Strahlentherapie
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Original Article

Exposure of Treating Physician to Radiation during Prostate Brachytherapy Using Iodine-125 Seeds

Dose Measurements on Both Hands with Thermoluminescence Dosimeters

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Background and Purpose: Only sparse reports have been made about radiation exposure of the treating physician during prostate seed implantation. Therefore, thermoluminescence dosimeter (TLD) measurements on the index fingers and the backs of both hands were conducted.
Material and Methods: Stranded iodine-125 seeds with a mean apparent activity of 27.4 MBq per seed were used. During application, the treating physician manipulated the loaded needle with the index fingers, partially under fluoroscopic control. Four physicians with varying experience treated 24 patients. The radiation exposure was determined with TLD-100 chips attached to the index fingertips and the backs of hands. Radiation exposure was correlated with the physician's experience.
Results: The average brachytherapy duration by the most experienced physician was 19.2 min (standard deviation σ = 1.2 min; novices: 34.8 min [σ = 10.2 min]). The mean activity was 1,703 MBq (σ = 123 MBq), applied with 16.3 needles (σ = 2.5 needles; novices: 1,469 MBq [σ = 229 MBq]; 16.8 needles [σ = 2.3 needles]). The exposure of the finger of the "active hand" and the back of the hand amounted to 1.31 mSv (σ = 0.54 mSv) and 0.61 mSv (σ = 0.23 mSv), respectively (novices: 2.07 mSv [σ = 0.86 mSv] and 1.05 mSv [σ = 0.53 mSv]).
Conclusion: If no other radiation exposure needs to be considered, an experienced physician can perform about 400 applications per year without exceeding the limit of 500 mSv/year; for novices, the corresponding figure is about 200.

Key Words: Prostate cancer · Brachytherapy · Iodine-125 seeds · Radiation exposure · TLD

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Strahlenexposition des applizierenden Arztes bei der Brachytherapie mit Iod-125-Seeds. Dosismessungen an beiden Händen mit Thermolumineszenzdosimetern

Hintergrund und Ziel: Zur Strahlenexposition des applizierenden Arztes bei der Brachytherapie mit Iod-125-Seeds, insbesondere an den Fingern, existieren kaum Informationen. Mit TLD (Thermolumineszenzdosimeter) wurden deshalb Dosismessungen an den die Nadel führenden Zeigefingern und den Handrücken jeweils beider Hände durchgeführt (Abbildung 2) und mit der Erfahrung des Applizierenden korreliert.
Material und Methodik: Es wurden Iod-125-Seedketten mit einer mittleren scheinbaren Aktivität von 27,4 MBq pro Seed verwendet (Tabelle 1). Während der Applikation manipulierte der Arzt die beladenen Nadeln mit den Zeigefingern, teilweise unter Durchleuchtung (Abbildung 1). Vier Ärzte mit unterschiedlicher Erfahrung behandelten 24 Patienten. Die Strahlenbelastung wurde mit TLD-100-Chips gemessen, welche auf beide Zeigefinger und die Handrücken aufgeklebt wurden (Abbildung 2).
Ergebnisse: Eine Applikation des Arztes mit der größten Erfahrung dauerte durchschnittlich 19,2 min (Standardabweichung σ = 1,2 min), wobei er im Mittel 1 703 MBq (σ = 123 MBq) in 16,3 Nadeln (σ = 2,5 Nadeln) verwendete. Ein unerfahrener Operateur benötigte für eine Applikation von durchschnittlich 1 469 MBq (σ = 229 MBq) mit 16,8 Nadeln (σ = 2,3 Nadeln) im Mittel 34,8 min (σ = 10,2 min) (Abbildungen 3 und 4). Die beim erfahrenen Arzt gemessene mittlere Strahlenexposition des stärker belaste-

