Reduction of Radiation Exposure for the Examiner in Angiography using a Direct Dosimeter

Reduktion der Strahlenexposition für den Untersucher in der Angiografie durch Anwendung eines direkten Dosimeters

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Zusammenfassung

Ziel: Prospektive Evaluation der Strahlenexposition des Untersuchers in der Angiografie. Kann durch Anwendung eines direkten Dosimeters mit akustischem Warnsignal eine Reduktion der Strahlenexposition erreicht werden?
Material und Methoden: Zur Auswertung kommen insgesamt 183 diagnostische und interventionelle Angiografien der unteren Extremitäten unter Anwendung eines direkten Dosimeters. Die vaskulären Eingriffe wurden entweder von einem Erfahrenen (> 5000 Eingriffe), einem Fortgeschrittenen (> 1000 Eingriffe) oder von einem Anfänger (< 200 Eingriffe) vorgenommen. Der Messsensor des direkten Dosimeters mit akustischem Warnsignal wurde auf den linken Handrücken, unterhalb des sterilen Handschuhs, befestigt und während der gesamten Untersuchungszeit getragen. Am Ende der Untersuchung konnte die Dosis bzw. die Dosisleistung direkt abgelesen werden.
Ergebnisse: Die Exposition ist deutlich abhängig von der Erfahrung des Untersuchers. Für den Anfänger ergibt sich die höchste Dosisleistung, gefolgt vom fortgeschrittenen Untersucher. Die geringste Dosisleistung verzeichnet der erfahrene Untersucher, obwohl dieser meistens komplexe Eingriffe vornahm. Im zeitlichen Verlauf über 3 Monate kann für den fortgeschrittenen Untersucher eine Verbesserung der durchschnittlichen Dosis bzw. Dosisleistung im 3. Monat gezeigt werden.
Schlussfolgerung: Die Anwendung eines direkten Dosimeters am Handrücken mit akustischem Warnsignal führt zu einer Reduktion der Strahlenexposition, vor allem für den fortgeschritten Untersucher. Die „Real-time"-Dosimetrie stellt ein sinnvolle Erweiterung zur indirekten Protektion des strahlenexponierten Untersuchers dar.

Abstract

Purpose: To evaluate whether a reduction in radiation exposure can be achieved using a direct dosimeter with an acoustic warning signal (model EDD-30, Unfors Instruments, Billdal, Sweden).
Materials and Methods: A total of 183 diagnostic and interventional angiographies of the pelvis and lower limbs using a direct dosimeter were analyzed. The vascular interventions were performed either by an experienced examiner (> 5000 interventions), an intermediate examiner (> 1000 interventions) or by a beginner (< 200 interventions). The measuring sensor of the direct dosimeter was attached to the back of the left hand, below the sterile glove, and was worn throughout the examination. If the limit values set on the dosimeter were exceeded, an acoustic signal sounded. At the end of the examination, the mean dose and the mean dose rate could be read off directly.
Results: Exposure is clearly dependent on the experience of the examiner. The highest mean dose rate was found for the beginner, followed by the intermediate examiner. The lowest dose rate was shown by the experienced examiner, even though he mostly performed complex interventions. Over the course of 3 months, an improvement in the average dose rate can be shown in the third month for the intermediate examiner.
Conclusion: The use of a direct dosimeter with an acoustic warning signal is a practicable tool for sensitizing interventional radiologists to unavoidable radiation exposure, with the aim of reducing the dose. "Real-time" dosimetry represents a sensible extension of indirect protection of the radiation-exposed examiner in angiography.

