Heavy Metal Pad Shielding during Fluoroscopic Interventions

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Significant direct and scatter radiation doses to patient and physician may result from routine interventional radiology practice. A lead-free disposable tungsten antimony shielding pad was tested in phantom patients during simulated diagnostic angiography procedures. Although the exact risk of low doses of ionizing radiation is unknown, dramatic dose reductions can be seen with routine use of this simple, sterile pad made from lightweight tungsten antimony material.

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THE increasing use of imaging to guide procedures has been accompanied by public health concerns about radiation exposure to patients and health care personnel (1). Whenever a medical image is obtained, a compromise must be made between the quality of the image and the radiation dose used to make that image. Certainly, the lowest dose that can produce a diagnostic image is ideal, which leads to the ALARA principle ("As Low As Reasonably Achievable") (2). This concept is paramount with the use of fluoroscopy because of continuous x-ray production and real-time imaging.

Interventional radiology procedures may expose the patient and physician to the effects of direct and scatter radiation (3). Patient exposure is usually mostly direct radiation, whereas physician exposure may be mostly scatter radiation (4). Biologic effects of ionizing radiation can be categorized as acute or delayed. Although the acute effects of radiation are not commonly a problem, the delayed effects remain a poorly quantifiable concern. Because the delayed effects may take years or decades to appear, they are difficult to distinguish from effects caused by other sources. For this reason, they are considered stochastic rather than deterministic effects. The likelihood of a stochastic effect is directly related to the radiation dose, but its severity is not related to the total dose received. Examples of stochastic effects include carcinogenesis and genetic mutation. This type of effect is of particular concern because it may occur at any dose and there is no threshold dose at which it occurs. However, the lower the dose received, the lower the incidence of consequences that will develop. The principle of ALARA is based on this concept.

The deterministic effects do have a threshold dose, and beyond this threshold, the severity is directly related to the dose (ie, cataracts, skin burns) (5,6).

In fluoroscopy, the exposure to ionizing radiation can be diminished in several ways, including judicious use of fluoroscopy, use of intermittent or pulsed fluoroscopy, holding of the last image, reduction of field size (ie, collimation), and minimization of field overlap (3). The use of intermittent fluoroscopy can diminish the radiation by 20%–70% (7). Additional methods described include minimization of the distance between the patient and the intensifier, maximization of the distance between the patient and the operator, choice of appropriate parameters to operate the machine, and use of movable lead surface shields (8,9) and shielded gloves (10,11).

The purpose of our study was to evaluate radiation exposure with and without a novel shielding device during interventional radiology procedures in the angiography suite for the patient and operator.

MATERIALS AND METHODS

A human adult anthropomorphic phantom (The Phantom Laboratory, Salem, NY) consisting of a torso and head was used that was constructed from a proprietary urethane formulation with an effective mass density that closely simulated muscle tissue with randomly distributed fat. This urethane encased a chest, abdomen, pelvis, and cranial skeleton. The phantom was composed of 35 axial slices, each 2.5 cm thick, that extended from the head to the proximal aspect of the thigh. Some of the slices were taped together, leaving two separate spaces at the neck and pelvis in which dosim-

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Figure 1. Scatter radiation to the thyroid of the phantom was measured with a dosimeter (gray arrow) by placing the sensor (white arrow) superficial to the neck with and without a shielding pad. During simulated celiac artery image acquisition in the phantom, single and double layers of the shielding pad were placed beneath the head/neck region (black arrow).

Figure 2. Scatter radiation to phantom patient ovaries was measured with a dosimeter (gray arrow) by placing the sensor (white arrow) deep in the pelvic cavity with and without a shielding pad. During simulated jugular venous access in the phantom, single and double layers of the shielding pad were placed underneath the pelvic area (black arrow) between the phantom and the table.

eters were placed to estimate the radiation exposure to the thyroid and male/female gonads.

