RESEARCH ARTICLE

Effective dose assessment in the maxillofacial region using thermoluminescent (TLD) and metal oxide semiconductor field-effect transistor (MOSFET) dosimeters: a comparative study

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Objectives: The objective of this study was to compare the performance of metal oxide semiconductor field-effect transistor (MOSFET) technology dosimeters with thermoluminescent dosimeters (TLDs) (TLD 100; Thermo Fisher Scientific, Waltham, MA) in the maxillofacial area.

Methods: Organ and effective dose measurements were performed using 40 TLD and 20 MOSFET dosimeters that were alternately placed in 20 different locations in 1 anthropomorphic RANDO[®] head phantom (the Phantom Laboratory, Salem, NY). The phantom was exposed to four different CBCT default maxillofacial protocols using small (4 × 5 cm) to full face (20 × 17 cm) fields of view (FOVs).

Results: The TLD effective doses ranged between 7.0 and 158.0 μSv and the MOSFET doses between 6.1 and 175.0 μSv. The MOSFET and TLD effective doses acquired using four different (FOV) protocols were as follows: face maxillofacial (FOV 20 × 17 cm) (MOSFET, 83.4 μSv; TLD, 87.6 μSv; −5%); teeth, upper jaw (FOV, 8.5 × 5.0 cm) (MOSFET, 6.1 μSv; TLD, 7.0 μSv; −14%); tooth, mandible and left molar (FOV, 4 × 5 cm) (MOSFET, 10.3 μSv; TLD, 12.3 μSv; −16%) and teeth, both jaws (FOV, 10 × 10 cm) (MOSFET, 175 μSv; TLD, 158 μSv; +11%). The largest variation in organ and effective dose was recorded in the small FOV protocols.

Conclusions: Taking into account the uncertainties of both measurement methods and the results of the statistical analysis, the effective doses acquired using MOSFET dosimeters were found to be in good agreement with those obtained using TLD dosimeters. The MOSFET dosimeters constitute a feasible alternative for TLDs for the effective dose assessment of CBCT devices in the maxillofacial region.

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Introduction

Since its introduction in 1977, CBCT technology has become increasingly popular amongst dentists and oral

and maxillofacial surgeons.¹ The major reason for this increase in popularity is the wide range of applications and reduced practitioner and patient cost of CBCT devices when compared with conventional CT technology. This rapid development has consequently raised new concerns amongst professionals and patients.

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Subsequently, there has been an increase in the number of studies focusing on CBCT dose assessment. Owing to the increasing number of CBCT devices in the market, a new demand for fast and reliable effective dose measurements has been created.

To date, the most effective dose assessment studies use thermoluminescent dosimeters (TLDs) (TLD 100; Thermo Fisher Scientific, Waltham, MA)^{2–6} in combination with anthropomorphic phantoms. However, TLD technology has one major drawback; namely, the need to replace the TLDs after every exposure. In cases where consecutive exposures are performed, the phantom head has to be dismantled, and the TLDs have to be replaced making extensive studies laborious, time consuming and prone to error and imprecision.⁷

The rapid progress in the field of metal oxide semiconductor field-effect transistor (MOSFET) technology offers new possibilities for dose assessment and is an interesting alternative to conventional TLDs. The major benefits of MOSFET dosimeters are real-time measuring capability and the possibility to perform multiple measurements without the need to repeatedly dismantle and reposition the phantom. Historically, MOSFET dosimeters have been successfully used for dose assessment in radiotherapy and have only recently been implemented in different fields of diagnostic radiology.^{8–12}

The aim of this study was to evaluate the feasibility of MOSFET dosimeters in effective dose assessment by comparing their performance with TLDs in an anthropomorphic head phantom using typical CBCT head examination protocols.

Materials and methods

Scanner

TLD and MOSFET measurements were performed using a ProMax[®] 3D Mid, CBCT device (Planmeca Oy, Helsinki, Finland). Four different CBCT default head protocols were used. The protocols differed in volume, hence, the field of view (FOV) ranged from a single tooth to a full-face FOV (Table 1).