Introduction

Interventional procedures represent fundamental elements of medical diagnostics and therapy. In particular, vascular interventions require a certain proximity to the patient in a sterile environment, which means that the examiner is subject to greater radiation exposure [1 – 4].
An important element of radiation protection is the monitoring of staff exposed to radiation during their work. The radiation dose is officially monitored in the medical field by the use of so-called "badges or TLDs" (film or thermoluminescence dosimeters), but they only supply data at a later stage (retrospective analysis). For this reason, in most cases it is no longer possible to determine in which situation increased exposure occurred and whether it might have been avoidable. Additionally, directly readable dosimeters can be used, e. g. the rod dosimeter, which only provides limited information during the examination [5]. In the everyday clinical routine, a direct dosimeter (**Fig. 1a–c**) with an acoustic warning signal might thus be helpful in detecting unnecessary radiation exposure and learning to avoid it and in training the examiner in radiation protection [6 – 8].
The aim of our single-center study was to prospectively evaluate if a reduction of radiation exposure can be achieved using a direct dosimeter with an acoustic warning signal in the clinical routine.

Material and Methods

A direct dosimeter was used in interventional angiography in the clinical routine to determine partial-body dose measurements on the left hand. The mean dose (in µSv) and the mean dose rate (in µSv/s) were established.

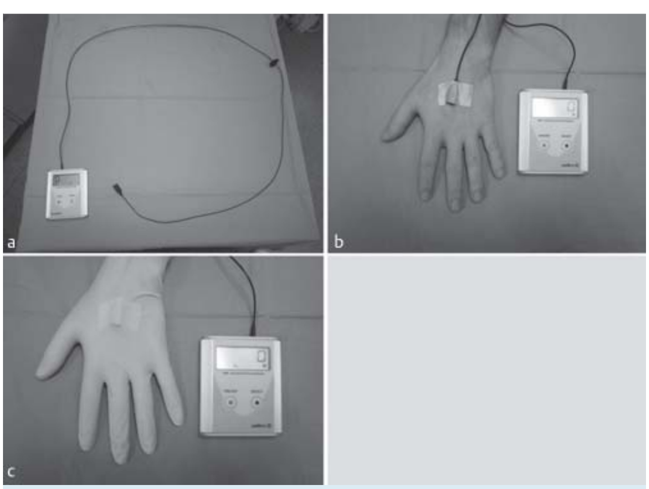

Fig. 1 The dosimeter device is flexible with a small sensor **a**. The sensor was attached to the back of the left hand **b**, below the sterile glove **c**.

Abb. 1 Das Dosimeter hat einen flexiblen kleinen Sensor **a**. Der Sensor wurde am linken Handrücken **b**, unter einem sterilen Handschuh **c** befestigt.

Patients (Table 1)

183 patients (male: 110, female: 73; mean age: 68.7) underwent diagnostic angiography (42/183) or angiography with subsequent angioplasty (141/183). The main reason for the vascular intervention was peripheral arterial occlusive disease (PAOD: stage II b to IV according to Fontaine). There was only one case of an inguinal vascular injury after attempted intravenous drug abuse, with the development of a pronounced false aneurysm (approx. 5 cm), the reason for contrast medium visualization of the arteries for planning surgical therapy.
In 24/141 cases treatment of the pelvic area was necessary. 117/141 patients were treated on the lower limb by an antegrade (80/141) or cross-over technique (37/141).

Examiners

The 3 interventional radiologists were classified according to 3 grades of experience. The examiner with initial angiography experience and less than 200 examinations was referred to as a beginner (BE). The examiners with more than 1000 vascular interventions and more than 5000 interventions were designated as intermediate (IE) and experienced (EE), respectively. The examination distribution among the examiners was: BE: 83; IE: 47; EE: 53. Each examiner used radiation protection clothing with a 0.35 mm lead equivalent and an additional thyroid shield. Safety glasses were also worn.
Data were included in the study if they provided a complete dataset without interruption, i. e., if the respective examiner fully completed the intervention. If, for example, the beginner had to ask for the help of an experienced examiner, who then took over the intervention, the collected data were discarded.

Angiography

The examinations were conducted on a digital flat detector angiography system (Allura Xpert FD 20, Philips Healthcare, Da Best, Netherlands) using pulsed fluoroscopy (image frequency: 15/s).
The common femoral artery was punctured under sterile conditions, using either an antegrade (80/183) or retrograde technique (103/183). A mechanical contrast medium injection system was used to prepare serial angiograms for diagnostic pelvis-leg angiography. Interventions, especially those using an antegrade technique, were usually conducted with manual contrast medium application.

