00	0.92%
Bladder	6.71E−01	1.79%	1.00E+00	1.57%	1.35E+00	1.42%	1.66E+00	1.32%	1.94E+00	1.24%	2.14E+00	1.20%	2.35E+00	1.15%
Oesophagus	1.65E−01	3.97%	2.89E−01	3.22%	4.26E−01	2.77%	5.46E−01	2.51%	6.82E−01	2.29%	7.96E−01	2.14%	9.05E−01	2.03%
Liver	4.96E−01	0.36%	7.02E−01	0.33%	9.21E−01	0.30%	1.11E+00	0.29%	1.28E+00	0.27%	1.42E+00	0.27%	1.53E+00	0.26%
Thyroid	4.86E−01	3.31%	7.17E−01	2.96%	9.19E−01	2.75%	1.10E+00	2.59%	1.32E+00	2.42%	1.48E+00	2.30%	1.63E+00	2.23%
Bone Surface	1.09E+00	0.10%	1.51E+00	0.09%	1.95E+00	0.09%	2.33E+00	0.08%	2.65E+00	0.08%	2.91E+00	0.07%	3.12E+00	0.07%
Brain	1.49E−01	0.75%	2.39E−01	0.64%	3.44E−01	0.57%	4.50E−01	0.52%	5.41E−01	0.48%	6.29E−01	0.46%	7.03E−01	0.44%
Salivary Glands	9.33E−01	1.16%	1.17E+00	1.10%	1.43E+00	1.05%	1.64E+00	1.01%	1.81E+00	0.98%	1.99E+00	0.95%	2.13E+00	0.92%
Skin	2.80E+00	0.08%	3.26E+00	0.08%	3.67E+00	0.08%	3.99E+00	0.08%	4.24E+00	0.08%	4.43E+00	0.08%	4.58E+00	0.08%
Adrenals	3.43E−01	4.64%	5.53E−01	3.91%	7.78E−01	3.48%	9.55E−01	3.19%	1.20E+00	3.00%	1.32E+00	2.83%	1.43E+00	2.71%
Extrathoracic (ET) region	3.93E−01	2.77%	5.84E−01	2.45%	7.48E−01	2.25%	9.38E−01	2.08%	1.10E+00	1.97%	1.22E+00	1.89%	1.36E+00	1.81%
Gall bladder	4.03E−01	4.95%	6.13E−01	4.21%	8.14E−01	3.77%	1.01E+00	3.56%	1.20E+00	3.32%	1.36E+00	3.17%	1.49E+00	2.98%
Heart	6.75E−01	0.69%	9.67E−01	0.62%	1.29E+00	0.56%	1.60E+00	0.52%	1.82E+00	0.50%	2.04E+00	0.48%	2.22E+00	0.46%
Kidneys	3.57E−01	1.00%	5.45E−01	0.87%	7.75E−01	0.77%	9.67E−01	0.71%	1.13E+00	0.67%	1.30E+00	0.64%	1.43E+00	0.61%
Muscle	1.57E+00	0.04%	1.97E+00	0.04%	2.36E+00	0.04%	2.69E+00	0.04%	2.95E+00	0.04%	3.15E+00	0.04%	3.32E+00	0.04%
Oral Mucosa	9.16E−01	1.27%	1.19E+00	1.19%	1.45E+00	1.13%	1.70E+00	1.09%	1.93E+00	1.04%	2.10E+00	1.01%	2.23E+00	0.99%
Pancreas	1.21E+00	0.80%	1.69E+00	0.72%	2.25E+00	0.66%	2.67E+00	0.62%	3.10E+00	0.59%	3.39E+00	0.57%	3.64E+00	0.56%
Protate	2.36E+00	0.39%	2.87E+00	0.38%	3.36E+00	0.37%	3.73E+00	0.36%	4.05E+00	0.36%	4.29E+00	0.35%	4.48E+00	0.35%
Small intestine	1.41E+00	0.34%	1.90E+00	0.32%	2.41E+00	0.30%	2.83E+00	0.28%	3.17E+00	0.27%	3.47E+00	0.26%	3.71E+00	0.26%
Spleen	8.93E−01	0.91%	1.31E+00	0.81%	1.70E+00	0.75%	2.09E+00	0.70%	2.39E+00	0.67%	2.69E+00	0.64%	2.91E+00	0.62%
Thymus	2.20E−01	4.39%	3.19E−01	3.90%	4.85E−01	3.31%	6.16E−01	3.04%	7.63E−01	2.76%	8.54E−01	2.62%	9.83E−01	2.48%
E/KAP	1.21E+00	4.76%	1.59E+00	4.54%	1.97E+00	4.35%	2.30E+00	4.21%	2.58E+00	4.13%	2.79E+00	4.04%	2.98E+00	3.94%

Table B.8
HT/KAP and E/KAP in μSv/Gy cm^2 to orthopedic surgeon in scenarios without PPE and without UTS in latero-lateral (LL) projection and the statistical uncertainties (%).

