Uterine Artery Embolization: Reduced Radiation with Refined Technique

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PURPOSE: To determine the estimated absorbed ovarian dose (EAOD) and absorbed skin dose (ASD) that occurs during uterine artery embolization (UAE) using pulsed fluoroscopy and a refined procedure protocol.

MATERIALS AND METHODS: The absorbed dose was measured in 20 patients who underwent UAE procedures. Radiation was limited by using low frequency pulsed fluoroscopy, bilateral catheter technique with simultaneous injections for embolization as well as pre-and postembolization exposures and focus on limitation of magnified and oblique fluoroscopy. Lithium fluoride dosimeters were placed both in the posterior vaginal fornix and on the skin at the beam entrance site. The vaginal dose was used to approximate the EAOD. Fluoroscopy time and exposures were recorded. The mean values for all patients were calculated and compared to our previous results obtained with conventional fluoroscopy and to threshold doses for the induction of deterministic skin injury.

RESULTS: Mean fluoroscopy time was 10.95 min. (range 6–21.3 min.) and the mean number of angiographic exposures was 20.9 (range 14–53). The mean EAOD was 9.5 cGy (range 2.21–23.21 cGy) and the mean ASD was 47.69 cGy (range 10.83–110.14 cGy). This compares to previous results with non-pulsed fluoroscopy of an EAOD of 22.34 cGy (range 4.25–65.08 cGy) and an ASD of 162.32 cGy (range 66.01-303.89 cGy) as well as threshold doses for induction of deterministic radiation injury to the skin (400–500 cGy).

CONCLUSION: When pulsed fluoroscopy is used with emphasis on dose reduction techniques, the EAOD and ASD can be substantially reduced to less than 1/2 ($P = .017$) and 1/3 ($P < .0001$) when compared to UAE performed with nonpulsed fluoroscopy. These radiation reduction tools should therefore be applied whenever possible.

Index terms: Fibroids • Radiations, injurious effects • Uterine arteries, embolization • Uterus, neoplasms

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Abbreviations: ASD = absorbed skin dose, BMI = body mass index, EAOD = estimated absorbed ovarian dose, GSD = genetically significant dose, TLD = thermoluminiscent dosimeter, UAE = uterine artery embolization

THE initial success of uterine artery embolization (UAE) for control of symptoms caused by leiomyomata was encouraging and has been confirmed by subsequent studies, with menorrhagia improved in 85% and bulk-related symptoms in 90% of cases (1–5). However, this procedure requires fluoroscopic and angiographic imaging and this causes a concern regarding the radiation dose associated with this therapy. Radiation-induced effects can be (didactically) separated into deterministic and stochastic effects. Deterministic effects are those effects that occur only if a certain threshold of radiation dose is exceeded. Deterministic effects include erythema of the skin or epilation (hair loss). Conversely, stochastic effects have no clearly defined threshold. The likelihood of their occurrence increases with an increase of the absorbed radiation dose, but the severity of the effect will be the same. Examples of stochastic effects include induction of cancer or genetic damage. The genetic risk of any particular source of radiation on the population as a whole is assessed by the genetically significant dose (GSD), which is "the dose equivalent to the gonads weighted for the age and sex distribution in those members of the exposed population expected to have offspring" (6).

Almost all patients who undergo UAE procedures are women of childbearing age, and limitation of radiation dose is important. We, therefore, tailored our fluoroscopic and angiographic technique to reduce the patient's absorbed radiation dose that is associated with the UAE procedure. We have previously reported on radiation dose in a group of patients early in our experience (7). In the current

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study, we measured the estimated absorbed ovarian dose (EAOD) and absorbed skin dose (ASD) in a group of patients using our refined protocol and pulsed fluoroscopy and compared our measurements to our previous results (7). Based on the mean estimated ovarian dose that we obtained, we computed the GSD and compared it to our previous GSD calculation (7).

MATERIALS AND METHODS

The study population consisted of patients who presented for UAE at our institution. One of the two angiography suites in our facility is equipped with pulsed fluoroscopy (Neurostar I; Siemens, Erlangen, Germany). This unit was not always available for use for embolization procedures. Radiation dose measurements were obtained in 20 consecutive patients treated in this angiographic suite.

