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Determination of Radiation Exposure of Individuals in the Population by Patients after Radioiodine Therapy – Comparison of two Measurement Systems

Ermittlung der Strahlenexposition von Einzelpersonen in der Bevölkerung durch Patienten nach einer Radiojodtherapie – Vergleich von 2 Messsystemen

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Key words

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ABSTRACT

According to the requirements of radiation protection legislation, patients may only be discharged from the nuclear medicine therapy ward if it is ensured that the cumulative radiation exposure of the population is below 1 mSv per year. In the present study, dose measurements of patients after radioiodine therapy (RIT) and their relatives are to be used to prove that the radiation exposure resulting from the medical application is low and that the legal framework conditions are complied with. Furthermore, the results allow conclusions to be drawn about the measurement accuracy of the dosimeters used.

Methods: In 147 patients after RIT and their relatives, the dosage was measured over 14 days with different measuring systems. Finger ring dosimeters (FRD) were worn during the whole day, furthermore the dose was determined by non-official OSL and TLD dosimeters during the sleep phase.

Results: 88 data sets were used for the final analysis. With the FRD, dose values between 0.1–50 mSv were determined for the patients. As expected, the finger ring dose of the relatives was significantly lower, averaging 0.75 mSv compared to 10 mSv for the patient. For the TLD and OSL used in the sleep phase, the measured values were in the same range. The reproducibility of the measurement results was significantly better for the OSL than for the TLD.

Conclusion: Despite method-related measurement uncertainties, it can be concluded that the exposure dose of patients' relatives after radioiodine therapy is low and that the legal requirements are met. Moreover, the now official OSL dosimeters represent a more accurate and for the chosen measurement task better suited measurement system than the TLD.

Key Points:

- The exposure dose of patients' relatives after radioiodine therapy is low.
- The requirements of radiation protection legislation after discharge from the nuclear medicine therapy ward are complied with
- OSL dosimeters are a accurate and for the measurement task suited system

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ZUSAMMENFASSUNG

Nach den Forderungen der Strahlenschutzgesetzgebung darf eine Entlassung von der nuklearmedizinischen Therapiestation erst erfolgen, wenn sichergestellt ist, dass die kumulative Strahlenexposition der Bevölkerung unter 1 mSv pro Jahr be-

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trägt. In der vorliegenden Untersuchung soll anhand von Dosismessungen von Patienten nach Radiojodtherapie (RIT) und deren Angehörigen nachgewiesen werden, dass die von der medizinischen Anwendung ausgehende Strahlenexposition niedrig ist und die gesetzlichen Rahmenbedingungen eingehalten werden. Weiterhin lassen die Ergebnisse Rückschlüsse auf die Messgenauigkeit der verwendeten Dosimeter zu.

Methodik: Bei 147 Patienten nach RIT und deren Angehörigen erfolgte über 14 Tage die Dosismessung mit verschiedenen Messsystemen. Es wurden ganztägig Fingerringdosimeter (FRD) getragen, weiterhin erfolgte die Dosisermittlung durch nichtamtliche OSL- und TLD-Dosimeter während der Schlafphase.

Ergebnisse: 88 Datensets wurden zur finalen Auswertung herangezogen. Mit den FRD wurden bei den Patienten Dosiswerte zwischen 0,1–50 mSv ermittelt. Die Fingerringdosis der Angehörigen war erwartungsgemäß deutlich niedriger und lag im Mittel bei 0,75 mSv gegenüber 10 mSv beim Patienten. Bei den in der Schlafphase eingesetzten TLD und OSL lagen die Messwerte im gleichen Bereich. Die Reproduzierbarkeit der Messergebnisse war für die OSL deutlich besser als für die TLD.

Schlussfolgerung: Trotz methodenbedingter Messunsicherheiten kann abgeleitet werden, dass die Expositionsdosis der Angehörigen von Patienten nach Radiojodtherapie gering ist und die gesetzlichen Forderungen eingehalten werden. Die jetzt amtlichen OSL-Dosimeter stellen zudem ein genaueres und für die gewählte Messaufgabe besser geeignetes Messsystem als die TLD dar.