Dosimeter

In accordance with the guidelines of the European radiation protection and X-ray ordinance [9], official personal dosimetry was conducted under the protective clothing on the front of the torso. Thermoluminescence dosimeters were used. A finger dosimeter was also worn. In addition, before the start of the examination, a direct dosimeter (model EDD-30, Unfors Instruments, Billdal,

		technique				
		antegrade	**retrograde**	**cross-over**	**diagnostic**	**total**
examiner	EE	26	3	12	12	53
	IE	23	13	6	5	47
	BE	31	8	19	25	83
	total	80	24	37	42	183

Table 1 Number of examinations distributed among the examiners.

Tab. 1 Anzahl der Untersuchungen in Bezug auf die Untersucher.

Sweden) was fixed to the body and the measuring probe was attached to the back of the left hand.

The sensor has a spherical response with an inaccuracy of ±6% at the calibration point. The dosimeter was calibrated to measure in terms of the personal dose equivalent at a depth of 0.07 mm (Hp 0.07). The dose rate range was 0.03 mSv/h to 2 Sv/h.

The measurement of the dosimeter starts at a trigger level of 0.054 mSv/h. If the dose falls below a value of 0.036 mSv/h, the measurement ends until the dose exposure again reaches the start trigger level.

In accordance with the specifications of the device, the hand could be chosen as a body part for dose measurement, with specified alarm limits. The alarm limits for the hand are divided into 4 levels, with signals of different intensity: Level 1 = 1.0 mSv/h, Level 2 = 5.0 mSv/h, Level 3 = 25.0 mSv/h and Level 4 = 1.0 mSv. The dosimeter gives immediate audible warnings, beginning with a single beep at level 1 to a constant beep at level 4.

Statistics

Statistical analysis was conducted using SPSS (version 15.0 for Windows). All values are given as means ± standard deviation or number of patients and percentage. The statistical significance of quantitative data was determined by analysis of variance (ANOVA), in part after controlling for a third variable. The learning effect over the chronological course was determined on the basis of an analysis of variance. The graphic presentation of the estimated marginal means, on the basis of the means of the dose rates of the individual examiners, shows the effect of the factors "examination technique" and "time point" and thus accentuates the learning effect. A p-value < 0.05 was rated as statistically significant.

Results

▼

Beside 42/183 diagnostic angiographies, 141/183 angiographies were performed with subsequent angioplasty. A total of 80/141 patients were treated with an antegrade technique, 24/141 with a retrograde technique and 37/141 with a cross-over technique (▶ **Fig. 2**). The highest mean dose rate (▶ **Fig. 3**) was found when retrograde angioplasty was performed (1.01 ± 0.56 µSv/s), followed by cross-over angioplasty (0.46 ± 0.42 µSv/s) and diagnostic angiography (0.76 µSv/s), while antegrade angioplasty (0.26 ± 0.19 µSv/s) was found to have the lowest exposure.

Compared to the mean dose rates, the mean dose (▶ **Fig. 4**) showed a different disposition: the highest values were registered in cross-over angioplasty (373.45 ± 357.83 µSv), followed by retrograde (295.73 ± 151.53 µSv) and antegrade angioplasty (114.63 ± 109.24 µSv), while diagnostic angiography was found to have the lowest accumulation (95.49 ± 99.45 µSv). There was no significant difference in the average BMI for the different groups: beginner: 30.3 ± 4.7; intermediate examiner: 29.5 ± 2.5; experienced examiner: 31.1 ± 3.5.

