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

Zusammenfassung

Ziel: Prospektive Evaluation der Strahlenexposition eines Untersuchers in der Angiografie. Kann durch Anwendung eines direkten Dosimeters mit akustischem Warnsignal eine Reduktion der Strahlenexposition erreicht werden?


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 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].

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.

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.

Data were included in the study if they provided a complete dataset without interruption, i.e., if the respective examiner fully completed the intervention. In other words, 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, Netherlands) was attached to the back of the left hand under a sterile glove (approx. 5 cm), the reason for contrast medium visualization of the arteries for planning surgical therapy.

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<table>
<thead>
<tr>
<th>technique</th>
<th>antegrade</th>
<th>retrograde</th>
<th>cross-over</th>
<th>diagnostic</th>
<th>total</th>
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<tbody>
<tr>
<td>examiner</td>
<td>EE</td>
<td>26</td>
<td>3</td>
<td>12</td>
<td>53</td>
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<tr>
<td></td>
<td>IE</td>
<td>23</td>
<td>13</td>
<td>6</td>
<td>47</td>
</tr>
<tr>
<td></td>
<td>BE</td>
<td>31</td>
<td>8</td>
<td>19</td>
<td>25</td>
</tr>
<tr>
<td>total</td>
<td></td>
<td>80</td>
<td>24</td>
<td>37</td>
<td>42</td>
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<table>
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<tr>
<th>Table 1</th>
<th>Number of examinations distributed among the examiners.</th>
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<tr>
<td>Tab. 1</td>
<td>Anzahl der Untersuchungen in Bezug auf die Untersucher.</td>
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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 mGycm²) and cross-over angioplasty (124 357 mGycm²), followed by diagnostic angiography.
(59,620 mGycm²). The lowest patient radiation exposure was found when antegrade angioplasty was performed (12,703 mGycm²). 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 mGycm², month 2: 12,294 mGycm² and month 3: 12,692 mGycm²; for the diagnostic angiography month 1: 57,251 mGycm², month 2: 59,391 mGycm² and month 3: 61,915 mGycm²; for cross-over angioplasty month 1: 105,667 mGycm², month 2: 88,130 mGycm² and month 3: 126,234 mGycm²; for retrograde angioplasty month 1: 126,920 mGycm², month 2: 89,812 mGycm² and month 3: 141,263 mGycm².

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 (● Tab. 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.

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 broadbeam 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].

Table 2  Dose rate distributed among the examiners.

<table>
<thead>
<tr>
<th>examiner</th>
<th>mean dose/sec</th>
<th>std. error</th>
<th>sig.</th>
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<tbody>
<tr>
<td>EE</td>
<td>0.377</td>
<td>0.064</td>
<td>0.000</td>
</tr>
<tr>
<td>IE</td>
<td>0.520</td>
<td>0.093</td>
<td>0.129</td>
</tr>
<tr>
<td>BE</td>
<td>0.597</td>
<td>0.082</td>
<td>0.008</td>
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</table>

Table 3  Dose distributed among the examiners.

<table>
<thead>
<tr>
<th>examiner</th>
<th>dose</th>
<th>std. error</th>
<th>sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>EE</td>
<td>106.467</td>
<td>29.572</td>
<td>0.000</td>
</tr>
<tr>
<td>IE</td>
<td>208.626</td>
<td>43.136</td>
<td>0.019</td>
</tr>
<tr>
<td>BE</td>
<td>224.676</td>
<td>37.854</td>
<td>0.002</td>
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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
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