To date, all patients had been treated under an Institutional Review Board approved protocol and each patient gave informed consent for the UAE procedure, as well as the use of radiation detectors. The mean age of the patients, in whom radiation dose was measured, was 43.45 years (range, 35–53 years). The fluoroscopy time and number of exposures, as well as the body height and weight at the time of the procedure, were recorded and the body mass index (kg/m^2) was calculated for each patient.

Thermoluminiscent dosimeters (TLDs), made out of lithium fluoride, were used for radiation measurements. Each TLD had been calibrated for an 80-kVp beam and the corresponding calibration factor was applied after the reading of the measurement was obtained. The TLDs were placed into plastic tube carriers (each carrier containing five TLDs), and placed onto the patient's skin at the level of the midbuttocks for the measurements of the ASD, and into the posterior vaginal fornix to approximate the absorbed ovarian dose; this process has been described and illustrated previously (7). Metallic markers were attached to the detectors in all cases and the detector position could thus be determined during each entire UAE procedure. These markers do not substantially influence the accuracy of the measurements, as evaluated in a previous study (7). The TLDs were read in a TLD reader (Harshaw, Solon, Ohio). Individual skin and ovarian dose were assessed by calculating the mean from all five measurements that had been obtained from the vaginal and skin detectors. The intraindividual consistency of measurements was monitored by calculation of the standard deviation of the vaginal and skin dose measurements for each patient. While the dose was measured in 20 patients, one set of skin dose measurements was unavailable for the reading because of dislodgment of the inner stylet of the plastic tube carrier and loss of the dosimeters. The remaining measurements for the ASD of 19 patients and ovarian dose of 20 patients were used for analysis.

The UAE procedure protocol was designed to reduce the patient's absorbed radiation dose. We used a bilateral femoral approach and two catheters. In all patients, the catheterization of the hypogastric arteries was performed in cross-over technique using 30 pulses per second fluoroscopy. Selective catheterization of the uterine arteries was then performed with a lower pulse rate of 15 pulses per second. In our experience, this still provides adequate image quality during static fluoroscopy and does not delay successful catheterization. The dose per pulse measured at the image intensifier entrance site was programmed as 23 nGy for all procedures. Both uterine arteries were catheterized prior to angiographic imaging and no abdominal aortography or hypogastric arteriography was performed prior to selective catheterization of the uterine arteries. After each hypogastric artery was catheterized, a digital roadmap using the appropriate oblique projection was obtained to identify the uterine artery, the location of its origin, and any anatomic variations. Once both uterine arteries were catheterized, angiographic imaging was done using simultaneous bilateral injections and a film rate of one film every other second for 8–10 images (including the scout films). Contrast material was hand-injected for angiographic imaging in all cases. All embolizations were performed with catheter placement in the distal third of the uterine artery. Both uterine arteries were embolized by separate physicians simultaneously to further reduce the fluoroscopic time. When flow-limiting spasm occurred, a coaxial microcatheter was used. The selective catheter used in most cases was a 5-F Glidecath (Boston Scientific/Meditech, Boston, MA). If a microcatheter was necessary, a Tracker 325 Fast Track (Boston Scientific/Medi-tech) was most commonly used. Polyvinyl alcohol particles (500–700 micron size) (Ivalon; Cook, Bloomington, IN; Trufill; Cordis, Miami Lakes, FL; Contour; Boston Scientific/Medi-tech) were used in all cases. Embolization was terminated when the flow to the fibroids had ceased and slight antegrade flow was still present in the uterine artery. A pulse rate of 15 pulses per second was used for fluoroscopy during the embolization. The angiographic technique that we used during this study was very similar to the one in our previous study, when the procedure had been performed with conventional fluoroscopy (7). However, the fluoroscopic technique was modified for the current study. While magnification, which had sometimes been combined with oblique fluoroscopy, had previously often been utilized for selective catheterization, we avoided magnified fluoroscopy in our current protocol in most patients. The selective catherizations were instead mostly performed with the appropriate oblique projection during roadmapping.