Introduction

In recent decades, radioiodine therapy has established itself as an effective, inexpensive procedure with few side effects for the treatment of thyroid disease, and is the most commonly performed treatment worldwide, along with surgical therapy [1–4]. In Germany, inpatient treatment is required by law. After patients are discharged from the nuclear medicine therapy ward, there is low radiation exposure for the relatives living in the common household as a result of the remaining incorporated I-131 residual activities.

According to the requirements of German radiation protection legislation, discharge from the therapy ward may not take place until it has been ensured that the cumulative radiation exposure of the population is below 1 mSv per year. This is realized with derived limit values and related measurement. Discharge becomes possible only when the patient's dose rate is measured below 3.5 µSv/h at a distance of 2 m, and is also permitted after a stay of 48 hours in a therapy ward at the earliest. Based on the patient information sheet, patients are educated prior to discharge regarding their behavior to protect others. Exceptions to this procedure, for example in the case of social necessity, require a compelling indication from a medical specialist and immediate notification of the reason for discharge to the competent authority. The conditions for this procedure are regulated by paragraph 9.1 of the Radiation Protection in Medicine guideline [5–8]. Officially-approved dosimeters are available for monitoring radiation exposure of personnel, including thermoluminescent dosimeters (TLD) and optically stimulated luminescent dosimeters (OSL), although their respective use varies nationally [9]. The characteristics of these measuring systems have been sufficiently studied and known [10–12], including the calibration for beta radiation and the use for partial body dosimetry [13, 14].

In the present work, measurement data were collected from patients and their cohabiting relatives using different detector systems (approved TLD finger ring dosimeters, TLD dosimeters and OSL dosimeters). The film dosimeter detector system was deliberately omitted because the size of the detector system does not allow it to be worn inconspicuously on the body all day. The purpose of the study was to demonstrate that radiation exposure resulting from the medical use of open radioactive substances, in this case radioiodine therapy, is low and that there is compliance with legal framework conditions. OSL dosimeters have been utilized for personal dosimetric monitoring since 2018. The available data thus also allow conclusions to be drawn about the measurement accuracy of the earlier and now officially-approved dosimeters.

Materials and Methods

The study recruited 147 patients after radioiodine therapy and their relatives. The age of the patients was between 22 and 86 years, (mean: 60.9 years). The dosage output rate at discharge was measured in the treatment ward at a distance of 1 m from the patient. A calibrated probe measuring station ISOMED 2101 (MED Nuklear-Medizintechnik Dresden GmbH, Germany/now NUVIA Instruments GmbH) with a scintillation detector is used for this purpose.

The patients and their relatives living in the household wore approved finger ring dosimeters (FRD) all day during a defined period of 14 days; in addition, the dose was determined by non-officially-approved OSL and TLD dosimeters for the duration of the sleep phase. OSL dosimeters consisting of beryllium oxide (BeO) and marketed by Brush Wellmann Inc. (USA) as Thermalox Beo 99.5 were used. The TLD dosimeters used for the measurement were TLD-100 units, distributed by Harshaw-Bicron (Wermelskirchen, Germany). These dosimeters are made of LiF doped with magnesium and titanium (LiF: Mg, Ti). The non-official dosimeters were provided in a cassette to be placed under the family member's pillow and were equipped with 4 OSL and 2 TLD dosimeters each. The exposure time was limited to 14 days, and the dosimeters were then returned for evaluation. In order to measure a realistic exposure situation, no instructions were provided regarding distance or exposure time.

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Primarily patients with benign thyroid disease were considered. The disease structure of the patients was composed as follows: autonomy 67 %, Graves' disease 18 %, thyroid carcinoma 9 %, hyperthyroidism 6 %.

If the data were incomplete (e. g., loss of an FRD) or implausible (dose of the relative's FRD higher than that of the patient), the entire data set was excluded from the analysis (details in ▶ **Fig. 1**).