In accordance with the radiation exposure of the examiner, the highest dose-area product (DAP) as a method of monitoring patient dose was found in retrograde (107 906 mGycm^2) and cross-over angioplasty (124 357 mGycm^2), followed by diagnostic angiography

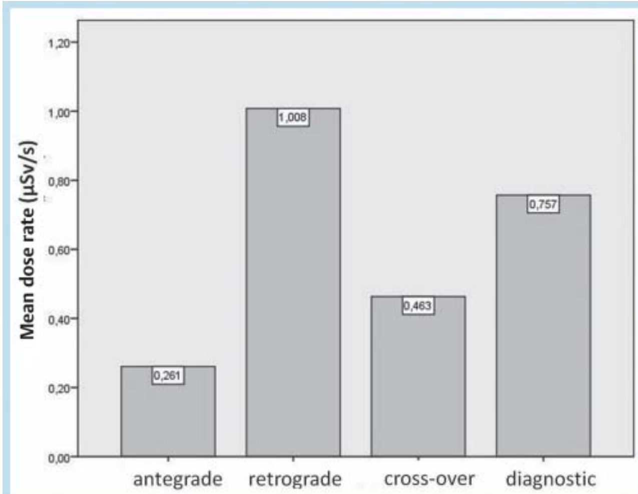

Fig. 3 Mean dose rate (µSv/s) of the different techniques.

Abb. 3 Mittlere Dosisleistung (µSv/s) der unterschiedlichen Techniken.

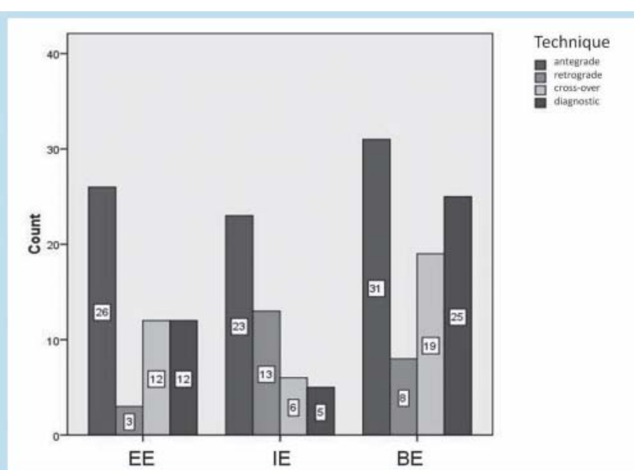

Fig. 2 Number of examinations distributed among the examiners and approaches.

Abb. 2 Anzahl der Untersuchungen in Bezug auf die Untersucher und Technik.

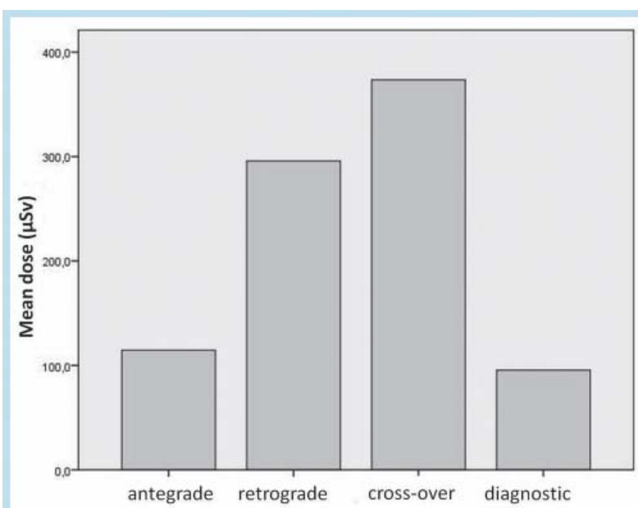

Fig. 4 Mean dose (µSv) of the different techniques.

Abb. 4 Mittlere Dosis (µSv) der unterschiedlichen Techniken.

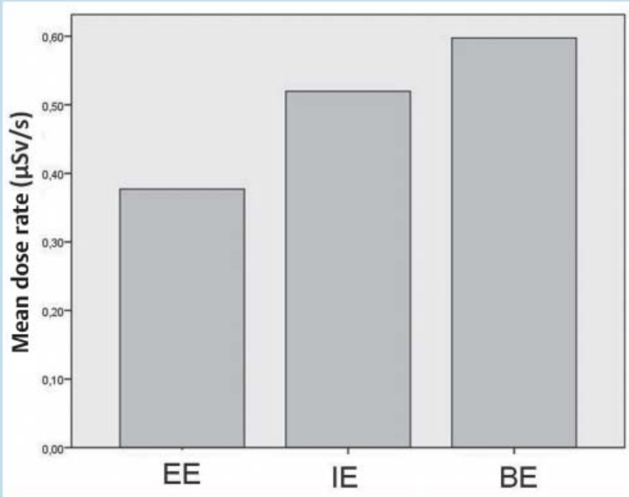

Fig. 5 Mean dose rates as a function of the examiner's experience.

