Direct and Indirect Evaluation of Radiation Dose during Uterine Artery Embolisation of Leiomyomas

Introduction:
Uterine fibroids are the most common tumors of the female reproductive tract, found in 40% by the age of 35 and in up to 70% by the age of 50 of Caucasian women (Baird et al., 2003; Shen et al., 2013). Although most fibroids are asymptomatic, in 20-50% of cases they can be associated to symptoms including menorrhagia, dyspareunia, pelvic and abdominal pain, urinary or rectal incontinence, and subfertility. Traditionally, surgery (hysterectomy or myomectomy) has been the main treatment option for symptomatic fibroids. Since the late 1990s, uterine artery embolization (UAE) has been developed as a mini-invasive non-surgical alternative (Ravina et al., 1995).

UAE is a percutaneous procedure which results in the occlusion of the perifibroid vessels by different particles [polyvinyl alcohol (PVA) particles, micro-spheres, or gelatin-coated tris-acryl polymer microspheres etc.] injected into both uterine arteries. The reduction in blood supply produces an irreversible ischemic infarction of fibroid resulting in a decrease of fibroid volume and an improvement of woman’s symptoms. UAE is a fluoroscopically-guided technique and is associated to patient radiation exposure. In the last decade many authors investigated efficacy and safety of the procedure, but data on this issue are limited (Hirst et al., 2008; Wu et al., 2007). Because of the increasing use of this procedure as a treatment for fibroids also in young women, the evaluation of patient radiation exposure and potential radiation related injury become relevant. Radiation risks can be divided into two types: deterministic (such as skin damage) and stochastic effects (DNA damage). These risks are of particular interest in UAE since the uterus and ovaries are directly exposed to the radiation beam and cannot be shielded. Therefore the aim of this study was to evaluate the absorbed radiation doses (AD) to the skin, uterus, and ovaries during UAE.

Experimental Section

Abstract:

To estimate the absorbed radiation dose (AD) to patients undergoing uterine artery embolization (UAE) for fibroids. Methods: We prospectively compared the AD of 21 patients during UAE performed by 3 experienced interventional radiologists with standardized protocol using two different radiation evaluation methods. Dose area product (DAP) and entrance skin exposure were recorded by angiographic unit dose report. Uterine dose (UD), ovarian dose (OD) and skin dose (SD) were indirectly calculated by PC-based Monte Carlo software (PCXMC). UD and SD were also directly measured by thermo-luminescent dosimeters (TLDs) placed in the posterior vaginal fornix and on the skin. Results: No significant differences of AD were identified between operators. Overall median UD was 49.6 mGy calculated by PCXMC and 33.4 mGy at TLDs. Overall median Entrance skin exposure was 334 mSv by PCXMC and 235 mGy at TLDs. Overall median OD (PCXMC) was 34.4 mGy. Even if a good correlation was found between PCXMC and TLDs measurements (k=0.72 for OD and 0.86 for SD), Wilcoxon test revealed a significant difference between PCXMC and TLDs measurement both for UD (p=0.02) and SD (p=0.002). Comparing AD due to angiographic runs and fluoroscopy, the first represent the 63% of overall AD. Conclusions: Both estimation methods revealed a low AD associated to UAE for standard procedures. We should consider to routinely use indirect calculation (easy reproducibility, no positioning error, reduced cost). A strategy based on reduction of angiographic exposures, by using tools like road mapping or last image review, could reduce significantly the AD.

Keywords:
Radiation Exposure, Leiomyoma, Uterine Artery Embolization, Thermoluminescent Dosimetry, Radiation Dosage.

Methodology:

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Introduction

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This prospective study involved 21 consecutive patients (age range 33-53 years; mean 43 years) with a diagnosis of uterine fibroids by ultrasound and magnetic resonance imaging (MRI) referred to Interventional Radiology (IR) for UAE.

Patients were counseled by gynecologist and interventional radiologist about the possible risks and complications of, and alternatives to, the procedure. Each patient gave written informed consent and volunteered to participate in the follow-up examinations. The study was approved by the institutional review board of the local Institution.

Three consultant interventional radiologists (A, B, C, with respectively 5, 10, and 15 years of experience in UAE) were involved in all UAE procedures. The procedure was performed using the same technique.

Seven patients were randomly assigned and performed by each operator. The X-ray tube was positioned under the table. The angle of the X-ray beam varied depending on the patient’s position on the table. If needed, during the catheterization, oblique projections (20° ipsilateral) were used due to the catheterization of both the left and right uterine arteries.