Different calibration methods were used. Each OSL dosimeter was assigned an individual calibration factor obtained from calibration by irradiation at a Xylon-type X-ray irradiation system (tube voltage: 200 kV, beam current: 2 mA, focus of the tube: 5.5 and an irradiation time of 46 s, dose: 100 mGy). In addition, the response of the OSL dosimeters was determined with an I-131 radiation source (I-131 capsule free air). As a result, the OSL dosimeters showed a 25–30 % higher response for I-131 compared to calibration with X-rays.

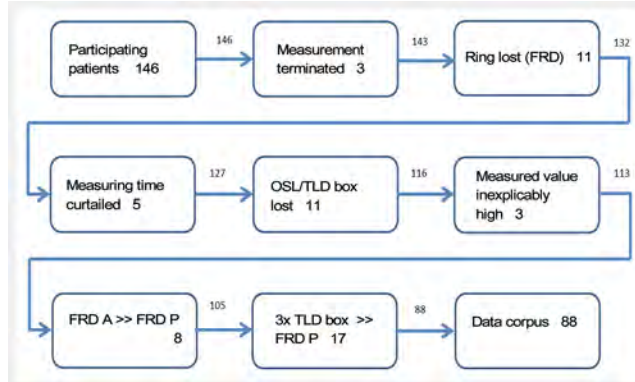
In the case of the TLD dosimeters, a dosimetric classification of a large number of dosimeters was carried out. The non-official TLD dosimeters used were calibrated in the Verein für Kernverfahrenstechnik und Analytik e. V. Rossendorf (VKTA) [English: Association for Nuclear Process Engineering and Analysis] in the same way as the OSL dosimeters with an I-131 capsule free air acting as a point source. The HARSHAW TKD 2000 ring dosimeter with the official designation LPS-TLD-TD 05 was used for the finger ring dosimeters. A PTB-type approval (approval number: 23.02/98.01) with a measuring range of 0.3 mSv to 10 000 mSv and a response capability of 95 % at I-131 free air related to the calibration with the X-ray tube was available for these finger ring dosimeters.

For the evaluation of the dosimeters, the following procedure was chosen: the official FRD of the patient and relatives were evaluated by the officially recognized measurement center in Berlin (LPS). The stationary TLD and OSL (in the box under the relative's pillow) were evaluated by an external measurement facility (TLD) and in-house (OSL), respectively.

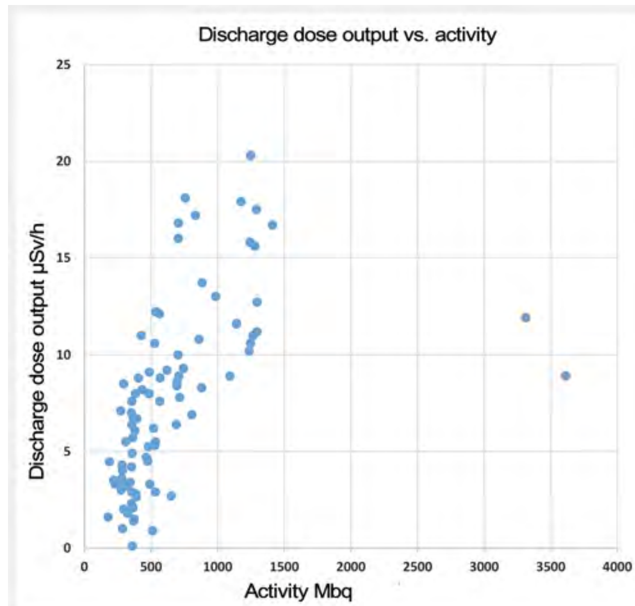
Results

Of the 147 study participants, the measurement results of 88 sets could be finally evaluated. ▶ **Fig. 1** shows in detail which reasons led to the exclusion of measured values.