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ten Fingers betrug 1,31 mSv (σ = 0,54 mSv), jene des Handrückens 0,61 mSv (σ = 0,23 mSv). Die korrespondierenden Werte des unerfahrenen Operateurs lagen bei 2,07 mSv (σ = 0,86 mSv) bzw. 1,05 mSv (σ = 0,53 mSv) (Abbildungen 5, 6a und 6b.
Schlussfolgerung: Ohne Berücksichtigung anderer Strahlenexpositionen kann ein erfahrener Arzt pro Jahr etwa 400, ein unerfahrener Arzt etwa 200 Applikationen durchführen, ohne den Dosisgrenzwert von 500 mSv/Jahr zu überschreiten.

Schlüsselwörter: Prostatakarzinom · Brachytherapie · Iod-125-Seeds · Strahlenexposition · TLD

Introduction

The standard radiotherapeutic approach to the treatment of localized tumors of the prostate has changed dramatically over the past 20 years [17]. The reasons are the increase in the proportion of low-risk cancers and new treatment techniques [26]. Brachytherapy of the prostate with iodine-125 seeds was introduced in Switzerland in 2001 and is increasing in importance. In addition to control of the tumor, preservation of the patient's quality of life is a prime objective of therapy. Furthermore, the risk of cancer induction by the irradiation is lower than with external irradiation [19].

At St. Gallen Cantonal Hospital, Switzerland, we use brachytherapy to treat patients with low- and moderate-risk clinically localized cancer of the prostate [11, 23]. The low-risk group includes patients with carcinomas that meet the following criteria: maximum clinical stage T2a, prostate-specific antigen (PSA) value ≤ 10 ng/ml, and Gleason Score ≤ 6 [7]. The moderate-risk group includes those who meet two of the low-risk criteria and have a maximum of one of the following: clinical stage T2b, PSA value > 10 to ≤ 20 ng/ml, or Gleason Score = 7. The patient's risk group, however, is of no relevance for the topic of this study. Patients who have undergone transurethral resection of the prostate are not eligible for brachytherapy. The prostatic volume has to be < 60 cm^3 mainly for technical reasons. Similar to other groups [15], we characterize the success of the application with the dose parameters V100 (volume receiving 100% of the prescribed dose), D90 and D80 (dose received by 90% and 80% of the target volume, respectively).

The basic principles of radiation protection are followed as far as possible: the manufacturer supplies the seeds in a metal magazine that absorbs most of the radiation (shielding). The trimming of the seed chains to the planned length and the loading of the needles is semiautomatic, using a loading station behind a lead glass shield (time, distance, shielding). The loaded needles are stored in a metal container at least 1 m from the surgical staff until they are used (shielding, distance). During application, however, the treating physician massively contravenes three golden rules of radiation protection: the distance between the finger inserting the needle and the radiation source is < 1 mm at times (no distance), and the seeds are manipulated without any protection at all (no shielding). The overall duration of manipulation close to the radiation source can be markedly longer than 10 min (time).

The dose burden to the patient is well known [10, 24]. A number of investigations have also evaluated the radiation dose for medical staff and the relatives of patients treated with radioactive substances. Cattani et al. [6] showed that the radiation exposure of relatives of brachytherapy patients is well below the legal threshold. Investigations into radiosynoviorthesis patients showed that the finger exposure of the staff can exceed the annual dose limit of 500 mSv when working at low protection standard [18]. Other groups studied radiation exposure in staff involved in interstitial brachytherapy with gold seeds and recommended that optimized radiation protection measures be applied [20]. Using thermoluminescence dosimeters (TLDs), a dose of 0.6 mSv per application was measured on the fingertips of the attending physicians involved in treatment of cervical carcinoma with implants of 60 mg radium [12].

Effective doses $H_p(10)$ and the equivalent dose $H_p(0.07)$ of < 30 and 420 µSv per application were measured using film and finger ring dosimeters during brachytherapy with iodine-125 seeds [1]. In contrast, $H_p(0.07)$ values up to 1 mSv were measured on the hands [14]. These measurements, however, can hardly be used as indicators of the dose absorbed by the most highly exposed side of the index finger which the treating physician uses to guide the needle.