Unilateral right common femoral arterial punctures were performed under local anesthetic. By crossing over technique, diagnostic DSA was performed contralaterally injecting contrast from a 5 Fr Cobra (Cook Medical, Bloomington, Indiana, U.S.) catheter in the main trunk of the left internal iliac artery. After catheterisation of the left uterine artery a diagnostic DSA was performed with a 2.8 Fr microcatheter (Progreat®, Terumo Corporation, Tokyo, Japan) to point out catheter position and possible ovarian anastomosis (Figure 1).

Polyvinylalcohol particles (Contour™ PVA, Boston Scientific, Marlborough, Massachusetts, U.S.) sized 255-350 µm were used in all cases under fluoroscopic guidance. The embolization end-point was the occlusion of the perileiomyoma plexus with sluggish flow remaining in the main uterine artery.

Later, a diagnostic DSA was performed omolaterally injecting contrast by a 5 Fr Simmons 2 (Cook Medical, Bloomington, Indiana, U.S.) catheter in the main trunk of the right internal iliac artery. Here after same procedure of left side, as above, was performed (Figure 2).

![Figure 1](image-url)
Figure 2: Same results of the left uterine artery were reached on the contralateral side (arrow). No ovarian arteries were embolized. Technical success rate was 100% (21/21).

The procedure was performed using the same angiographic equipment (Allura Xper FD20, Philips, Amsterdam, Netherlands). Equipment performance and calibration were tested regularly and automatic settings and filtration were utilized.

The field of view (FOV), source to image-receptor distance (SID), focus to skin distance (FSD) and collimation were adjusted by the radiologist.

An angiogram from each side of the internal iliac artery was prior to the embolization (the best projection being ipsilateral 20° and cranio-caudal 10°).

The mean error of the dose area product (DAP) meter with angiography equipment was < 10% at the X-ray tube voltage used in the study.

Radiation dose to Patients was measured indirectly by PCXMC, a software based on Monte-Carlo calculation, and directly by thermoluminescent dosimeters TLDs.

Radiation exposure was documented and collected in all cases.

A Medical Physics Expert prospectively recorded all technical factors to allow calculation of AD using the PC-based Monte Carlo program (PCXMC) version 2.0 (Figure 3).

Figure 3: Main software dialog box (a) and example of a patient dose report (b).

The required input data for the simulation program included: definition of all views (location and size of the radiation field and projection angle) and radiation factors (DAP, kVp and total filtration). After entering the above data
into the program, the radiation dose received by the uterus, ovaries and skin was automatically calculated by the software.

To measure the uterine dose (UD), numbered X-ray positive radiophotoluminescence dosimeters, type LiF:Mg, Ti (TLD-100, Harshaw Chemical Company, Cleveland, Ohio, U.S.) were stored in plastic tubes and placed within the vagina near the uterine cervix by a gynecologist (Figure 4).

![Vaginal applicator with thermoluminescent dosimeters inside.](image)

**Figure 4:** Vaginal applicator with thermoluminescent dosimeters inside.

To measure the skin dose (SD), TLDs were stored in a plastic bag and positioned as support on the back of the Patient (Figure 5).

Figure 5: Thermoluminescent dosimeter matrix on a transparent plastic film used as support.

The estimated mean error of the TLD was about 3% (Nishizawa et al., 2003).

The study population was divided into three groups according to the operator to evaluate any statistically difference between interventional radiologists.

Anthropometric data (body mass index), number of fibroids and uterine volume were evaluated for each patient at her admission for the intervention and correlated to dosimetric data.

Variables employed for primary objective of the study did not show normal distribution. For these data descriptive statistics were reported with median values and nonparametric tests (Wilcoxon signed rank test and Spearman’s test) were employed for inferential statistics. A $p$ value <0.05 was considered significant.

**RESULTS AND DISCUSSION**

No significant differences of AD were identified between operators.

Body mass index, number of fibroids and uterine volume resulted comparable between the three groups ($p > 0.05$).