Phantom

An anthropomorphic RANDO[®] RAN102 male head phantom (Radiation Analogue Dosimetry System; The

Phantom Laboratory, Salem, NY) was used for all dose measurements. The phantom comprised a human skull embedded in a soft-tissue equivalent synthetic material to match the attenuation and scattering properties of the bone, soft tissues and airways of the human head. The phantom consisted of ten 25-mm thick layers with a 15 × 15 mm grid of ø5 mm holes filled with removable, soft-tissue equivalent plugs for dosimeter placement.

Thermoluminescent dosimeters

The TLD measurements were performed using TLDs. The dosimeters were fixed to the allocated phantom head positions using a custom-made holder Figure 1a. Each holder contained two TLDs. The reset and annealing procedures of the TLDs were performed in a microprocessor-controlled TLD oven (PTW, Freiburg, Germany). The TLD read-out process was performed in a Fimel LTMW device (Fimel, Fontenay-aux-Roses, France). All TLD calibrations and read-out procedures were performed according to a protocol described by Rottke *et al.*¹³

Metal oxide semiconductor field-effect transistor technology dosimeters

A mobile MOSFET device TN-RD-70-W20 was used to record all dose measurements. The device comprised a TN-RD-38 wireless bluetooth transceiver, a TN-RD-16 reader module, high-sensitivity TN-1002RD-H detectors and TN-RD-75M software (Best Medical Canada; Ottawa, ON, Canada). The TN-1002RD-H detector consists of two MOSFETs mounted on a flexible printed circuit board with an epoxy resin encapsulation bulb. Prior to the measurements, the MOSFET device was calibrated according to a previous study by Koivisto *et al.*¹⁴ and referenced to the secondary standard dosimetry laboratory at the Finnish Radiation and Nuclear Safety Authority. MOSFET dosimeter angular sensitivity divergences were taken into consideration based on the results of an earlier study.¹⁵ All MOSFETs were placed in the phantom with their epoxy shielding bulbs facing in the anterior direction of the phantom. A soft-tissue plug provided by the phantom manufacturer was used to support the dosimeters and, furthermore, to minimize the air gap between the MOSFETs and surrounding phantom material Figure 1b. The positioning of the dosimeters was performed according to a previous

Table 1 Exposure parameters of measured protocols

Protocol name	Face Maxillofacial Low dose	Teeth Upper jaw Low dose	Tooth Mandible Low dose	Teeth Both jaws Standard dose
Protocol number	1	2	3	4
Tube voltage (kVp)	90	90	90	90
Tube current (mA)	6	4	4	10
Exposure time (s)	18.0	2.8	2.5	12.0
Q (mAs)	108	11.4	15.1	121.0
Voxel edge length (mm)	0.6 × 0.6	0.4 × 0.4	0.4 × 0.4	0.2 × 0.2
Frame number	300	300	300	300
Scan field of view (cm)	20.0 × 17.0	8.5 × 5.0	4.0 × 5.0	10.0 × 10.0

Q, tube-current exposure-time product.

Figure 1 A schematic diagram of a polymethyl methacrylate (PMMA) holder used to position two thermoluminescent dosimeters (TLDs) (TLD 100; Thermo Fisher Scientific, Waltham, MA) (a), a metal oxide semiconductor field-effect transistor (MOSFET) dosimeter support is presented in (b). PCB, printed circuit board.

study.¹⁴ The MOSFET cables were routed from the phantom base via the airways and unused dosimeters voids to the designated layers. Furthermore, tightening of the nuts at the end of two threaded plastic bolts passing through the layers of the phantom allowed the airspace between the layers to be minimized. The positioning of the dosimeters is presented in Table 2.