Abb. 5 Mittlere Dosisleistung in Abhängigkeit der Erfahrung des Untersuchers.

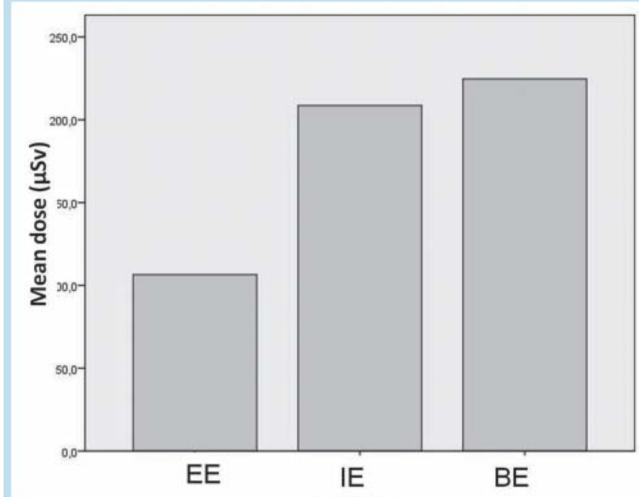

Fig. 6 Mean dose as a function of the examiner's experience.

Abb. 6 Mittlere Dosis in Abhängigkeit der Erfahrung des Untersuchers.

(59 620 mGycm^2). The lowest patient radiation exposure was found when antegrade angioplasty was performed (12 703 mGycm^2).
DAP values were recorded in this study over the 3-month course. There was no major deviation in the average DAP for the different techniques: for antegrade angioplasty month 1: 13 812 mGycm^2, month 2: 12 294 mGycm^2 and month 3: 12 692 mGycm^2; for the diagnostic angiography month 1: 57 251 mGycm^2, month 2: 59 391 mGycm^2 and month 3: 61 915 mGycm^2; for cross-over angioplasty month 1: 105 667 mGycm^2, month 2: 88 130 mGycm^2 and month 3: 126 234 mGycm^2; for retrograde angioplasty month 1: 126 920 mGycm^2, month 2: 89 812 mGycm^2 and month 3: 141 263 mGycm^2.
Exposure of the operator's hand is clearly dependent on the experience of the examiner. On the basis of an analysis of variance (ANOVA), the mean values of dose rate of an intermediate examiner or of a beginner were 0.14 + 0.38 µSv/s ($p = 0.13$) or 0.22 + 0.38 µSv/s ($p = 0.008$) higher than the average dose of the expert of 0.38 µSv/s (**Fig. 5, 6**). This means that the beginner had the highest mean dose rate, followed by the intermediate examiner. The experienced examiner was found to have the lowest.
Controlling for a third variable as part of the ANOVA, i. e. controlling for the individual examination techniques did not show any relevant change in the statistically different results (**Table 2, 3**).
Over the 3-month course, an improvement in the average dose of –110 µSv ($p = 0.04$) in the second month and –116 µSv ($p = 0.03$) in the third month and a dose rate improvement of –0.155 µSv/s ($p = 0.246$) in the second month and –0.145 µSv/s ($p = 0.271$) in the third month can be shown for the intermediate examiner. Analogously, the ANOVA showed a trend towards a slight drop in the average dose/sec by approx. 0.09 µSv/s ($p = 0.40$) for the beginner. For the experienced examiner, a significant difference in dose or dose rate was not found over the observation period (**Fig. 7 – 9**).
In comparison to the radiation exposure for the different grades of experiences and techniques, the beginner had the highest frequency as well as levels of alarms. Up to 5 audible warnings in level 1 to 3 were observed per intervention. In only two cases the beginner had to tolerate a constant beep of level 4 in line with the retrograde/ crossover technique.