Descriptive statistics regarding dosimetry are reported in table 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Median</th>
<th>25th percentile</th>
<th>75th percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAP acquisitions</td>
<td>mGy/cm$^2$</td>
<td>56031</td>
<td>37257</td>
<td>75184</td>
</tr>
<tr>
<td>DAP fluoroscopy</td>
<td>mGy/cm$^2$</td>
<td>14260</td>
<td>10003</td>
<td>20041</td>
</tr>
<tr>
<td>DAP overall</td>
<td>mGy/cm$^2$</td>
<td>67732</td>
<td>51507</td>
<td>91162</td>
</tr>
<tr>
<td>DAP % acquisitions</td>
<td>%</td>
<td>75</td>
<td>70</td>
<td>82</td>
</tr>
<tr>
<td>Skin dose Air Kerma</td>
<td>mSv</td>
<td>503</td>
<td>350</td>
<td>692</td>
</tr>
<tr>
<td>Skin Dose TLD§</td>
<td>mSv</td>
<td>384</td>
<td>252</td>
<td>567</td>
</tr>
<tr>
<td>Uterine Dose PCXMC</td>
<td>mGy</td>
<td>50,9</td>
<td>37,4</td>
<td>78</td>
</tr>
<tr>
<td>Uterine Dose TLD§</td>
<td>mSv</td>
<td>33,4</td>
<td>28,6</td>
<td>56,4</td>
</tr>
</tbody>
</table>

*DAP* dose area product; *TLD* thermoluminescent dosimeter; *PCXMC* Monte Carlo dose simulation
Overall median UD was 49.6 mGy (range 34.9–78) calculated by PCXMC and 33.4 mGy (range 28.6–56.4) at TLDs (median respectively 62 and 43.7 in group A, 56.3 and 48.1 in group B, 43.2 and 56.8 and 40.2 in group C).

Overall median entrance skin exposure was 503 mSv (range 213–1160) by PCXMC and 384 mSv (range 102–866) at TLDs (median respectively 477 and 673 in group A, 374 and 357 in group B, and 463 and 643 in group C).

Overall median OD calculated by PCXMC was 34.4 mGy (range 22–64.3).

Even if a good correlation was found between PCXMC and TLDs measurements (k=0.72 for OD and 0.86 for SD), Wilcoxon test revealed a significant difference between PCXMC and TLDs measurement both for UD (p=0.02) and SD (p=0.002).

Both PCXMC and TLDs showed a positive high correlation with body mass index regarding SD (r=0.69 and 0.55 respectively) while for the UD the correlation between BMI and PCXMC and TLDs resulted less evident (r=0.42 and 0.20 respectively). A weak correlation was also shown between uterine volume with UD and SD estimated with both PCXMC and TLDs (r<0.2).

Comparing angiographic runs and fluoroscopy, the first represents the 63% of overall AD. Exposure to patients from medical examinations is of large interest as reference for quality of radiology practice. The absorbed radiation dose is still a relevant issue as the largest contribution to the population dose from man-made ionizing radiation sources is the medical exposure (Mettler et al., 2006; Samara et al., 2012).

From last analysis reports, the medical utilization of imaging facilities rose rapidly in last 15 years, so efforts should be employed for technique standardization with the lower AD for each exam (Hayton et al., 2013; Chen et al., 2008).

Interventional procedures contribute for a large amount of it (Samara et al., 2012; Tung et al., 2011).

Several factors influence patient dose and interventional radiologists should continually monitor and reconsider their technique in order to exploit the full potential for dose optimization. Awareness of the problem of radiation exposure with the aim of keeping the dose as low as reasonably achievable, is ultimately positive not only for the patient but also for the interventionalist and assisting personnel, especially in cases of dose escalation, e.g., in obese women or women requiring longer fluoroscopy due to difficult anatomy (Scheurig-Muenkler et al., 2015).

Limiting the radiation dose to patient’s ovaries is of additional importance in UAE because many of these patients are of childbearing age, and the gonads, which are in the direct XRay beam during embolization, are one of the most sensitive organs to radiation.

Ovarian dysfunction has been reported after UAE (Bradley et al., 1998; Nikolic et al., 2000), although is unlikely to be due to radiation exposure. Based on experience with radiation therapy, doses higher than that typically absorbed during UAE would be necessary to cause permanent ovarian dysfunction (Horning et al., 1981).

In 2006 our IR team efforts led us to standardize UAE procedures (described in M&M), according to CIRSE guidelines, in order to minimize radiation exposure and to phase out radiation dose differences between IR operators.

No significant differences of AD, measured in both methods, were identified between IR consultant operators, in spite of their different experience. In this way we think that IR operator experience did not influence the patients’ exposure and more than practice, the definition of a standardized protocol would be useful for standardize radiation dose. Different radiation dose exposure was found by Stuart et al (Stuart et al., 2012) comparing the AD between fellowship operators. Their results show a significant and clinically relevant training effect over the course of a yearlong interventional radiology fellowship program.