In the present study, measurements of the radiation dose using TLD on both index fingers and the backs of the hands of physicians performing brachytherapy are reported.

Material and Methods

Patients

Data were collected during application of seeds for prostate brachytherapy in 24 consecutive patients at two institutions from April 2006 to January 2007. Clinical T-categories were T1 and T2 in 18 and six patients, respectively, Gleason Scores of 6 and 5 were found in biopsy specimens of 22 and two patients, respectively. The mean PSA level was 6.5 ng/ml (σ = 3.0 ng/ml; minimum = 2.1 ng/ml, maximum = 14.0 ng/ml).

Material

Isocord iodine-125 seed chains (Eckert & Ziegler, BEBIG, Berlin, Germany) were used for brachytherapy of the prostate. The half-life of the nuclide is 59.4 days. A seed consists of a sealed 4.5 mm long titanium rod with an external diameter of 0.8 mm surrounding the isotope iodine-125. Under normal conditions of use, this prevents escape of the radioactive isotope and rules out any possibility of contamination. The hollow needles (18 G) are made of stainless steel with an internal diameter of 1.1 mm. There is only negligible shielding of radiation because the needle wall is thinner than 0.1 mm.

Figure 1. Application of the hollow needles.
Abbildung 1. Applikation der Hohlnadeln.

Figure 2. Position of the TLDs on the index fingers and backs of hands.
Abbildung 2. Position der TLDs an den Zeigefingern und Handrücken.

The ultrasound head used for rectal imaging is mounted onto the stepping unit (Brachystepper with Brachystand 6 Ultra, Barzell-Whitmore Maroon Bells, Inc. Sarasota, FL, USA) and can be gradually advanced longitudinally into the rectum [8]. A plastic template with a grid of 5-mm holes is fixed onto the stepping unit (B & K Standard, BK Medical, Herlev, Denmark). Together with the stepping unit, this template determines the coordinate system. The prostate is coupled to the coordinate system using two fixation needles [13] (Figure 1). The software of the ultrasound device superimposes the template grid on the ultrasound image. The Variseed 7 (Varian Medical Systems Inc., Palo Alto, CA, USA) program is used to plan the irradiation. A loading station developed by the seed manufacturer is used to trim the seed chains and load the needles.

Methods

The application method is described elsewhere [13]. The planning target volume (PTV) is defined of the prostate plus a margin of 3 mm (laterally), 5 mm (base), and 2 mm (apex), respectively. The prescribed dose based on the PTV is 145 Gy. To determine the optimum seed position, the planning system takes the following dosimetric constraints into account:

PTV:	V_{100}	$\geq 95\%$ of the prescribed dose;
	D_{90}	$\leq 125\%$ of the prescribed dose;
urethra:	D_5	$\leq 150\%$ of the prescribed dose;
rectum:	V_{100}	$\leq 0.3\ cm^3$.

During application, the physician uses the ultrasound image (all three planes) and the fluoroscope (longitudinally) for orientation. The staff wear lead aprons and the treating physician also a thyroid shield.

The treating physician controls the insertion direction of the needle by turning the beveled end of the needle. If this is not enough, the physician applies pressure on the needle with the side of the finger controlling the needle facing the thumb. At this time, the hand is between the template and the patient's perineum, at times therefore in the scatter region of the fluoroscope (Figure 1). The distance between the side of the index finger and the seeds is therefore markedly less than 1 mm at such times. Since this procedure relies a great deal on "feeling" [16, 22], the treating physician does not wear lead gloves. These would impede sensitivity and lengthen the duration of the application, and in turn increase the exposure to radiation [1, 9, 25].