At least two interventionalists were involved in all UAE procedures. The UAE procedures were performed by different radiologists, but supervised by the same interventionalist in all cases.

The measurements of the absorbed ovarian and skin dose were statistically compared to our previous results that were obtained with nonpulsed fluoroscopy (7). This comparison was performed with the unpaired *t* test using the Stat View software program (StatView for Macintosh version 5.0; SAS, Cary, NC).

The GSD was computed based on the following formula (7):

$$GSD = \frac{N_{xy}P_{xy}D_{xy}}{N_xP_x}$$

Short of the mean estimated ovarian dose (D_{xy}), the same assumptions were used in the calculation as in our previous study (7) to facilitate direct comparison. The potential population treated by the UAE procedure (N_{xy})

Patient Data and Dose Measurements*

Patient No.†	Height (cm)	Weight (kg)	Body Mass Index (kg/m^2)	Exposure Numbers	Fluroscopy Times (min)	Mean Ovarian Dose and STDV (cGy)	Skin Dose: Mean and STDV (cGy)
1	169	105.9	37.08	14	17.6	14.7 ± 0.64	110.14 ± 5.01
2	159	66.8	26.42	22	12.1	10.80 ± 0.66	52.50 ± 2.17
3	154.9	78.2	32.59	14	9.8	7.64 ± 1.1	49.70 ± 1.22
4	175	97.3	31.77	17	21.3	9.85 ± 0.62	84.05 ± 2.15
5	162.5	66.8	25.30	20	10.3	9.11 ± 0.38	Not Available
6	170	74.5	25.78	17	10.9	5.22 ± 0.72	41.36 ± 1.49
7	175	64.5	21.06	14	10.0	2.21 ± 0.34	12.98 ± 0.36
8	161.5	65.5	25.11	17	16.6	12.98 ± 2.59	27.78 ± 1.00
9	160	77.3	30.20	19	14.3	17.70 ± 2.63	65.74 ± 2.38
10	168	100	35.43	14	15.0	23.21 ± 1.87	71.98 ± 5.28
11	170	80	27.68	18	10.4	7.50 ± 0.96	57.30 ± 4.94
12	170	98.6	34.12	19	7.6	12.80 ± 0.44	54.67 ± 0.92
13	180	153	31.67	53	6	2.69 ± 0.44	14.54 ± 1.22
14	153	75	24.05	26	12.5	12.15 ± 0.62	73.18 ± 0.18
15	173	102.6	19.71	17	10.5	8.62 ± 0.92	49.55 ± 1.76
16	157	56.3	28.93	45	7.2	4.40 ± 0.51	18.27 ± 0.30
17	168	59	20.90	16	6.4	2.76 ± 0.09	10.83 ± 0.28
18	164	71.3	26.51	15	7.6	9.24 ± 1.08	35.85 ± 1.11
19	174	60.4	19.95	17	6.2	6.48 ± 0.42	52.50 ± 2.17
20	160	62.7	24.47	24	6.6	9.90 ± 1.71	23.16 ± 0.13
All patients	166.20	80.79	27.44	20.9	10.95	9.50	47.69

Note.—STDV = within-patient SD.
* The numbers for the radiation dose represent the mean of the obtained measurements for each patient.
† The patient number is not the chronological procedure number.

was estimated as one in 10 (10%) of all patients who undergo hysterectomy for fibroids in the United States in a year (assessed 17,500 patients) (7). We assessed the number of expected children (P_{xy}) for each patient treated by UAE as 0.1. The number of women of childbearing age in the country (N_x), according to Census data (1990), was approximated as 58,540,000 and the average number of children of all women of childbearing age (P_x) was estimated as 1.22. We calculated the mean ovarian dose (D_{xy}) from the measurements that we obtained from 20 subsequent patients in our current study.

RESULTS

The mean body weight of the patients, in whom radiation dose was measured, was 80.79 kg (range, 56.3–153 kg), the mean body height was 166.2 cm (range, 153–180 cm), and the mean body mass index (BMI) was 27.44 kg/m^2 (range, 19.71–37.08 kg/m^2) (**Table**). Statistical evaluation of the relation between the BMI and the absorbed radiation dose was not undertaken because fluoroscopic time and exposure numbers differ from patient to patient and the measured dose represents the sum of the doses resulting from the fluoroscopy and the angiographic imaging of each UAE procedure.