The dosimeter (Model EDD-30; Educational Direct Dosimeter; Unfors Instruments, Billdal, Sweden) provided immediate exposure dose measurement and could be reset rapidly. A long cable was used to connect the small sensor to the display unit. This arrangement allowed the detector to be placed on the surface of the phantom or between individual slices to provide an estimated dose measurement of the organs of interest and spend less time on resetting the dosimeter. Also, the sensor had a spherical response system that can measure radiation exposure from all angles. The dose range of the dosimeter was from 10 nGy to 9,999 Gy with a start trigger level of 15 nGy/sec and an end trigger level of 10 nGy/sec.

The shielding device investigated (RadPad; Worldwide Innovations and Technologies, Overland Park, KS) consisted of a single- and double-layer tungsten antimony material (a steel-gray to tin-white metal) within a proprietary sterilizable polymer sheet measuring 12 inches by 17 inches, less than 1 mm thick, and less than 1 pound in weight. The pad is currently commercially available for $39 US per pad (verbal communication, Worldwide Innovations and Technologies, February 2006).

The study was conducted in an interventional radiology suite with use of an Integris V3000 unit (Philips, Bothell, WA). Automated settings for fluoroscopy and angiographic image acquisitions used were as follows: for fluoroscopy, the calibrations were 60 kVp and 68 kVp with 5.2 mA and 6.8 mA; those for angiography were 67–75 kVp with 6.5–8.1 mA.

PHANTOM PATIENT SHIELDING

Institutional review board approval was not obtained because our institution does not require such approval for phantom studies.

To reduce scattered radiation to gonads and thyroid, the shielding device was placed between the procedure table and the phantom patient (head/neck and pelvic area) while procedures were simulated at the thorax/abdomen level. The dosimeter sensor

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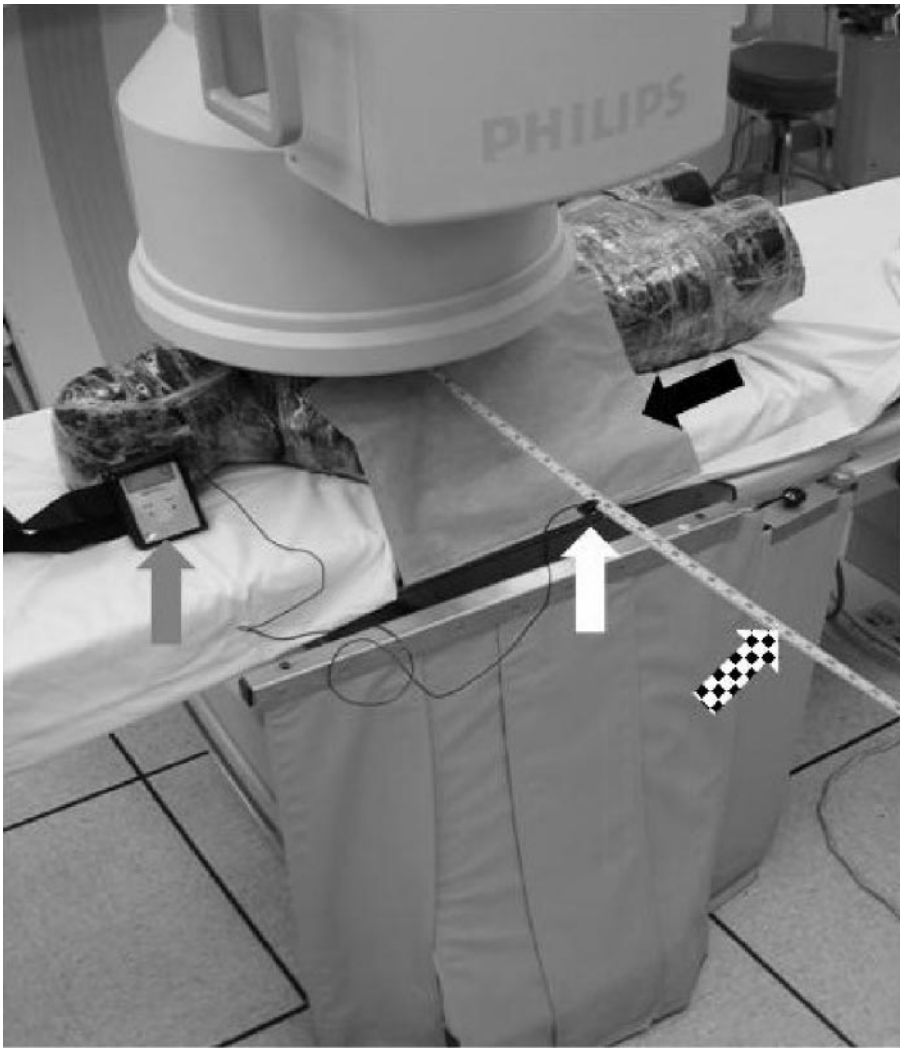