In particular, Vetter calculated organ and effective doses using Monte Carlo simulation in 31 patients, showing a mean total DAP value of 59.9 Gycm (median 23.4 range 8.8–317.5 Gycm) and (mean DAP during fluoroscopy= 20.4 Gycm; mean DAP caused by DSA acquisition= 39.5 Gycm) a mean effective dose of 34 mSv (median 13 mSv, range 5–182 mSv), mean absorbed ovarian and skin doses (in only five procedures) respectively of 51 mGy and 4.88 mGy (Vetter et al., 2004). They also concluded that the exposure level from UAE was approximately twice the exposure from abdominal CT examinations.

Our exposure values resulted similar to those showed also by Sapoval et al., being closer to doses for optimized fluoroscopy and angiographic settings, based on the use of low-dose/low-frame fluoroscopy and angiography (Mean DAP= 9.515 ± 4.520 µGy m²; Mean estimated AD to ovaries 83 ± 41 mGy; Mean estimated AD to uterus 85 ± 39 mGy; effective dose = 24 ± 12 mSv).
They evaluated the ability of low-dose/low-frame fluoroscopy/angiography with a flat-panel detector angiographic suite to reduce the dose delivered to patients during UAE. Results showed a significant dose decrease using a low-dose profile, respect to a standard setting (Sapoval et al., 2010).

As we know, the improvement of new and dose saving angiographic devices led to an exposure reduction in recent years (Nikolic et al., 2000).

The study by Nikolic et al. documented a non significant contribution of angiographic exposures to absorbed ovarian dose (only less than 7% to the total AD for the average UAE procedure), so they suggested to reduce the AD in UAE by limiting fluoroscopy time and using oblique or magnified fluoroscopy. Our data show that angiography contributed to the 63% of overall absorbed ovarian dose, probably due to different techniques, so more attention should be paid for reduction of angiographic sequences.

The efficiency of the fluoroscopic equipment, for instance the conversion efficiency of the image intensifier and the dose per pulse during pulsed fluoroscopy, are other predetermined factors feasible to further reduce the dose. When pulsed fluoroscopy is used with emphasis on dose reduction techniques, the absorbed OD and SD can be substantially reduced when compared to UAE performed with non pulsed fluoroscopy (Nikolic et al., 2001). These radiation reduction tools should therefore be applied whenever possible.

Furthermore bilateral femoral puncture for UAE can reduce fluoroscopy time, without increasing the frequency of puncture site complications compared with unilateral puncture, and with minor puncture site pain (Costantino et al., 2010; Bratby et al., 2007). Another way to significantly reduce the OD is the employment of flat panel system instead of conventional DSA (Sapoval et al., 2010).

The study by Minano et al (Minano et al., 2014) evaluated the AD using two different angiography units; the results showed different dose performance and filtration for each unit, highlighting the importance to normalize the operation modes between the units at the facility as far as technically possible, without degrading image quality to the extent that it is insufficient for the clinical purpose. They recommend to perform UAE with the most recent angiographic unit available and to replace older equipment regularly to exploit the dose saving potential of modern technology.

We already expected to have a significant discrepancy between PCXMC and TLDs measurement both for UD ($p=0.02$) and SD ($p=0.002$), as already reported in literature by Manninen et al (Manninen et al., 2014), for the different dosimetric calculation technique.

We ascribe the major differences between the two methods concerning to TLDs, to the distance, even if of few centimeters, from the uterus and to the varying location of the FOV relative to the position of the dosimeters and the varying absorption of photons by adjacent tissues between different patients, as well as the small sample size.

Conversely, Monte Carlo scoring system is based only on orthogonal array, so different angulation can induce calculation errors; on the other hand reducing XRay dose can induce error increase.

All measures proposed to reduce radiation during UAE also apply to other interventions using angiography for guidance (Scheurig-Muenkler et al., 2015).

**Limitations**

PCXMC Monte Carlo is an indirect dosimetric calculation with risk of error, but with easy reproducibility.

TLDs have limits of uncomfortable anatomical positioning, they can be outside of the direct XRay photons and have huge costs.

We are aware of the small study population, which might be responsible for both type I and II errors, but currently, there are no large studies of this measurement during UAE performed by three IR operators

**CONCLUSION**

AD during UAE is low overall and comparable to the dose shown by literature (Sapoval et al., 2010).

AD is substantially equal between IR experienced operators when UAE procedure is standardized, achieving an expected radiation dose to the Patients.

We have no data allowing us to suggest one of the two dosimetric methods, but the routine use of indirect calculation should be considered for its easy reproducibility, no positioning error and reduced costs.
The importance of awareness of dose reduction techniques amongst radiologists is crucial for reducing dose and UAE should be performed only if justified on clinical grounds.

**REFERENCES**