Table 2 Locations of the thermoluminescent dosimeter (TLD 100; Thermo Fisher Scientific, Waltham, MA) and metal oxide semiconductor field-effect transistor technology dosimeters in RANDO[®] phantom (the Phantom Laboratory, Salem, NY)

Dosimeter number	Layer	Location	Tissue
1	2	Calvarium anterior	Bone marrow
2	3	Mid-brain	Brain
3	3	Pituitary fossa	Brain
4	4	Right orbit	Eyes
5	4	Right lens	Eyes
6	6	Right cheek	Skin
7	7	Right ramus	Bone marrow
8	7	Left ramus	Bone marrow
9	6	Right parotid	Salivary gland
10	6	Left parotid	Salivary gland
11	7	Centre C-spine	Bone marrow
12	8	Left back neck	Skin
13	7	Right mandible body	Bone marrow
14	7	Left mandible body	Bone marrow
15	8	Right submandibular gland	Salivary gland
16	8	Left submandibular gland	Salivary gland
17	8	Centre sublingual gland	Salivary gland
18	9	Midline thyroid	Thyroid
19	9	Thyroid surface	Thyroid
20	9	Pharyngeal-oesophageal space	Oesophagus

Measurements

Organ and effective doses were assessed using four different protocols (Table 1). Consecutive measurements were performed using 40 TLD and 20 MOSFET dosimeters that were alternatively placed in 20 designated sites in the RANDO phantom (Table 2). In total, 2 TLD dosimeters and 1 MOSFET dosimeter were alternatively placed in each of the 20 designated sites. The chosen locations represented the most radiosensitive organs in the maxillofacial region.

All TLD and MOSFET measurements were repeated ten times to improve the overall statistical outcome. The exposure protocols and dosimeter locations are presented in Tables 1 and 2.

To ensure the reproducibility of the phantom position and to minimize phantom shift or rotation,¹⁶ the RANDO phantom holder was tightly fixed to the CBCT chin support. The acquisition FOVs were controlled using a scout image acquired prior to the actual CBCT exposures. The investigated FOVs are presented in Figure 2.

CBCT source variation assessment

CBCT source variations were assessed using two identical ProMax Mid devices. All measurements were performed on the same phantom using identical protocols (protocol 1).

Calculation of effective dose

The effective dose (D) was assessed using 2 TLD dosimeters at each of the 20 designated sites. The TLD read out was subsequently multiplied with the calibration factor, and averaged and subtracted by the background radiation according to a previous study by Rottke *et al.*¹³

To obtain absorbed organ doses (cGy), the MOSFET dosimeter readings (mV) were multiplied with the corresponding calibration coefficients (cGy mV⁻¹) using the TN-RD-75M software. Furthermore, all tissue-specific doses were averaged and weighted using the tissue fraction factor (f_i). The calculation of the equivalent or radiation-weighted dose H_T for all organs or tissues T was performed using the following equation.^{6,17}

$$H_T = w_R \sum_i f_i \cdot D_{Ti} \quad (1)$$

Where the radiation weighting factor $w_R = 1$ (Sv Gy⁻¹) for X-rays, f_i is the mass fraction of tissue T in layer i and D_{Ti} being the average absorbed dose of tissue T in layer i . Summation was performed for all phantom layers. Where an organ was not fully contained within the head, a partial volume was considered,¹⁸ as recommended by the International Commission on Radiological Protection (ICRP 103).¹⁹ In this study, the fractions irradiated (f_i) that described the exposed and dosimetrically evaluated coverage of each studied organ in relative scale were accounted for similarly to previous studies.^{2,7}

The effective dose was obtained from the measured organ doses using the revised guidelines given by the

Figure 2 Image demonstrating the default CBCT (ProMax[®] 3D Mid; Planmeca Oy, Helsinki, Finland) fields of view used in the study (a) face (20 × 17 cm), (b) teeth upper jaw (8.5 × 5.0 cm), (c) tooth mandible (4 × 5 cm) and (d) teeth both jaws (10 × 10 cm).