Fluoroscopy time for the UAE procedures ranged from 6 to 21.3 minutes, with a mean of 10.95 minutes. The mean number of exposures was 20.9 (range, 14–53).

The mean ovarian dose was calculated as 9.50 cGy (range, 2.21–23.21 cGy; standard deviation of the mean, 5.24 cGy) and the mean skin dose was 47.69 cGy (range, 10.83–110.14 cGy; standard deviation of the mean, 26.55 cGy).

The mean within patient standard deviation was calculated from the average standard deviation of the five detectors of each individual patient and computed as 9.89% (absolute number, 0.94 cGy). The corresponding mean within patient standard deviation for the skin was calculated as 3.75% (absolute number, 1.79 cGy). The range for the relative standard deviation as a percentage from the corresponding mean was from 3.26% (absolute number, 0.09 cGy/patient 17) to 20.09% (absolute number, 2.59 cGy/patient 8) for the ovarian dose and from 0.25% (absolute number, 0.18 cGy/patient) to 8.62% (absolute number, 4.94 cGy/patient 11) for the skin dose (**Table**).

The comparison numbers from our previous study that was performed with nonpulsed fluoroscopy were: mean fluoroscopy time = 21.89 minutes (range, 8.9–52.5 minutes), mean number of exposures = 44 (range, 21–62), mean estimated ovarian dose = 22.34 cGy (range, 4.25–65.08 cGy; standard deviation of the mean, 17.11 cGy; mean within patient standard deviation, 1.37 cGy), mean skin dose = 162.32 cGy (range, 66.01–303.89 cGy; standard deviation of the mean, 75.16 cGy; mean within patient standard deviation, 6.73 cGy) (7).

In comparison to our previous results (7), the mean fluoroscopy time (mean difference, 10.94 minutes; t value, 3.90; $P = .0004$), the mean number of exposures (mean difference, 23.1 exposures; t value, 7.38; $P < .0001$), the estimated mean ovarian (mean difference, 12.85 cGy; t value, 3.38; $P = .017$), and the mean skin dose (mean difference, 114.63 cGy; t value,

6.61; $P < .0001$) were all statistically significantly reduced.

The GSD was estimated as 0.0023 mSv, thus contributing 1% to the GSD from medical diagnostic procedures (estimated dose equivalent of 0.23 mSv [23 mrem]) (7) and adding close to 0.2% to the GSD from all sources (assessed as 1.2 mSv) (7).

DISCUSSION

We have previously reported the mean estimated absorbed ovarian dose associated with UAE as 22.34 cGy and the mean ASD as 162.32 cGy (7). These UAE procedures had been performed with nonpulsed fluoroscopy and were early in our experience. Since that time, we have refined our technique by using two catheters and performing simultaneous embolization and also improved our catheterization skills, which resulted in a significant reduction of the fluoroscopy time from 21.89 to 10.95 minutes ($P = .0004$). Additionally, we have used pulsed fluoroscopy in our current study, which is known to substantially decrease the radiation dose. This has been shown by Schueler and Hernandez, who compared radiation dose from pulsed and conventional fluoroscopy during pediatric cardiac catheterization and conventional fluoroscopic procedures and obtained a dose reduction between 40% and 75%, depending on the pulse rate that was used (8,9). We also obtained our own measurements from a simulated UAE procedure utilizing an anthropomorphic phantom and found a decrease of the absorbed ovarian dose of approximately 43% from pulsed fluoroscopy, when compared to nonpulsed fluoroscopy (10). In the same study, we additionally assessed the impact of magnified and oblique fluoroscopy on the absorbed ovarian dose. In comparison to nonmagnified posterior-anterior fluoroscopy, we obtained an approximately 1.9-fold increase of the absorbed ovarian dose from magnified fluoroscopy and a 1.2-fold increase from oblique fluoroscopy. We also determined that the majority of the absorbed ovarian dose from the average UAE procedure originates from the fluoroscopy and that the dose contribution from the exposures is much less substantial. Based on these results, we have adjusted our protocol to decrease the use of magnified and oblique fluoroscopy and to significantly reduce the fluoroscopic time.