Table 2 Dose rate distributed among the examiners.

Tab. 2 Dosisleistung in Bezug auf die Untersucher.

		mean dose/sec	std. error	sig.
examiner	EE	0.377	0.064	0.000
	IE	0.520	0.093	0.129
	BE	0.597	0.082	0.008

Table 3 Dose distributed among the examiners.

Tab. 3 Dosis in Bezug auf die Untersucher.

		dose	std. error	sig.
examiner	EE	106.467	29.572	0.000
	IE	208.626	43.136	0.019
	BE	224.676	37.854	0.002

Discussion

Angiographic interventions mean high radiation exposure for the examiner, even if this is mainly caused by scatter radiation [10]. Exposure can be reduced by actively adhering to the known rules for radiation protection in accordance with the European radiation protection ordinance and X-ray ordinance [7], by consistently applying the protective measures (lead apron, thyroid protection, safety glasses, lead lamellae on the examination table, lead glass protection, etc.) and by constantly improving the interventional techniques (learning curve).
To ensure adequate protection, the shielding effect of the protective clothing must be verified. For the determination of shielding properties of protection clothing, DIN EN 61331-1 (measurement in the narrow and broad beam) and DIN 6857-1 (inverse broad-beam geometry) are available [11].
Dose limit values have been established to protect the examiner from the effects of radiation. Official personal dosimetry is therefore an important part of radiation protection [8, 9].

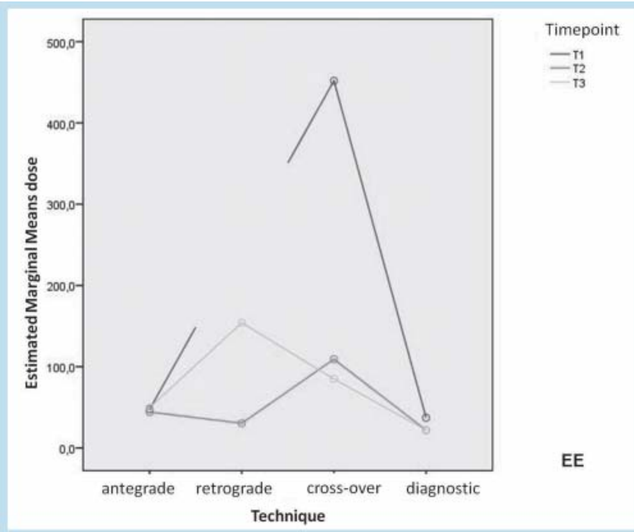

Fig. 7 Dose of the different techniques for the experienced examiner (EE) over the course of 3 months.

Abb. 7 Dosis des erfahrenen Untersuchers in Bezug auf die unterschiedlichen Techniken über einen Zeitraum von 3 Monaten.

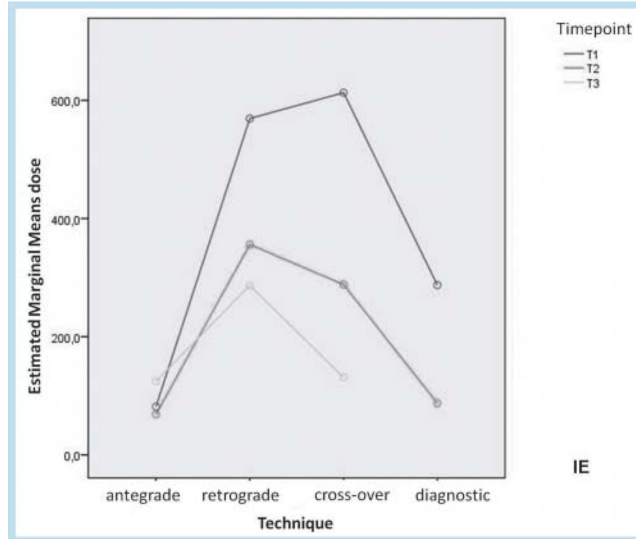

Fig. 9 Dose of the different techniques for the intermediate examiner (IE) over the course of 3 months.