ICRP 103.¹⁹ The effective dose E is calculated with the following equation:

$$E = \sum_T w_T \cdot H_T \quad (2)$$

where w_T is the weighting factor of tissue T and H_T is the equivalent dose in tissue T . According to the ICRP recommendation, the calculation of effective dose is based on a large number of organs and tissues in the body and the sum of their weighting factors w_T is 1. Some of the organs considered in the calculation are grouped as “remainder tissues”. The w_T for the remainder tissues specified by ICRP 103 is 0.12. The ICRP 103 weighting factors w_T used are identical to those presented in an earlier study.⁷

Results

The TLD effective doses ranged between 7.0 and 158.0 μSv and the MOSFETs doses between 6.1 and 175.0 μSv . The effective doses acquired using different protocols are presented in Table 3.

The effective dose and the organ dose contributions of the radiosensitive organs, and the difference percentages between the results and the fractions of the effective dose obtained using MOSFET and TLD dosimeters (protocol 1 in Table 3) are presented in Table 4.

Furthermore, a statistical analysis was carried out on all four protocols presented in Table 1 to compare

the organ dose contributions of the MOSFET and TLD dosimeters. The statistical calculation of protocol 1 was performed using the MOSFET (μSv) and TLD (μSv) values presented in Table 4; “face maxillofacial” (FOV, 20 × 17 cm). The calculated correlation coefficient between the MOSFET and TLD values was 0.99636. The correlation coefficients for protocols 2, 3 and 4 yielded the following results: “teeth upper jaw” (FOV, 8.5 × 5.0 cm) (0.808007); “tooth mandible left molar” (FOV, 4 × 5 cm) (0.987600) and “teeth both jaws” (FOV, 10 × 10 cm) (0.989940).

Source variation

The CBCT source variation uncertainty was evaluated using two identical CBCT devices and the same full-face protocol 1 (face, maxillofacial; FOV, 20 × 17 cm). The effective doses were 87.2 and 83.3 μSv resulting in a source variation of 5%.

Absorbed and effective dose uncertainty

Type A standard uncertainty evaluation was conducted according to a previous study.¹⁴ The point dose measurement uncertainty was calculated as the weighted sum of variances and included the statistical measurement error according to a former study,¹⁵ dosimeter and phantom positioning uncertainties (10%, 10%), X-ray source variation (5%) observed in this study and cable irradiation uncertainties²⁰ (1%).

The total measurement uncertainty, *e.g.* in the face (FOV, 20 × 17 cm) protocol for a single dosimeter, varied

Table 3 Effective dose (μSv) results attained using thermoluminescent dosimeter (TLD) (TLD 100; Thermo Fisher Scientific, Waltham, MA) and metal oxide semiconductor field-effect transistor (MOSFET) dosimeters and four different CBCT protocols

Number	Protocol	Field of view (cm)	TLD (μSv)	MOSFET (μSv)	Difference (%)
1	Face, maxillofacial	20.0 × 17.0	87.6	83.4	−5
2	Teeth, upper jaw	8.5 × 5.0	7.0	6.1	−14
3	Tooth, mandible (left molar)	4.0 × 5.0	12.3	10.3	−16
4	Teeth, both jaws	10.0 × 10.0	158.0	175	11

Table 4 Metal oxide semiconductor field-effect transistor (MOSFET) and thermoluminescent (TLD) (TLD 100; Thermo Fisher Scientific, Waltham, MA) estimates of effective dose (μSv), dose contributions and fraction (%) of effective dose in face (maxillofacial) field of view 20×17 cm protocol

Organ	MOSFET (μSv)	TLD (μSv)	Difference (%)	MOSFET fraction (%)	TLD fraction (%)
Bone marrow	24.2	24.6	-2	29	28
Thyroid	11.4	11.4	0	14	13
Oesophagus	1.2	1.3	-12	1	2
Skin	0.7	0.7	-3	1	1
Bone surface	2.0	2.0	-2	2	2
Salivary glands	10.6	10.4	2	13	12
Brain	12.2	13.2	-8	15	15
Remainder	21.2	24.0	-12	25	27
Lymphatic nodes	0.5	0.5	-7	1	1
Extrathoracic airways	10.5	11.9	-12	13	14
Muscle	0.5	0.5	-11	1	1
Oral mucosa	9.8	11.0	-11	12	13
Effective dose	83.4	87.6	-5	100	100