The relationship between applied activity and dose rate output at discharge is shown in ▶ **Fig. 2**. ▶ **Fig. 2** shows the values of the discharge dose output rate at a distance of 1 m from the patient, thus a value of 14 µSv/h corresponds to the value of 3.5 µSv/h at a distance of 2 m. Lower prescribed activity levels were generally associated with lower discharge output dose rates. Exceptions to this are two patients with thyroid carcinoma, whose discharge dose rate was measured comparatively in the low range at high applied activity. In ten patients, use was made of the exception to the limiting discharge dose rate of 3.5 µSv/h at a distance of 2 m for social reasons. This procedure is regulated by paragraph 9.1 of the German Radiation Protection in Medicine guideline. Early discharge was reported to the relevant authorities. ▶ **Table 1** shows the mean effective half-lives of each disease for the patients included in the study at the time of discharge. The listing demonstrates that the mean effective half-life in thyroid carcinoma in the studied patient



▶ **Fig. 1** Scheme of plausibility consideration.



▶ **Fig. 2** Correlation of the discharge dose rate with the applied activity.

population is the lowest, at 1.5 ± 0.40 days. The mean discharge dose rate was 7.69 ± 4.7 µSv/h. The disease structure of the patients has already been explained in the Materials and Methods section.

The FRD exposure of the patients was determined to be between 0.1 and 50 mSv and correlates with the discharge dose rate (▶ **Fig. 3**). Depending on the biological half-life, a higher or lower FRD exposure was to be expected, but the effective half-life was not determined separately. In this context, it was important that measured values from patients exist over a wide dose range in order to be able to determine the exposure of family members. For this purpose, in ▶ **Fig. 4A**, the exposure of the FRD of the relative is correlated with that of the patient. As expected, the dose of the relatives is significantly lower than that of the patients. On average, 0.75 mSv in the relative is compared with 10 mSv in the patient, which corresponds to a factor of 13.

The evaluation of the individual values from two TLD and OSL dose sensors, which were positioned stationary under the rela-

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▶ **Table 1** Patients' diseases and the associated mean effective half-life at discharge.

Disease	Mean effective half-life in d
Autonomy	4.0 ± 2.43
Basedow's disease	4.6 ± 2.27
Thyroid cancer	1.5 ± 0.40
Hyperthyroidism	5.3 ± 2.47

tives' pillows, are shown in ▶ **Fig. 4 D, C**. The TLD pairs show a much higher deviation from each other than the OSL pairs. The measuring range of the TLD and OSL is comparable. The comparison of the mean values of OSL and TDL (▶ **Fig. 4B**) shows a clear scatter, with a deviation occurring in both directions. No measurement error can be specified since individual measured values are available here

▶ **Fig. 5A–D** shows the FRD values of the patient as well as the FRD values of the relatives in comparison with the stationary measurement systems. Both stationary measurement systems show significant deviations from the FRD and do not allow any correlation.

Discussion

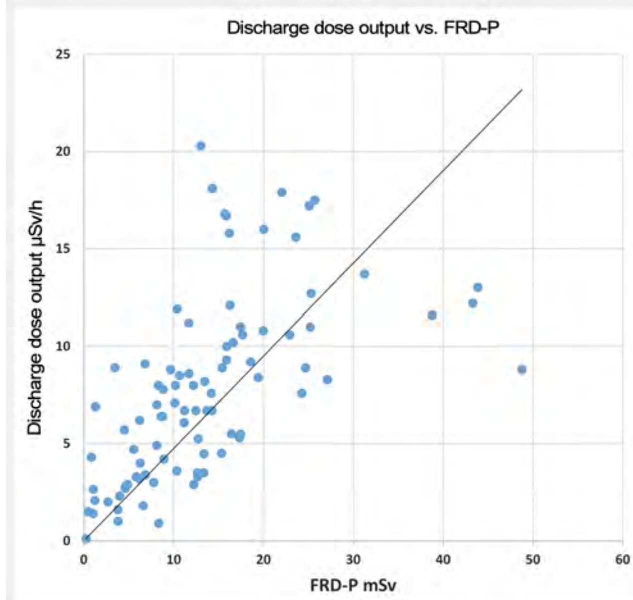
The value of the present work is that a former officially-approved and the currently mandatory measurement system were used in patients and their relatives after radioiodine therapy and the dose measurements were directly compared.