Both the seeds and the fluoroscope contribute to the radiation exposure to the hands. TLD-100 discs (Ø = 4.5 mm; thickness = 0.9 mm; manufacturer: Harshaw, now: Thermo Scientific Inc., Waltham, MA, USA) sealed in plastic sheeting are affixed to the radial index finger sides and on the back of both hands to measure the exposure (Figure 2). Three or four TLDs are applied per measuring point.

The most experienced physician (about 50 brachytherapies within the last 2 years) performed six applications. The other three treating physicians (fewer than ten applications at the beginning of the exposure measurements) performed a total of 18 applications. The doses at the fingertips were measured for all 24 applications, and on the backs of the hands for 22. The higher values are used for interpretation.

A PTW-TLDO oven (PTW, Freiburg, Germany) was used to anneal the TLDs, and a 5500 Reader (Harshaw) was

Table 1. Mean, standard deviation (SD), minimum and maximum for application parameters.

Tabelle 1. Mittelwert, Standardabweichung (SD), Minimum und Maximum verschiedener Applikationsparameter.

	Mean	SD	Minimum	Maximum
Prostate volume (cm^3)	44.3	11.0	26.8	64.6
Seeds per application (n)	55.5	6.9	40	70
Activity per seed (MBq)	27.4	1.5	23.6	28.8
Activity per application (MBq)	1,527.4	231.4	1,124.8	1,947.7
Needles per application (n)	16.7	2.4	12	22
Application time (min)	30.9	11.2	17	60

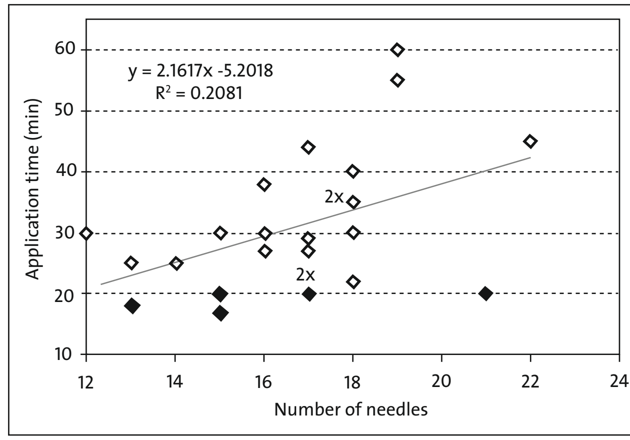


Figure 4. Correlation between application time and number of needles. Black diamonds: datapoints for experienced physician.

Abbildung 4. Zusammenhang zwischen Applikationszeit und Zahl der Nadeln. Die Datenpunkte für den erfahrenen Urologen sind mit schwarzen Rauten dargestellt.

used for evaluation. The actual sensitivity of the TLD reader system was determined by irradiating ten TLDs from the same evaluation batch using a cobalt-60 device. The conversion factor from cobalt-60 to iodine-125 was taken from the literature and verified with phantom measurements.

The degree of radiation exposure measured was correlated with the experience of the treating physician.

Results

Statistics of Applied Seeds

Statistical information on prostate volumes, the seeds applied, their activity, the needles, and application times are given in Table 1.

Per session, the experienced physician applied a mean of 1,703 MBq (σ = 123 MBq) in 16.3 needles (σ = 2.5 needles), and the novices 1,469 MBq (σ = 229 MBq) in 16.8 needles (σ = 2.3 needles). Although the experienced physician applied a slightly higher activity of Δ = 235 MBq (σ = 260 MBq), the overall mean number of needles applied can be assumed as identical (Δ = 0.5; σ = 3.4). The mean application time for the experienced physician was 19.2 min (σ = 1.2 min; minimum = 17 min, maximum = 20 min). The novices needed almost twice as long with a mean of 34.8 min (σ = 10.2 min; minimum = 22 min, maximum = 60 min) (Figure 3).

