KERMA-AREA PRODUCT AS A DOSE INDICATOR IN DENTAL CBCT

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Abstract

Dose indicators are used in diagnostic radiology for quality assurance and optimization. Their values provided by X ray units can be converted to effective dose via conversion coefficients and used for estimation of the risk to the patient. For instance computed tomography (CT) conversion coefficients using the dose length product, $P_{\mathrm{KL,CT}}$, dose indicator are available in literature. Their applicability for wide cone beams and off-center beams in dental cone beam CT (CBCT) is, however, questionable. In this case, coefficients based on the kerma-area product, P_{KA}, dose indicator may be more suitable, but so far not much information about their values has been published. The aim of this work is to point out the importance of P_{KA} as a dose indicator in dental CBCT and estimate how corresponding conversion coefficients may vary with field size and shift of the reference point. Calculations for a typical dental CBCT examination were done using the PCXMC code. The results showed that the largest relative difference between the conversion coefficients was about 20%. Thus for accurate estimates of effective dose, proper conversion coefficients should be used.

1. INTRODUCTION

Radiation protection of the patient includes justification of the X ray examination, optimization of the procedure to minimize the received dose, and quality assurance to ensure consistently adequate diagnostic information [1]. An important radiation protection measure in medicine is the usage of dose indicators. In dental radiology P_{KA} [2] for intraoral, panoramic, cephalometric and cone beam computed tomography (CBCT) units, and C_{VOL} and $P_{\mathrm{KL,CT}}$ for CBCT and CT units [2] are used to define diagnostic reference levels (DRL) [1] for optimization of procedures in a country or a region. These dose indicators can be used to estimate the effective dose [3] (which cannot be directly measured) and hence the risk to the patient. Coefficients converting values of dose indicators to effective doses (conversion coefficients) have been reported in literature for some procedures common in dental radiology. Their accuracy is often sufficient for a rough estimate of the effective dose. However for an optimization task which includes a comparison of effective doses between different X ray examinations, the accuracy of existing conversion coefficients may be insufficient for the following reasons: (i) Coefficients published before 2007 use weighting coefficients according to ICRP 60 [4] while newer coefficients most likely use recommendations by ICRP 103 [3]. (ii) Irradiation geometries different from the ones for which the coefficients were published may lead to large uncertainties since the radiosensitivity of organs that may be hit by dental radiology beams (salivary glands, thyroid, mucosa, esophagus, skin and skeleton) noticeably varies. For instance coefficients based on conventional fan beam CT geometries may not be fully applicable for dental CBCT with wide cone beams and reference points (points around which the X ray tube rotates) shifted from the imaged object center. This is especially true for conversion coefficients for C_{VOL} and $P_{\mathrm{KL,CT}}$ as the IEC measurement procedure [5] assumes that the beam hits a free-in-air pencil ionization chamber positioned in the rotation axis. (The measurement for a wide beam combines a traditional measurement in the standard dosimetry phantom for a narrow beam with a measurement quantifying the beam width. The latter is done with the free-in-air pencil ionization chamber positioned in the rotation axis.) In this case, the P_{KA} quantity is a more suitable measure that provides complementary information about the total amount of energy in the radiation beam. The aim of this work is to (i) point out the importance of P_{KA} as a dose indicator in dental CBCT since, contrary to C_{VOL} and $P_{KL,CT}$, it monitors the used beam, (ii) point out the importance of using the correct conversion coefficients, and (iii) estimate how the conversion coefficient for P_{KA} may vary with field size and shift of the reference point.

2. METHOD

Coefficients converting the kerma-area product to effective dose were calculated for three field sizes typical for dental cone beam CT (4×4, 6×6, 8×8 cm^2) and for one field size resembling a conventional CT (14.8×4 cm^2, a fan beam) using the PCXMC code (Monte Carlo Program for Calculating Patient Doses in Medical X Ray Examinations) [6]. Effective dose received by the code's mathematical phantom modelling an average adult (height of 178.6 cm and mass of 73.2 kg) during one 360° rotation of the X ray tube was approximated by a sum of effective doses received from 8 projections (projection angles are listed in Table 1). Positions of the phantom with respect to the iso-center of the CT scanner were set to mimic common dental exams: for 4×4 and 6×6 cm^2 field sizes the reference points were positioned in the left jaw, and for the 8×8 cm^2 field size the reference point was positioned in the centre of the mouth, see Fig. 1. The reference point of the fan beam was positioned so that the beam covered most of the phantom for all projection angles. To evaluate the sensitivity of effective dose on the position of the reference point, calculations were also done for reference points positioned in the centre of the mouth for the 4×4 and 6×6 cm^2 field sizes. The X ray tube voltage of 85 kV, total beam filtration of 3.1 mm Al, and target (anode) angle of 5° modelled an Accuitomo, J Morita MFG. Corp CBCT scanner. For each projection, 200000 photons simulated an irradiation with P_{KA}=100 mGy cm^2; the P_{KA} values were calculated by the PCXMC code. The conversion coefficient was then calculated as E/P_{KA}, where E and P_{KA}= 800 mGy cm^2 were the cumulative effective dose and kerma-area product, respectively, from all eight projections.