Special aspects of the measuring systems, the exposure duration and the geometry have to be considered in order to interpret the data. Plausibility checks were used to identify outliers and eliminate numerous data sets prior to evaluation (see ▶ **Fig. 1**).

In phantom measurements, Al-Senan et al. found very good agreement between OSL dosimeters and TLDs for different geometries over a wide dose range [11]. In contrast, in the present study of patients and relatives, OSL dosimeters were found to have the highest agreement, whereas TLDs were subject to significant variation.

The obtained results support the conclusion that the fluctuation of the measured values of the TLDs read out in the VKTA applies similarly to the official dosimeters (FRD), because they do not have an individual history, but are calibrated as a group. Since there were no duplicate determinations for the FRD, this assumption can be neither confirmed nor denied. The type approval examination specifies a measuring range of 1 mSv to 10 000 mSv and a fluctuation margin of 30 % [15]. Since single measurement values were collected, no measurement error can be specified.

In contrast, the accuracy or reproducibility of the OSL dosimeters is reported to be < 5 %, and the present study supports this claim. It was shown that the OSL dosimeters had higher precision



▶ **Fig. 3** Discharge dose rate plotted against patient finger ring dosimeter readings.

than the TLDs even when both measurement systems were calibrated to I-131. According to type testing, the sensitivity of the OSL is higher than that of the TLD. For the OSL dosimeters, a measurement range of 0.05 mSv–10 mSv is indicated, while for the TLD a lower threshold of 0.3 mSv is reported. References in the literature also support this statement for the OSL dosimeters in the so-called "diagnostic energy range" (29 keV to 120 keV X-ray radiation). OSL dosimeters show homogeneous and linear measured values as well as high stability and measured value reproducibility even in the low dose range [11].

The fact that the finger ring dose of the patients only correlates moderately well with the finger ring dose of the relatives may (as explained above) be due to the measuring system, the variable exposure duration and the radiation geometry. It was not documented whether, for example, the patient or relative was still working or whether separate bedrooms were available.

Regarding the exposure duration of the TLD and OSL, an 8-hour night rest can be assumed, so that an exposure of the stationary measurement systems should always be lower than that of the FRD of the relative who should wear his FRD all day. Thus, more exposure up to a factor of 3 could be documented in the FRD than in the stationary measurement system; however, this is not always the case. Whether this difference is real or caused by the fluctuation range of the measuring system cannot be conclusively determined. Estimates of nighttime geometry suggest that significant differences or uncertainties are present in this case. ▶ **Fig. 6** shows the distances between the radiation source and the respective detector. Bed width, distance from one another, position of the stationary detectors and wearing location of the FRD for the patient and relatives, as well as body size not taken into account, already lead to uncertainties by a factor of 3–5.