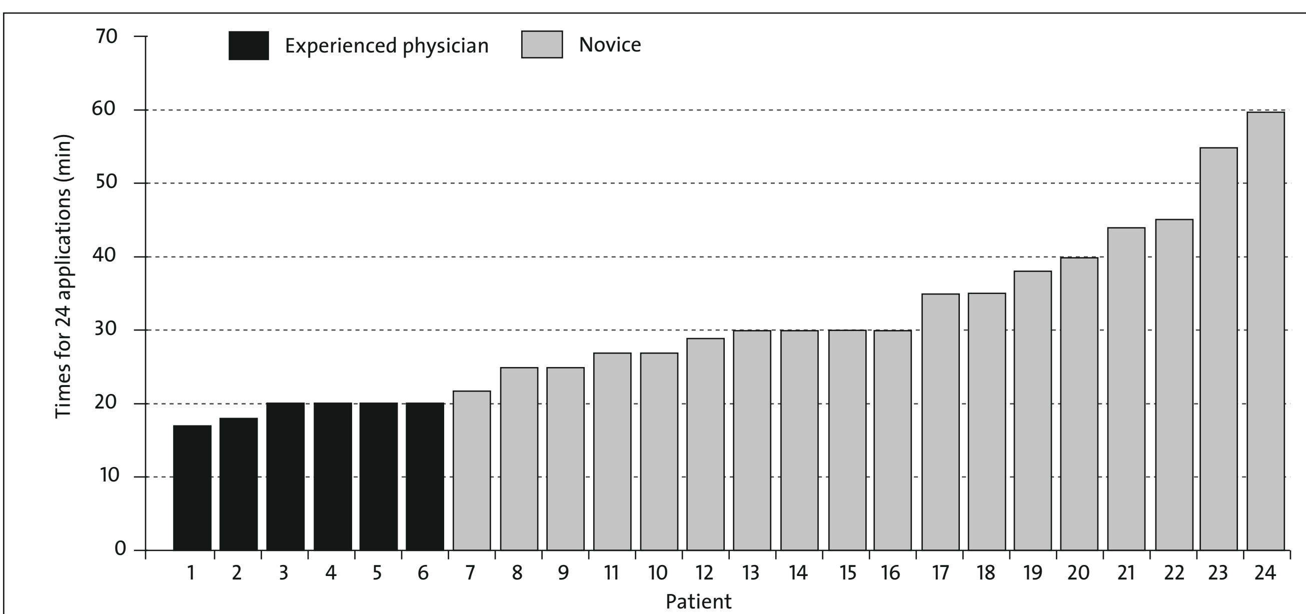


Figure 3. Application times for 24 seed implantations of the prostate.

Abbildung 3. Applikationszeiten für 24 Prostataimplantationen.

There was only a weak correlation between the number of needles applied and application time (Figure 4): Pearson's correlation coefficient R was 0.46.

Dose Measurements

Means of 1.31 mSv (σ = 0.54 mSv) on the fingers and 0.61 mSv (σ = 0.23 mSv) on the backs of the hands were found for the experienced physician. The respective values for the novices were 2.07 mSv (σ = 0.86 mSv) and 1.05 mSv (σ = 0.53 mSv; Figure 5). Anglesio et al. [1] reported a 50% lower dose on the hands of experienced surgeons, which is in the same order of magnitude.

The following plausible assumptions were made with regard to the extent of exposure to radiation:

- The doses measured on the backs of the hands were primarily attributable to the fluoroscope.
- The fingers and backs of the hands were subject to similar degrees of exposure from the fluoroscope.

The ratio between the doses measured for the fingers and backs of hands were determined for 22 applications. The mean was 2.09 (σ = 0.61), and there was no significant difference between the experienced physician (2.04; σ = 0.35) and the novices (2.11; σ = 0.67; p = 1.0). Based on the above assumptions, it can be concluded that the fluoroscope accounts for about half of the exposure at the fingers.