Abb. 9 Dosis des fortgeschrittenen Untersuchers in Bezug auf die unterschiedlichen Techniken über einen Zeitraum von 3 Monaten.

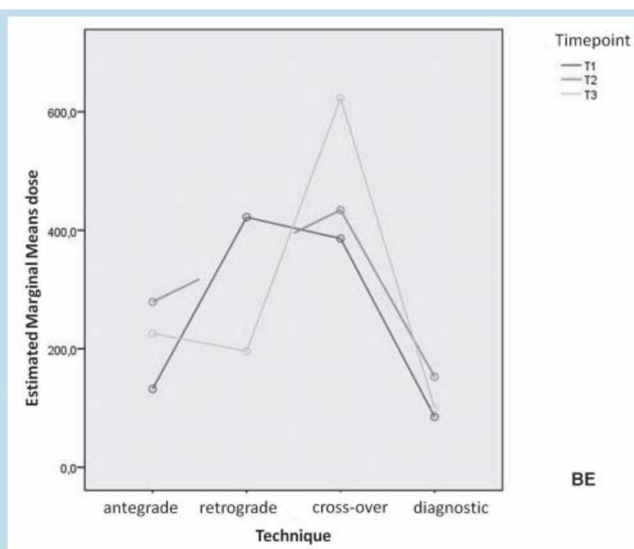

Fig. 8 Dose of the different techniques for the beginner (BE) over the course of 3 months.

Abb. 8 Dosis des Anfängers in Bezug auf die unterschiedlichen Techniken über einen Zeitraum von 3 Monaten.

Official personal dosimetry requires a whole-body dosimeter, which is to be worn under the protective lead clothing on the front of the torso. However, this dosimeter does not allow monitoring at the site of unprotected exposure, in particular. Within the context of optimizing radiation protection, one should not only rely on the data from dosimeters worn underneath the protective clothing, but also take dose measurements on other, unprotected parts of the body. For example, an additional finger ring dosimeter worn on the hand can supply appropriate information [12, 13]. However, this information is insufficient to make the examiner aware of unnecessary radiation exposure and enable him to take immediate protective action during an intervention with intensive doses of radiation, since these dosimeters are not evaluated until a later stage. In addition, personal dosimeters that supply direct information are in use in the medical field, such as the rod dosimeter. However, this has the following disadvantages: inaccuracy of reading, low resolution, small measuring range and shock sensitivity [5]. Electronic personal dosimeters are also in use. The research group of Wucherer M et al. [6] investigated personal dosimetry in interventional measures using a direct dosimeter for partial-body dose measurement. Direct dosimetry makes it possible to call up information about acute radiation exposure during an intervention [8, 9].

In our experience there were no restrictions in the framework of the preparation for the procedure.

An additional acoustic signal when a threshold value has been reached reinforces the flow of information and can lead to a situational analysis on the part of the examiner, possibly resulting in a change in behavior. However, the warning signal can be a stressor with the level of intensity varying on an individual basis. In the case of an audible warning signal, the shielding was optimized, the position of the examiner was changed or the image intensifier was moved closer to the patient. In other words, a form of training takes place with which an improvement in radiation protection can be achieved. Through a precise knowledge of the exposure, the acceptance and application of additional protective measures can be influenced [14].

The dosimeter used in our study was attached to the back of the left hand under the sterile glove, since the radiation exposure of the left side of the body and left hand is significantly higher than that of the right side [15]. For the left hand of the interventional radiologist, the paper by Hidajat et al. describes dose values of 0.92 mSv, which roughly reflect the dose values of an experienced examiner in the present study (1.06 mSv).

Pecher G et al. [14] reported high values of DAP and mean doses in angioplasties of the pelvic area (retrograde or cross-over), while vascular interventions of the lower limb were accompanied by low radiation exposure.

In our prospective study, measurement of the partial-body dose of the left hand revealed that experience represents a form of protection against unavoidable radiation exposure.

In order to achieve this stage earlier, regular training through direct dosimetry with a real-time flow of information can accelerate this process. This was displayed over a period of three months, especially for the advanced examiner. A learning effect was observed, which is reflected by a reduction in dose and is presumably the result of a change in behavior.