between 16% and 21%. The tissue dose uncertainty was dependent on the dosimeter uncertainty and the estimated uncertainty of the fraction irradiated f_i (25%). The tissue dose uncertainties of the bone marrow, thyroid gland, oesophagus, skin, bone surface, salivary glands and brain were 25%, 24%, 34%, 20%, 25%, 20% and 21%, respectively. For the remaining tissues, the tissue uncertainties for the lymphatic nodes, extrathoracic airways, muscles and oral mucosa were 14%, 18%, 14% and 10%, respectively. The expanded effective dose uncertainties (two standard deviations) were calculated as a weighted sum of the variances of all tissues. The results for the measured protocols were as follows: 20% for “face” (FOV, 20×17), 66% for “teeth upper jaw” (8.5×5.0), 22% for “teeth both jaws” (FOV, 10×10 cm) and 42% for “tooth mandible left molar” (FOV, 4×5 cm).

Discussion

In this study, MOSFET dosimeters were evaluated using an anthropomorphic phantom. The acquired MOSFET results were subsequently compared with TLD reference values obtained in identical conditions.

To date, TLDs are the most commonly used dosimeters in dose measurement studies owing to their sensitivity and small size.²¹ Furthermore, TLDs are often used for effective dose assessments.^{2–5,13} Nevertheless, TLDs have certain limitations, especially when using a small number of dosimeters in point-dose measurements.⁶ Furthermore, TLDs and MOSFETs are sensitive to phantom tilting¹⁶ and, therefore, minor shifts in the FOV can have a significant impact on the effective dose results.⁷ Previous studies using TLDs have also reported differences between the X-ray sources, phantoms, phantom positioning and the placement of the dosimeters in the phantoms.

To minimize the above discussed dosimeter limitations, the following precautions were undertaken in this study: all measurements were performed using the same CBCT device to minimize the source variations;

only one anthropomorphic phantom was used in this study offering equal attenuation and scattering conditions; identical TLD and MOSFET dosimeter positions were used in the phantom head; and the phantom head was specially fixed to the CBCT device allowing exact repositioning after replacing the dosimeters in the phantom. Furthermore, the positioning of the acquisition volume in each case was verified using a reconstructed three-dimensional image of the anatomical structures in the FOV.

To avoid any inaccuracies induced by the limited number of exposed dosimeters in the small FOV, the organ dose contributions were assessed using the full-face protocol 1 (face, maxillofacial; FOV, 20×17 cm). The large FOV protocol yielded 5% less effective dose values in the MOSFETs than with the TLDs. The largest differences in the effective dose contributions were measured in the remainder tissues (-12%) and oesophagus (-12%). These differences could be owing to minor variations in the phantom positioning, as previously discussed.

When comparing the effective doses acquired using protocol 2 (teeth upper jaw; FOV, 8.5×5.0 cm), the MOSFET dosimeters recorded 14% lower effective dose ($6.1 \mu\text{Sv}$) values than the TLD dosimeters ($7.0 \mu\text{Sv}$). The highest variability between MOSFET and TLD measurements were observed in the thyroid gland (MOSFET, $1.5 \mu\text{Sv}$; TLD, $0.7 \mu\text{Sv}$; +121%). The largest difference in the effective dose contribution was attained in the remaining tissues (MOSFET, $1.9 \mu\text{Sv}$; TLD, $3.0 \mu\text{Sv}$; -36%). The higher effective dose observed in the thyroid gland and the lower values attained in the remaining tissues are possibly owing to vertical shifting of the FOV position in between different TLD and MOSFET measurements.

The greatest difference between the effective doses obtained using MOSFET and TLD dosimeters was observed in protocol 3 (tooth, mandible; FOV, 4×5 cm) with the smallest FOV. In this protocol, the MOSFET effective dose values were 16% lower than those obtained using TLDs. The largest difference in the effective dose contribution was observed in the bone marrow ($0.8 \mu\text{Sv}$)

and the thyroid gland (0.4 μ Sv). One explanation for the differences could be the limited number of dosimeters used in this study and the uncertainty of doses measured near the X-ray field edge.