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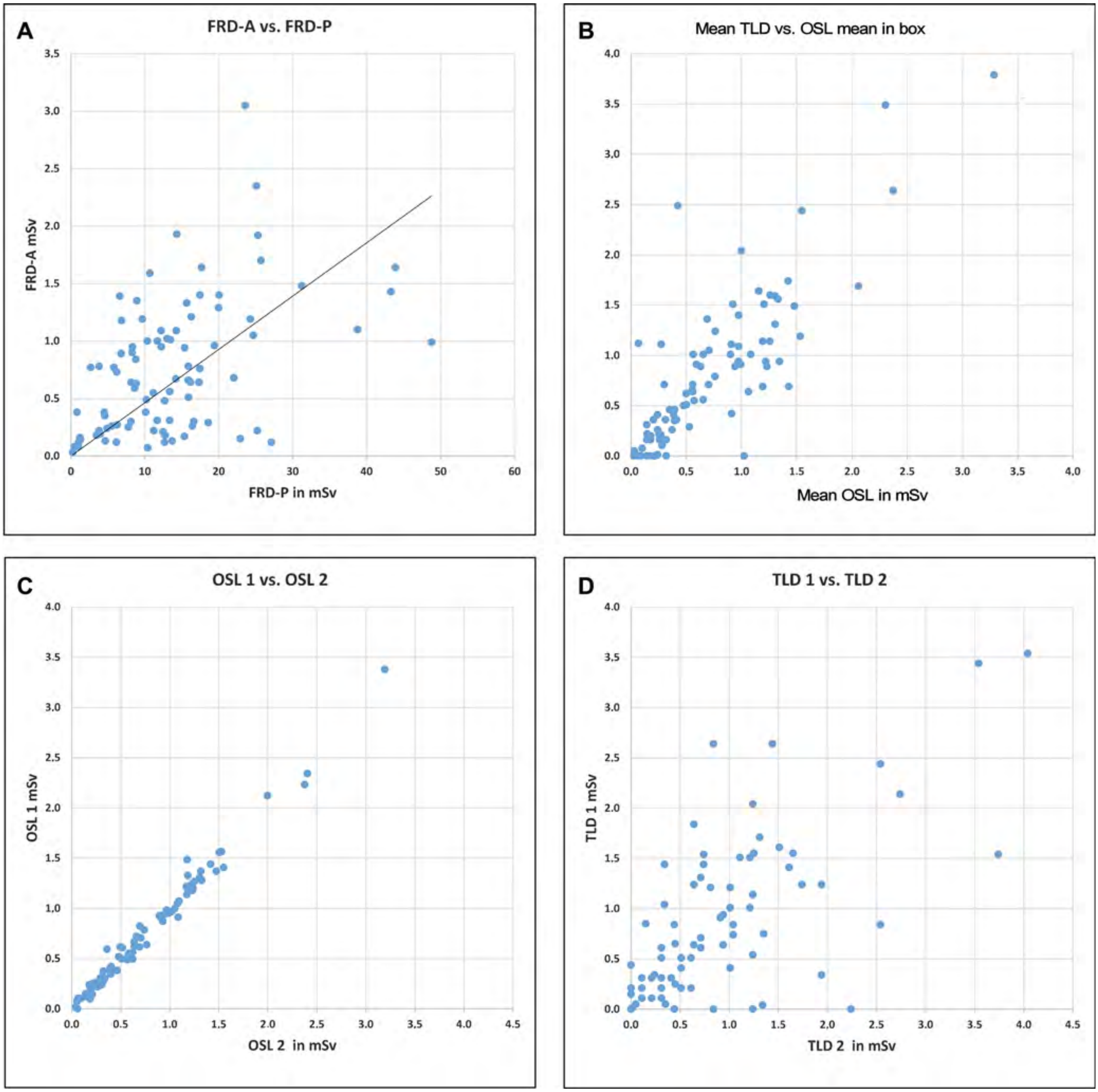

▶ **Fig. 4** **A** Comparison of finger ring dosimeter readings from patients to relatives, **B** Comparison of the mean values of the TLD dosimeters with the OSL dosimeters from the box, **C** Comparison of the individual measured values of the OSL dosimeters from the box, **D** Comparison of the individual measured values of the TLD dosimeters from the box.

Further, it should be taken into account that the location of the patient's FRD is not stationary with respect to the thyroid gland and changes both with movement during the day and depending on the sleeping position: when the patient is resting at night in a stable lateral position, the distance of the FRD from the radiation source is only a few centimeters. A computational estimate from the values in ▶ **Table 2** yields a geometrically determined difference in dose of no more than 200 (hand with FRD under head versus outstretched arm). Since a certain sleeping position cannot be reliably maintained or remembered afterwards, the dosimeters should be attached to a different wearing location on the body.

Due to the patient's movements during the night, even the stationary probes in the box under the relative's pillow do not have a constant distance to the radiation source. Similar considerations apply to the relatives. Thus, both the patient's FRD and the stationary box are only uncertain reference points with regard to the relative's actual exposure.