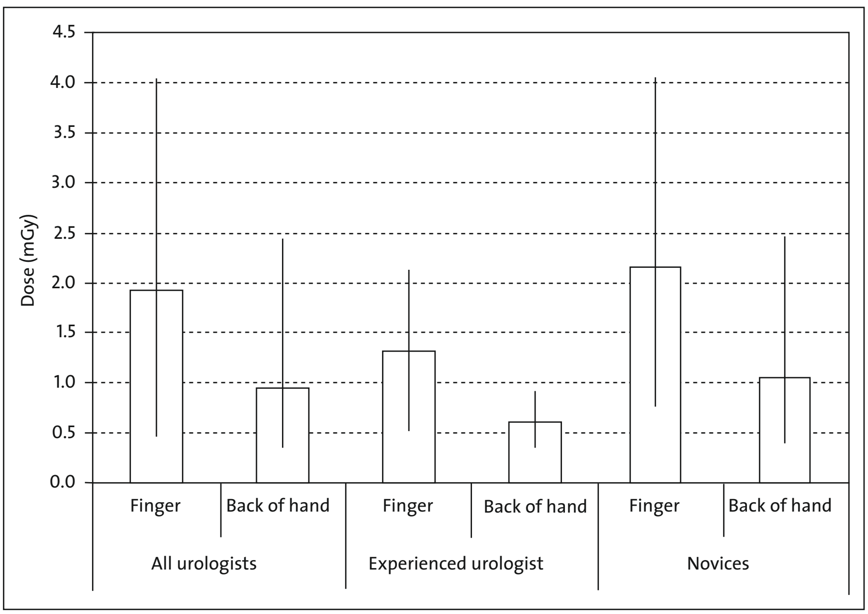


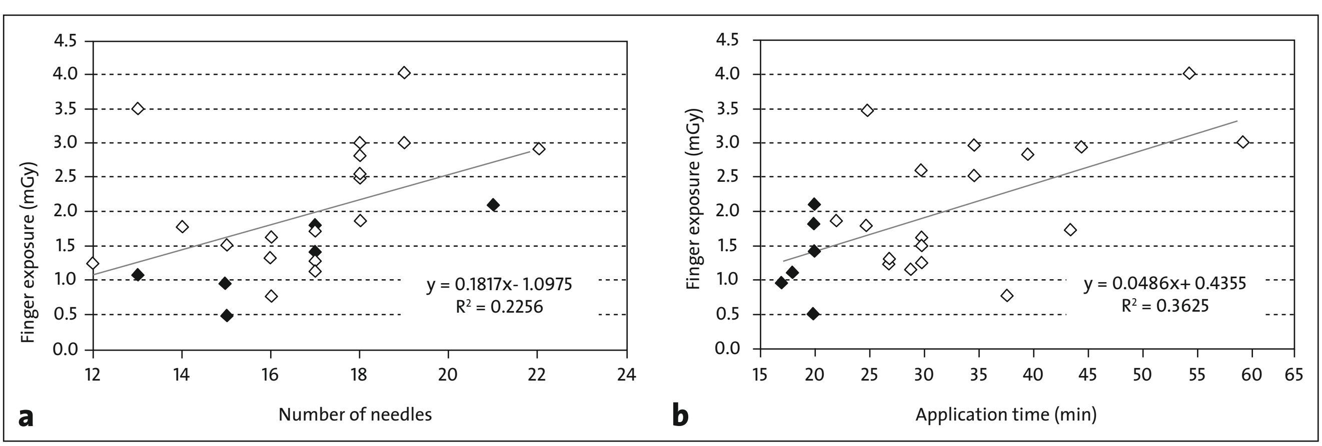
Figure 5. Exposure on fingers and backs of hands grouped according to experience of treating physician. The bars cover the dose range measured.

Abbildung 5. Dosisbelastung an den Fingern und Handrücken, gruppiert nach der Erfahrung der Applizierenden. Die Balken umspannen den gemessenen Dosisbereich.