In protocol 4 (teeth both jaws; FOV, 10×10 cm), the effective dose value obtained using MOSFETs was 11% higher than that obtained with TLDs. Furthermore, the largest variation between the different measurement methods was observed in the salivary glands (8.3 μ Sv) and the brain (5.6 μ Sv).

The limited number of dosimeters used in this study and the uncertainty of the doses measured near the X-ray field edge may have caused the differences in the small FOV results. This phenomena has been previously observed by Pauwels et al.⁶ The greatest effective dose contribution difference was observed in the thyroid gland. When comparing the source variation using two CBCT devices, only minor differences of 5% in the effective doses were observed. This could be an indication of position differences between two MOSFET set-ups.

References

- Ganguly R. *Accuracy of linear measurement in Galileos cone beam CT under simulated clinical condition*. PhD thesis. Iowa city, IA: University of Iowa; 2009.
- Ludlow JB, Davies-Ludlow LE, Brooks SL. Dosimetry of two extraoral direct digital imaging devices: NewTom cone beam CT and Orthophos Plus DS panoramic unit. *Dentomaxillofac Radiol* 2003; **32**: 229–43.
- Ludlow JB, Brooks SL, Davies-Ludlow LE, Howerton B. Dosimetry of 3 CBCT units for oral and maxillofacial radiology. *Dentomaxillofac Radiol* 2006; **35**: 219–26.
- Roberts JA, Drage NA, Davies J, Thomas DW. Effective dose from cone beam CT examinations in dentistry. *Br J Radiol* 2009; **82**: 35–40. doi: [10.1259/bjr/31419627](https://doi.org/10.1259/bjr/31419627)
- Suomalainen A, Kiljunen T, Käser Y, Peltola J, Kortensniemi M. Dosimetry and image quality of four dental cone beam computed tomography scanners compared with multislice computed tomography scanners. *Dentomaxillofac Radiol* 2009; **38**: 367–78. doi: [10.1259/dmfr/15779208](https://doi.org/10.1259/dmfr/15779208)
- Pauwels R, Beinsberger J, Collaert B, Theodorakou C, Rogers J, Walker A, et al; The SEDENTEXCT Project Consortium. Effective dose range for dental cone beam computed tomography scanners. *Eur J Radiol* 2012; **81**: 267–71. doi: [10.1016/j.ejrad.2010.11.028](https://doi.org/10.1016/j.ejrad.2010.11.028)
- Koivisto J, Kiljunen T, Tapiovaara M, Wolff J, Kortensniemi M. Assessment of radiation exposure in dental cone-beam computerized tomography with the use of metal-oxide semiconductor field-effect transistor (MOSFET) dosimeters and Monte Carlo simulations. *Oral Surg Oral Med Oral Pathol Oral Radiol* 2012; **114**: 393–400. doi: [10.1016/j.oooo.2012.06.003](https://doi.org/10.1016/j.oooo.2012.06.003)
- Lee R, Thomas KE, Connolly BL, Falkiner M, Gordon CL. Effective dose estimation for pediatric voiding cystourethrography using an anthropomorphic phantom set and metal oxide semiconductor field-effect transistor (MOSFET) technology. *Pediatr Radiol* 2009; **39**: 608–15. doi: [10.1007/s00247-009-1161-5](https://doi.org/10.1007/s00247-009-1161-5)
- Kim S, Sopko D, Toncheva G, Enterline D, Keijzers B, Yoshizumi TT. Radiation dose from 3D rotational X-ray imaging: organ and effective dose with conversion factors. *Radiat Prot Dosimetry* 2012; **150**: 50–4. doi: [10.1093/rpd/ncr369](https://doi.org/10.1093/rpd/ncr369)