Tube voltage (kVp)	60		70		80		90		100		110		120	
Bone Marrow	4.75E−02	0.41%	8.41E−02	0.33%	1.33E−01	0.27%	1.81E−01	0.24%	2.29E−01	0.22%	2.75E−01	0.20%	3.20E−01	0.19%
Colon	2.23E−01	1.11%	3.31E−01	0.98%	4.55E−01	0.88%	5.73E−01	0.81%	6.71E−01	0.77%	7.67E−01	0.73%	8.54E−01	0.69%
Lung	6.13E−02	0.94%	1.11E−01	0.76%	1.73E−01	0.64%	2.33E−01	0.57%	2.93E−01	0.52%	3.52E−01	0.48%	4.06E−01	0.45%
Stomach	1.38E−01	2.23%	2.41E−01	1.82%	3.62E−01	1.56%	4.86E−01	1.39%	6.07E−01	1.27%	6.97E−01	1.20%	7.95E−01	1.13%
Breast	2.06E−01	4.19%	3.31E−01	3.61%	4.60E−01	3.19%	5.76E−01	2.91%	6.86E−01	2.72%	7.92E−01	2.53%	8.59E−01	2.45%
Testicles	3.99E−01	2.76%	6.00E−01	2.42%	7.82E−01	2.22%	9.60E−01	2.06%	1.11E+00	1.96%	1.29E+00	1.85%	1.41E+00	1.78%
Bladder	8.39E−02	5.04%	1.47E−01	4.08%	2.18E−01	3.49%	2.90E−01	3.15%	3.86E−01	2.79%	4.46E−01	2.63%	5.33E−01	2.44%
Oesophagus	2.88E−02	9.51%	5.91E−02	7.04%	1.01E−01	5.72%	1.39E−01	5.10%	1.85E−01	4.39%	2.20E−01	4.07%	2.51E−01	3.84%
Liver	4.36E−02	1.19%	7.42E−02	0.99%	1.16E−01	0.84%	1.57E−01	0.75%	1.98E−01	0.69%	2.35E−01	0.64%	2.70E−01	0.61%
Thyroid	2.81E−01	4.39%	4.34E−01	3.80%	5.98E−01	3.38%	7.66E−01	3.12%	9.22E−01	2.90%	1.07E+00	2.72%	1.14E+00	2.64%
Bone Surface	1.54E−01	0.27%	2.53E−01	0.22%	3.73E−01	0.19%	4.88E−01	0.17%	5.95E−01	0.16%	6.95E−01	0.15%	7.83E−01	0.14%
Brain	8.12E−02	1.02%	1.41E−01	0.84%	2.19E−01	0.71%	2.98E−01	0.63%	3.77E−01	0.58%	4.46E−01	0.54%	5.10E−01	0.51%
Salivary Glands	2.55E−01	2.23%	3.93E−01	1.92%	5.62E−01	1.69%	6.86E−01	1.57%	8.47E−01	1.45%	9.46E−01	1.38%	1.04E+00	1.32%
Skin	3.44E−01	0.24%	4.74E−01	0.22%	6.16E−01	0.20%	7.42E−01	0.19%	8.58E−01	0.18%	9.53E−01	0.17%	1.04E+00	0.16%
Adrenals	2.44E−02	17.16%	4.96E−02	12.58%	8.68E−02	10.35%	1.17E−01	9.04%	1.36E−01	8.42%	1.79E−01	7.37%	2.19E−01	7.08%
Extrathoracic (ET) region	2.32E−01	3.58%	4.12E−01	2.93%	5.17E−01	2.73%	6.49E−01	2.51%	8.20E−01	2.27%	9.44E−01	2.13%	1.05E+00	2.05%
Gall bladder	4.33E−02	15.01%	5.70E−02	13.35%	9.95E−02	10.90%	1.34E−01	9.96%	2.05E−01	8.05%	2.60E−01	7.46%	2.78E−01	7.17%
Heart	7.81E−02	2.03%	1.39E−01	1.63%	2.18E−01	1.37%	3.11E−01	1.19%	3.90E−01	1.08%	4.70E−01	1.00%	5.39E−01	0.94%
Kidneys	2.89E−02	3.50%	5.55E−02	2.72%	8.39E−02	2.32%	1.28E−01	1.94%	1.65E−01	1.76%	1.99E−01	1.62%	2.36E−01	1.50%
Muscle	1.85E−01	0.12%	2.77E−01	0.11%	3.84E−01	0.10%	4.85E−01	0.09%	5.74E−01	0.09%	6.55E−01	0.08%	7.30E−01	0.08%
Oral Mucosa	2.70E−01	2.34%	4.43E−01	1.97%	5.98E−01	1.78%	7.77E−01	1.61%	9.43E−01	1.49%	1.07E+00	1.41%	1.25E+00	1.32%
Pancreas	8.78E−02	2.94%	1.58E−01	2.35%	2.51E−01	1.97%	3.38E−01	1.75%	4.29E−01	1.60%	4.90E−01	1.50%	5.80E−01	1.40%
Protate	2.72E−01	1.17%	3.96E−01	1.04%	5.31E−01	0.94%	6.55E−01	0.87%	7.74E−01	0.82%	8.60E−01	0.78%	9.67E−01	0.74%
Small intestine	1.38E−01	1.08%	2.23E−01	0.92%	3.18E−01	0.81%	4.10E−01	0.73%	5.01E−01	0.68%	5.81E−01	0.64%	6.49E−01	0.61%
Spleen	5.66E−02	3.60%	1.15E−01	2.71%	1.90E−01	2.24%	2.68E−01	1.96%	3.36E−01	1.77%	4.02E−01	1.64%	4.60E−01	1.55%
Thymus	6.26E−02	8.09%	1.27E−01	6.15%	2.02E−01	5.13%	2.76E−01	4.48%	3.68E−01	3.98%	4.15E−01	3.77%	4.77E−01	3.57%
E/KAP	1.54E−01	16.53%	2.45E−01	14.12%	3.46E−01	12.48%	4.44E−01	11.39%	5.38E−01	10.66%	6.24E−01	10.06%	6.97E−01	9.58%

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