Dependencies of the Measured Dose

With this limited number of applications, a mild correlation between the finger dose and the number of needles applied (R = 0.48) and application time was observed (R = 0.60), as shown in Figure 6. This is, however, not surprising, since the duration of the applications is weakly related to the number of needles applied.

However, the finger dose did not depend on the number of seeds applied (results not presented here, R = 0.08). This indicates that the local dose to the



Figures 6a and 6b. Correlation between finger exposure and number of needles applied (a) and application time (b). Black diamonds: datapoints for experienced physician.

Abbildungen 6a und 6b. Abhängigkeit der Fingerdosis von der Zahl der applizierten Nadeln (a) und der Applikationszeit (b). Die Datenpunkte für den erfahrenen Urologen sind mit schwarzen Rauten dargestellt.

finger mainly depends on the seed directly under the area where pressure is applied by the finger, and that the remaining seeds play a subordinate role because of the dose-distance inverse square law.

Discussion

Radiation protection legislation in the EU countries stipulates a threshold level for the effective dose on the hands of 500 mSv per year [2–4]. According to the Austrian radiation protection legislation the threshold value must not be exceeded by the dose averaged over 1 cm^2 [4]. The mean annual extremity dose in radiation therapy, reported for France, Germany and Ireland for the year 2005, is between 2 and 8 mSv. Individual doses > 50 mSv are reported [9]. It has to be assumed that the maximum skin dose is several times larger [25]. Nevertheless, there are very few published data about the dose to the hands in manual brachytherapy [9, 25].

In most diagnostic radiology procedures the dose to the hands will be fairly homogeneous. During manual seed insertion into the prostate, however, it is obvious that the skin of the fingertip leading the needle gets the maximum dose and therefore limits the number of applications from the viewpoint of radiation protection [5, 9, 25].

The dose to the fingertips can be considerably higher than the dose measured with a ring dosimeter worn at the usual position [25]. It is composed of two dose contributions with varying weights, originating from the seeds and the fluoroscopy. Consequently, it is difficult to deduce the dose to the fingertips from ring dosimeter measurements, as proposed by Vanhavere et al. [25]. These considerations have motivated the measurements presented in this study.

The TLDs used in our study covered an area of about 1 cm^2 and were applied on the regions of highest exposure. We were therefore able to assess whether the threshold value mentioned in [4] was complied with.

Our measurements of exposure of the side of the finger introducing the needle showed that the annual threshold value will usually not be exceeded. An experienced physician with a mean application time of about 20 min can conduct almost 400 brachytherapy sessions without exceeding the threshold value. Physicians with little experience (less than ten applications, mean application time of about 35 min) are exposed to almost twice as much radiation, which agrees with measurements made by other research groups [1]. This means that novices could perform about 200 applications per year – not taking into account that by the end of the year they would no longer have to be considered as novices (the "experienced" physician in the present study had conducted about 50 brachytherapy applications). These estimates do not, however, take radiation exposures from other sources into account.

Palladium-103 seeds are also used for prostatic brachytherapy [17]. A simple estimate based on a comparable application procedure indicates that palladium seeds are likely to expose the finger sides about 50% higher than iodine-125 seeds.

The fluoroscope accounts for about half of the radiation exposure of the fingers. The same degree of exposure, however, can be expected for a much larger area of the body. The contribution of fluoroscopy therefore markedly exceeds that of the seeds [21]. Careful attention should be paid to protection of the whole body, and especially the thyroid, when performing brachytherapy of the prostate.

Conclusion

Unless other radiologic procedures contribute considerably to the exposure of the fingers, some 200–400 manual prostate seed implants may be performed by a single individual without exceeding critical values.

For doses to the trunk the contribution from the seeds is negligible. Standard radiation protection measures for comparable radiologic procedures should be applied.

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