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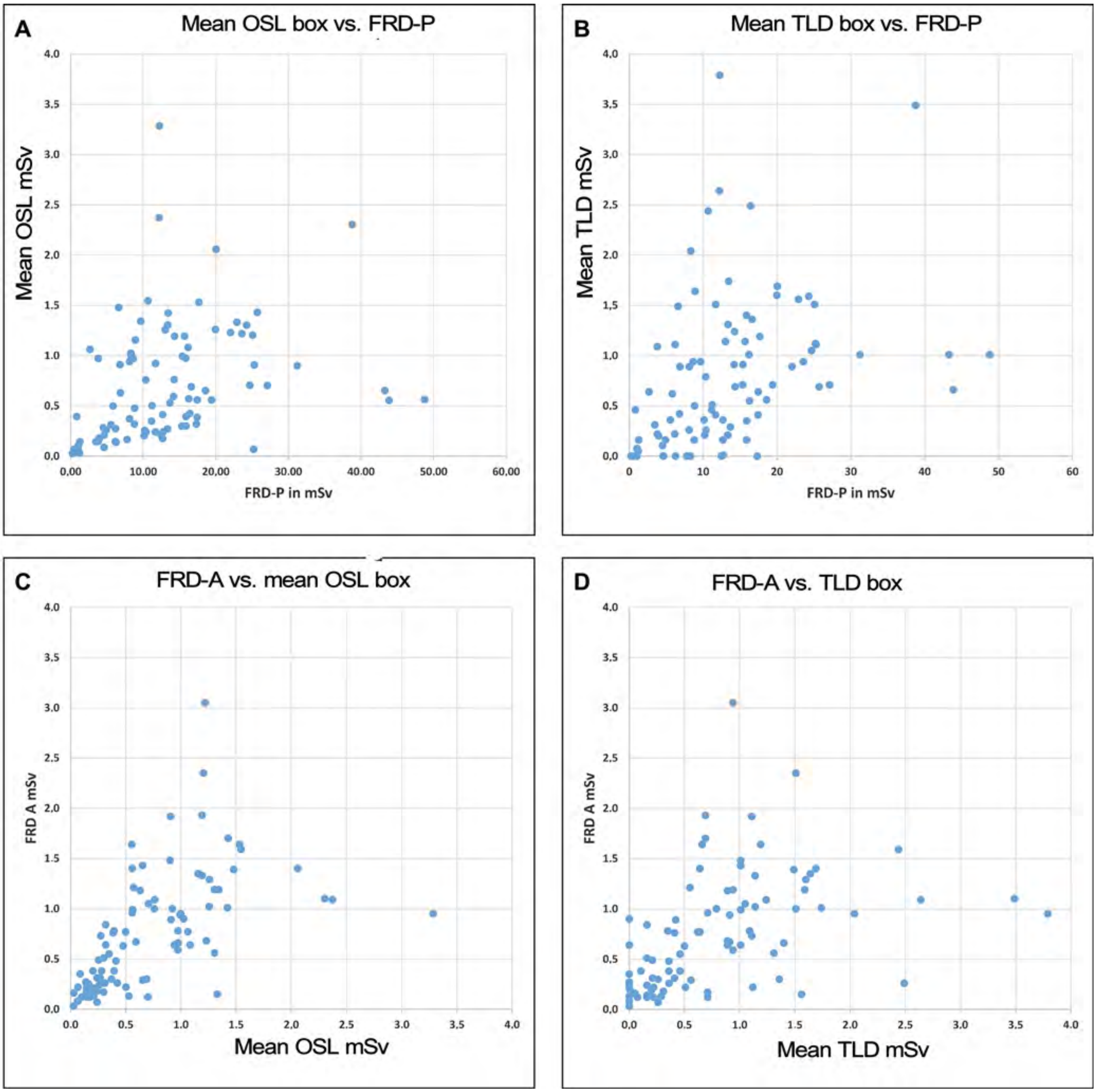

▶ **Fig. 5** **A** Comparison of the mean value of the OSL dosimeters from the box with the patient's finger ring dosimeter, **B** Comparison of the mean value of the TLD dosimeters from the box with the patient's finger ring dosimeter, **C** Comparison of the finger ring dosimeters of the relative with the mean value of the OSL dosimeters from the box, **D** Comparison of the finger ring dosimeters of the relative with the mean value of the TLD dosimeters from the box.