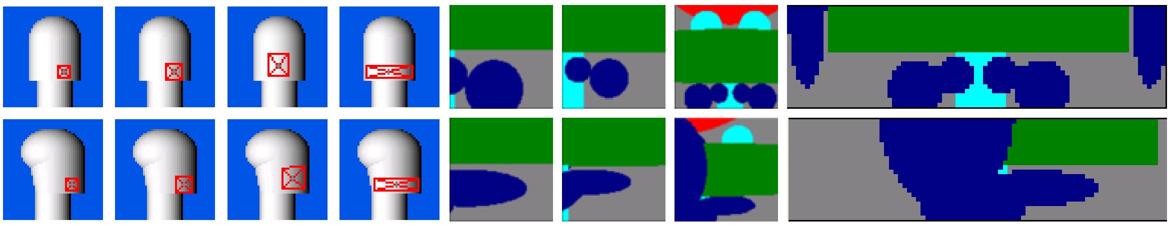

FIG. 1. Schematic view of the beam positions (left) and corresponding organs in the beam path (right). AP and LR projections are in the top and bottom rows, respectively. Color coding: salivary glands (blue), oral mucosa (green), pharynx/trachea/sinus (cyan), brain (red), skeleton (not shown).

3. RESULTS

Effective doses delivered by each considered beam and resulting conversion coefficients E/P_{KA} are in Table 1. Though the conversion coefficients were approximately the same for the considered field sizes (0.13, 0.13 and 0.14 µSv mGy^{-1} cm^{-2} for the typical 4×4, 6×6 and 8×8 cm^2 fields), there were noticeable variations in effective doses from individual projections caused by different radiosensitivity of organs in the beam path. For instance in case of the 4×4 cm^2 field size, effective dose for the 45° projection (21.1 µSv) was three times larger than the one for the 135° projection (6.7 µSv). Averaging over all directions significantly reduced the variation, but still there were differences between the shifted and centered beams (0.13 vs. 0.16 µSv mGy^{-1} cm^{-2} for the 4×4 cm^2 beams and 0.13 vs. 0.14 µSv mGy^{-1} cm^{-2} for the 6×6 cm^2 beam.) Value of conversion coefficient for the fan beam (0.14 µSv mGy^{-1} cm^{-2}) was between values representing the shifted and centered cases. These results indicate that a better accuracy in conversion coefficients can only be achieved by taking the position of the reference point into account.

TABLE I. CALCULATED EFFECTIVE DOSES IN µSv FOR ALL PROJECTION ANGLES AND FIELD SIZES. BEAM INTENSITY WAS SET TO P_{KA} = 100 mGy cm^2 PER PROJECTION. THE

LAST ROW OF THE TABLE GIVES THE CONVERSION COEFFICIENTS E/P_{KA} IN µSv $mGy^{-1}cm^{-2}$. POSITIONS OF BEAMS ARE DEPICTED IN FIGURE 1. PROJECTION ANGLES OF 0°, 90°, 180°, AND 270° CORRESPOND TO LATL, PA, LATR, AND AP PROJECTIONS.

Angle	4×4 shifted	4×4 centered	6×6 shifted	6×6 centered	8×8 centered	Fan beam
0°	13.0	12.9	13.1	13.1	17.8	14.3
45°	21.1	21.2	17.5	17.5	18.1	13.1
90°	10.2	9.2	9.5	9.4	8.3	10.2
135°	6.7	16.6	6.7	14.2	5.6	13.0
180°	12.9	12.9	13.1	13.1	17.7	14.3
225°	13.4	16.4	14.2	15.4	15.8	15.3
270°	14.3	17.8	14.4	16.6	16.0	14.3
315°	14.6	17.7	15.6	16.5	15.8	15.3
E/P_{KA}	0.133	0.156	0.130	0.145	0.144	0.137

4. DISCUSSION

The P_{KA} dose indicator can be used for all types of examinations in dental radiology as shown by Helmrot, et al. [7, 8] and Lofthag-Hansen, et al. [9]. For accurate measurements, the KAP meters must be properly calibrated since the commonly available types exhibit strong energy dependence; for instance deviations of about 20% were reported by Malusek, et al. [10].

The calculated effective dose can be used to compare different types of examination methods and devices as is commonly done, but care has to be taken to (i) use proper conversion coefficients for the imaged body part, and (ii) correctly interpret the risk to the patient as effective dose is based on risks averaged over age and sexes [11, 12, 13]. Development of age and sex dependent mathematical computation models including more detailed description of organs would improve the accuracy of conversion coefficients.

In dental radiology the most commonly used estimation of effective dose is done by using TL dosimeters in human-like phantoms. In the guidelines for implant dentistry examination [14] effective doses for different CBCT examinations and devices show large variations. The causes of these variations are not, however, easy to understand as no detailed information is given. This limits the usability of these data for optimization in clinics. Compared to measurements with TL dosimeters, the usage of dose indicators for routine optimizations in clinics is simpler and faster.

5. CONCLUSION

In dental cone beam CT, the P_{KA} dose indicator provides information about the amount of energy entering the patient and thus is conceptually more accurate than the C_{VOL} and $P_{KL,CT}$ dose indicators whose definitions are problematic for wide cone beams. The largest relative difference between the calculated conversion coefficients was about 20%. This indicates that for accurate estimates of effective dose, proper conversion coefficients should be used. To improve optimization processes: (i) P_{KA} should be used for setting DRLs, and (ii) accurate conversion coefficients should be available to radiologists and medical physicists so that effective doses delivered by different devices could be compared.

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