To obtain an approximation of the absorbed ovarian dose, we placed the TLDs into the posterior vaginal fornix. Although this approximation does not provide the actual absorbed ovarian dose, it is an established method of ovarian dose approximation (11) and is as valid as is practically achievable.

To increase the transparency of our measurements, we calculated the BMI for each patient. In many patients, both the BMI and the fluoroscopy time are above average and result in a high skin dose (patients 1, 4, 9, and 10), or both parameters (BMI and fluoroscopy time) are below average and the skin dose is clearly below the mean (patients 5, 17, 18, and 20). In individual cases, an unfavorable effect of a BMI greater than the mean and a favorable effect for a BMI lower than the mean on the absorbed skin dose can also be noted. For instance, patient 12, who had an above average BMI, received a skin dose above the mean, despite below-average fluoroscopy time and exposure numbers. Conversely, in two patients (patients 6 and 8) with a BMI below the mean, long or near average fluoroscopy time, and approximately average exposure numbers, a skin dose that is substantially below the mean was obtained. There may be, however, exceptions to this trend, as in our patient 19, whose BMI, fluoroscopy time, and exposure numbers are all below the mean, but the absorbed skin dose that resulted from the UAE procedure is above the average number. We theorize that this is due to variations in body morphology among individual patients.

The effects of the BMI on the estimated ovarian dose are similar to those on the skin dose. Patients with an above average BMI have generally a high ovarian dose estimation (eg, patients 1, 9, and 10). A below the mean BMI of patient 6 (approximately average fluoroscopy time) may explain her relatively low ovarian dose assessment. A higher-than-average BMI of patient 12 (fluoroscopy time below the mean) could account for this patient's unexpectedly high ovarian dose estimation (12.8 cGy). However, the analysis of the assessed ovarian dose is also complicated by variances in anatomy, as well as position and depth of the vaginal fornix in addition to the influence of BMI and body morphology on the dose absorption. In some patients, the vaginal fornix may have been displaced posterior and inferior by the enlarged myomatous uterus. This may explain the ovarian dose estimation of patient 4, which is only slightly above the mean, despite substantially above-average fluoroscopy time and BMI.

The BMI as a parameter that might influence the absorbed skin and ovarian dose was not available from our previous study, which slightly limits comparability to our current measurements. However, we believe that the significant reduction of the absorbed skin and estimated ovarian dose are predominantly a result of the combination of significant decrease in fluoroscopy time, refinement of our procedure protocol, and the use of pulsed fluoroscopy in our current series of patients.

The earliest of all deterministic effects to the skin is a transient early erythema, which usually resolves spontaneously. A threshold of 400–500 cGy for its occurrence is often found in the literature (12,13), but one of the lowest numbers reported is approximately 200 cGy (14). The mean value for the absorbed skin dose of our series is substantially lower than this threshold, and even our highest measured dose to the skin (patient 1, 110.14 cGy) is clearly below this threshold number. Thus, if a technique similar to ours is used, the occurrence of deterministic skin effects is very unlikely, even in technically challenging procedures.

To the best of our knowledge, an exact threshold that causes temporary disruption of ovarian function is currently not known, but the occurrence of temporary ovarian dysfunction after performance of UAE procedures has been reported and the reason for these events is unknown (7,15). Ovarian failure has been reported after pelvic irradiation for Hodgkin disease (16–20) and obstetric embolotherapy (21). Permanent ovarian dysfunction has been observed in 41%–75% of patients after receiving an ovarian dose of 263–3500 cGy from pelvic irradiation for Hodgkin disease (19,20); approximately 375–400 cGy can generally be considered a threshold for induction of permanent ovarian failure, depending on the patient's age (22).