Despite the aforementioned uncertainties and fluctuations, the present study with 3 different measurement systems shows that an exposure dose of 3 mSv was not exceeded for the relatives of patients after radioiodine therapy. This assumes that after completion of the 14-day measurement campaign, no further significant dose contribution occurs in the exposure of the relative. This limits the study's conclusions. This result concurs with the literature. Data were provided on the effect of various radionuclide therapies on the exposure of relatives [16], ranging from 0.1–3.08 mSv. In another study by Matheud et al. [17] similar effective doses for relatives and other groups of people (employees, traveling companions) are listed, the range is given as 0.3 mSv to 3 mSv. Concurring with the current study, Kadhim et al. [18] demonstrate hat a mathematical estimation of the exposure dose is very difficult due to the diverse factors such as the patient's activity, distance, age of the relatives and other personal factors and that no significant correlation was found. However, even with these data, there are different measuring probes as well as unde-

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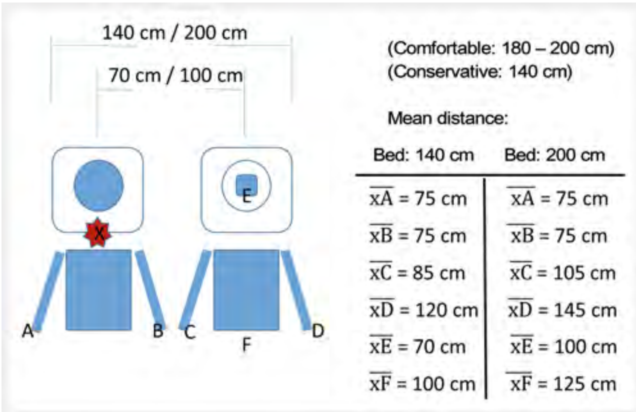

► **Fig. 6** Geometric estimation of the lying position (X-thyroid of the patient, E-position of the dosimeter box, A–D position of the finger ring dosimeters, F-finger position when lying on the side).

► **Table 2** Table of the calculated discharge dose rate, respectively the ratios at the distances from ► **Fig. 6**. A value of 15 µSv/h at a distance of 100 cm was assumed as a reference value.

Distance to thyroid	**Dose (discharge dose)**	**Ratio**
In cm*	**µSv/h in 100 cm**	**100 cm/distance to thyroid**
	15	0.00
10 (*)	1500	0.01
70	30.61	0.49
75	26.67	0.56
85	20.76	0.72
100	15.00	1.00
105	13.61	1.10
120	10.42	1.44
125	9.60	1.56
145	7.13	2.10

* Distance characterizes the special position of the hand when sleeping "hand under chin".

fined wearing sites and missing data regarding the daily exposure duration. Based on all literature data, however, it can be concluded that a relevant radiation exposure of the relatives due to contamination and ingestion does not play a role if minimal hygiene rules are observed [11, 17, 19, 20]. Electronic detector systems (COTI system) have been available for some time, making it possible to perform real-time monitoring by wearing a collar positioned directly over the thyroid gland. This makes it possible to perform the measurements across a period of time points. However, more extensive studies are required for a reliable assessment of the achievable measurement accuracy [21].

Outlook

The large uncertainties in the measurement system, the exposure time and the irradiation geometry make the previous reports in the literature appear in a different light and much more uncertain. The measurements of the exposure of relatives after radionuclide therapy with OSLs should be repeated, and double measurements should be taken into account. In addition, exposure times should be documented in more detail and the geometry of nighttime exposure should be considered. For this purpose, behavioral measures must be communicated and deviations from them must be documented.

Conclusions

In summary, it could be shown that the now official OSL dosimeters represent a more accurate measuring system than the TLD units and are more suitable for the chosen measuring task. The determined measured value is linked to an exact recording of the exposure time (wearing time) of the dosimeter. Further uncertainties result from the wearing location on the body. Despite method-related measurement uncertainties, it has been shown that the exposure dose to relatives of patients after radioiodine therapy is low. Nevertheless, it seems sensible to repeat the investigations, taking the limitations into account.

Conflict of Interest

The authors declare that they have no conflict of interest.

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