- Kim S, Yoshizumi TT, Frush DP, Toncheva G, Yin FF. Radiation dose from cone beam CT in a pediatric phantom: risk estimation of cancer incidence. *AJR Am J Roentgenol* 2010; **194**: 186–90. doi: [10.2214/AJR.08.2168](https://doi.org/10.2214/AJR.08.2168)
- Miksys N, Gordon CL, Thomas K, Connolly BL. Estimating effective dose to pediatric patients undergoing interventional radiology procedures using anthropomorphic phantoms and MOSFET dosimeters. *AJR Am J Roentgenol* 2010; **194**: 1315–22. doi: [10.2214/AJR.09.3634](https://doi.org/10.2214/AJR.09.3634)
- Kim S, Yoshizumi TT, Toncheva G, Frush DP, Yin FF. Estimation of absorbed doses from paediatric cone-beam CT scans: MOSFET measurements and Monte Carlo simulations. *Radiat Prot Dosimetry* 2010; **138**: 257–63. doi: [10.1093/rpd/ncp257](https://doi.org/10.1093/rpd/ncp257)
- Rottke D, Patzelt S, Poxleitner P, Schulze D. Effective dose span of ten different cone beam CT devices. *Dentomaxillofac Radiol* 2013; **42**: 20120417. doi: [10.1259/dmfr.20120417](https://doi.org/10.1259/dmfr.20120417)
- Koivisto J, Kiljunen T, Wolff J, Kortensniemi M. Assessment of effective radiation dose of an extremity CBCT, MSCT and conventional X-ray for knee area using MOSFET dosimeters. *Radiat Prot Dosimetry* 2013; **157**: 515–24. doi: [10.1093/rpd/nct162](https://doi.org/10.1093/rpd/nct162)
- Koivisto J, Kiljunen T, Wolff J, Kortensniemi M. Characterization of MOSFET dosimeter angular dependence in three rotational axes measured free-in-air and in soft-tissue equivalent material. *J Radiat Res* 2013; **54**: 943–9. doi: [10.1093/jrr/rrt015](https://doi.org/10.1093/jrr/rrt015)
- Ludlow JB. Dose and risk in dental diagnostic imaging: with emphasis on dosimetry of CBCT. *Korean J Oral Maxillofac Radiol* 2009; **39**: 175–84.
- Loubele M, Bogaerts R, Van Dijk E, Pauwels R, Vanheusdena S, Suetens P, et al. Comparison between effective radiation dose of CBCT and MSCT scanners for dentomaxillofacial applications. *Eur J Radiol* 2009; **71**: 461–8. doi: [10.1016/j.ejrad.2008.06.002](https://doi.org/10.1016/j.ejrad.2008.06.002)
- Davies J, Johnson B, Drage N. Effective doses from cone beam CT investigation of the jaws. *Dentomaxillofac Radiol* 2012; **41**: 30–6. doi: [10.1259/dmfr/30177908](https://doi.org/10.1259/dmfr/30177908)
- International Commission on Radiological Protection (ICRP). Recommendations of the ICRP. ICRP Publication 103. *Ann ICRP* 2008; **37**: 2–4.
- Ehringfeld C, Schmid S, Poljanc K, Kirisits C, Aiginger H, Georg D. Application of commercial MOSFET detectors for *in vivo* dosimetry in the therapeutic x-ray range from 80 kV to 250 kV. *Phys Med Biol* 2005; **50**: 289–303.
- Davis SD, Ross CK, Mobit PN, Van der Zwan L, Chase WJ, Shortt KR. The response of lif thermoluminescence dosimeters to photon beams in the energy range from 30 kV x rays to 60Co gamma rays. *Radiat Prot Dosimetry* 2003; **106**: 33–43.

Conclusions

Taking into account the uncertainties related to TLD and MOSFET effective dose assessment, MOSFET dosimeters gave similar results to the TLD measurements. MOSFETs can be considered feasible dosimeters for the effective dose assessment in the maxillofacial area.

Conflicts of interest

Juha Koivisto is an employee of Planmeca Oy.