Several limitations have to be considered in this study. Due to the complex statistical design, the actual number of patients in each subgroup was relatively small, thus there is the possibility that actual statistically significant differences in radiation exposure could not be revealed due to a lack of statistical power. Furthermore, a correlation between the radiation exposure measured by our device and the readings from the TLDs could not be evaluated as the TLDs were always worn by the participants and thus also recorded other radiation exposure outside of the angio lab. In conclusion, the use of a direct dosimeter with an acoustic warning signal is a practicable tool for sensitizing the interventional radiologist to unavoidable radiation exposure, with the aim of reducing the dose.

"Real-time" dosimetry represents a sensible extension of the indirect protection of the radiation-exposed angiography examiner, in particular for the intermediate examiner, and less definitively for the beginner.

References

1 International Commission on Radiological Protection. Avoidance of radiation injuries from medical from medical interventional procedures. ICRP Publication 85. Ann ICRP 2000; 30: 7 – 67

2 *Hidajat N*, *Wust P*, *Kreuschner M et al.* Radiation Risks for the radiologist performing transjugular intrahepatic portosystemic shunt (TIPS). Br J Radiol 2006; 79: 483 – 486

3 *Schueler BA*, *Vrieze TJ*, *Bjarnason H et al.* An investigation of operator exposure in interventional radiology. Radiographics 2006; 26: 1533 – 1541

4 *Layton KF*, *Kallmes DF*, *Cloft HJ et al.* Radiation Exposure to the Primary Operator During Endovascular Surgical Neuroradiology Procedures. Am J Neuroradiol 2006; 27: 742 – 743

5 *Borowski M*, *Poppe B*, *Looe HK et al.* Is it really not possible to use electronic personal dosimeters in clinical exposure situations? Fortschr Röntgenstr 2010; 182: 773 – 779

6 *Wucherer M*, *Loose R*, *Deichen I et al.* Strahlenschutz des Personals bei interventionellen Maßnahmen mittels individueller Teilkörperdosismessung. Fortschr Röntgenstr 2005; 177: 260

7 European Commission. Council Directive 97/43 Euratom on health protection of individuals against the dangers of ionizing radiation in relation to medical exposure, and repealing. Directive 84/466 Euratom. Off J Eur Commun L 1997; 180: 22 – 27

8 *Chiriotti S*, *Ginjaume M*, *Vano E et al.* Performance of several active personal dosemeters in interventional radiology and cardiology. Radiation Measurements 2011; 46: 1266 – 1270

9 *Clairand I*, *Bordy JM*, *Daures J et al.* Active personal dosemeters in interventional radiology: tests in laboratory conditions and in hospitals. Radiation Protection Dosimetry 2011; 144: 453 – 458

10 *Loose R*, *Wucherer M*. Occupational exposure to radiation. Radiologe 2007; 47: 27 – 40

11 *Pichler T*, *Schopf T*, *Ennemoser O*. Radiation Protection Clothing in X-Ray Diagnostics – Comparsion of Attentuation Equivalents in Narrow Beam and Inverse Broad-Beam Geometry. Fortschr Röntgenstr 2010; 183: 470 – 476

12 *Häusler U*, *Czarwinski R*, *Brix G*. Radiation exposure of medical staff from interventional x-ray procedures: a multicentre study. Eur Radiol 2009; 19: 2000 – 2008

13 *von Boetticher H*, *Lachmund J*, *Hoffmann W et al.* Optimizing staff radiation protection in radiology by minimizing the effective dose. Fortschr Röntgenstr 2005; 178: 287 – 291

14 *Pecher G*, *Koenig H*, *Pecher S et al.* Reduction of radiation exposure for patient and investigators in interventional radiography. Fortschr Röntgenstr 1998; 169: 505 – 509

15 *Hidajat N*, *Vogel T*, *Biamino G et al.* Radiation exposure in interventional radiology as exemplified by the chemoembolization of hepatocellular carcinoma and laser angioplasty of the pelvic arteries. Fortschr Röntgenstr 1996; 164: 249 – 256