In our institution, we have estab-

lished a standardized approach to UAE procedures to reduce the patient's absorbed radiation dose. We use a bilateral femoral approach and two catheters, which are placed into the distal uterine arteries. In our experience, this technique does not increase the incidence of ischemia or the complication rate and does not reduce the overall safety of the procedure compared to a unilateral approach with the performance of a Waltman loop. However, with the use of two catheters, injection of embolization particles, as well as contrast material, before and after embolization can be performed simultaneously. The bilateral approach therefore effectively reduces the absorbed radiation dose. Our protocol entails selective catheterization and embolization of the uterine arteries with a reduced pulse rate (15 pulses per second) and an imaging rate of one image every other second. Magnification and oblique fluoroscopy is used only if absolutely necessary. A future refinement of this protocol may be the performance of a postembolization contrast material injection with roadmapping, which may suffice to document the embolization success and would further reduce the radiation dose.

Initial flush aortography for potential identification of fibroid supply from the ovarian arteries is not part of our current protocol, although it is reported that arterial feeding to the fibroids from the ovarian artery can occur and potentially be the cause of treatment failure (23,24). However, the success rate of symptom improvement after performance of UAE is high (1–5) and the incidence and general significance of additional fibroid vascular supply from the ovarian artery are unknown. Once these additional feeding vessels are identified, it is also uncertain, whether their embolization can be performed with technical success in all cases with avoidance of ovarian injury, and whether this embolization would significantly contribute to symptom control. Considering the additional amount of fluoroscopy time, procedure time, contrast material, and absorbed radiation dose that are associated with the performance of initial aortography, we do not believe that its performance on a routine basis is currently justified.

Aortogram with position of the catheter tip at the level of the renal arteries may, however, be indicated in two distinct scenarios. First, in the rare case of unilateral congenital absence of the uterine artery and compensatory fibroid and uterine blood supply from the unilateral ovarian artery. A successful embolization of distal ovarian artery branches in such a case has been reported (24). Second, if bilateral uterine artery injection does not show aberrant tumor vessels corresponding to the areas of the fibroids that were previously seen on other imaging modalities. However, we believe that the combined rate of incidence of these two situations is very low and aortography can always still be performed after their recognition. We do, however, realize that routine initial diagnostic aortography during UAE is occasionally advocated (24) and also probably routinely performed in some institutions. The recording and reporting of additional fibroid supply from ovarian branches will be meaningful to determine their incidence and their significance regarding UAE treatment outcome.

In addition to the radiation effects associated with UAE procedures for the individual patient, radiation effects on the entire patient population, on which the procedure is performed, must also be considered. The genetic risk is estimated by the GSD. Based on the estimated absorbed ovarian dose that was obtained in our current study, the GSD is reduced to 0.0023 mSv (previously estimated as 0.005 mSv) (7), contributing 1% to diagnostic medical applications (previously assessed as 2.2%) (7) and close to 0.2% to the total GSD (previously 0.4%) (7). For this calculation, we assumed that there are 17,500 UAE procedures performed annually (10% of the total number of hysterectomies that are annually performed in the United States due to symptomatic uterine leiomyomata), the number of women of childbearing age is 58,540,000 (taken from the official census counts 1990), the average number of children of patients treated by UAE is 0.1, and the average number of children of women of childbearing age is 1.22 (census data 1990). The variables that could potentially cause substantial short-term changes in the magnitude of the GSD from UAE are the number of treated patients and the mean absorbed ovarian dose calculated from all UAE procedures.

The number of UAEs currently performed in the United States is well below the number we used in our calculation. As this procedure gains acceptance, the annual number will approach the value used in our calculation. We recommend that all physicians performing this procedure record both fluoroscopy time and number of exposures and use this information to monitor and improve their performance. We would hope the information could be accumulated and registered to allow a more accurate estimation of the population radiation burden.

CONCLUSION

We believe that UAE performed with proper technique is currently a safe treatment option for symptomatic uterine fibroids. The absorbed radiation dose associated with the procedure can be substantially reduced with use of a technique and equipment similar to ours. The application of these radiation reduction tools combined with dose monitoring and reporting, as well as careful follow-up of all patients treated by UAE, will substantially aid in ensuring the radiation safety of the UAE procedure.

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