Figure 3. Scatter radiation to the operator with and without a shielding pad was measured with a dosimeter (gray arrow) with the sensor (white arrow) placed every 25–200 cm on a tape measure (squared arrow). The phantom was imaged during a celiac artery image acquisition with use of single and double layers of the shielding pad by placing the pad(s) above the phantom between the phantom and the operator (black arrow).

Table 1
Fluoroscopy Procedures: Protocol Settings

Type of Procedure	kVp	mA	Time (Total)
Venous access fluoroscopy	68	6.8	15 sec, 30 sec, 1 min, 2 min, 3 min, and 5 min
Arterial access fluoroscopy	60	5.2	15 sec, 30 sec, 1 min, 2 min, 3 min, 5 min, 10 min

was placed in the organs being studied (**Figs 1**, **2**).

OPERATOR SHIELDING

Shielding material was placed above the phantom patient, between the phantom and the operator, adjacent to the scanned area of interest (**Fig 3**). The dosimeter was placed at a height of 110 cm above ground (estimated height of the operator's hands). Radiation doses were measured from the epicenter of the radiation field (center of image intensifier) starting at 25 cm with subsequent increments of 25–200 cm (**Fig 3**).

For both studies, the anthropomorphic phantom was in the supine position, and several different measurements were obtained. At first, no shielding protections were used to obtain the baseline scattered radiation measurements to phantom patient and operator, which served as a control. Subsequently, single and double layers of the tungsten antimony shielding material were placed in the corresponding position for phantom patient and operator shielding, followed by multiple readings of scatter radiation. Several routine fluoroscopic and angiographic procedures were simulated and tested (**Tables 1, 2**). Radiation doses were also measured during simulated chest tube placement, abdominal drainage procedures, and various arterial and venous access procedures. The image intensifier was placed over the upper chest wall (centered slightly to the right of midline) to simulate right internal jugular vein and right subclavian vein access device placement procedures and placed over the mid-abdomen to simulate selective arterial access and angiography, such as to the celiac axis, hepatic artery, splenic artery, and superior mesenteric artery.

The results were obtained with the tungsten antimony shield placed with the corresponding phantom and operator shielding technique as described earlier while adequate image quality was maintained.

RESULTS

Phantom patient and operator scatter radiation doses were markedly reduced with the placement of a tungsten antimony shield compared with the presence of no shield.

Phantom Patient

Maximum scattered radiation doses to the lens, male gonads, female gonads, and thyroid gland with and without shielding were documented for the adult phantom during an angiographic run of the celiac trunk (**Table 3**). With the use of a two-layer shield, the following phantom patient dose reductions were observed: 41% for lenses, 73% for female gonads, 94%

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Table 2
Angiography Procedures: Protocol Settings

Type of Procedure	kVp	mA	Frames/second for seconds
Celiac artery run	74	8.1	6 for 2, 4 for 2, 1 for 10
Pulmonary run	67	7.8	6 for 6, 3 for 3, 1 for 10
Pulmonary magnification run	75	6.5	6 for 6, 3 for 3, 1 for 10
Pulmonary left and right anterior oblique runs	75	6.5	6 for 6, 3 for 3, 1 for 10

Table 3
Scatter Radiation to Phantom Patient with and without Shielding during Celiac Artery Angiographic Runs (mGy)

Area of Phantom	Shielding		
	None	One Layer	Two Layers
Female gonad	142.3	61.79	38.12
Male gonad	40.86	6.724	2.608
Lens	4.147	3.269	2.449
Thyroid	33.77	26.97	21.94

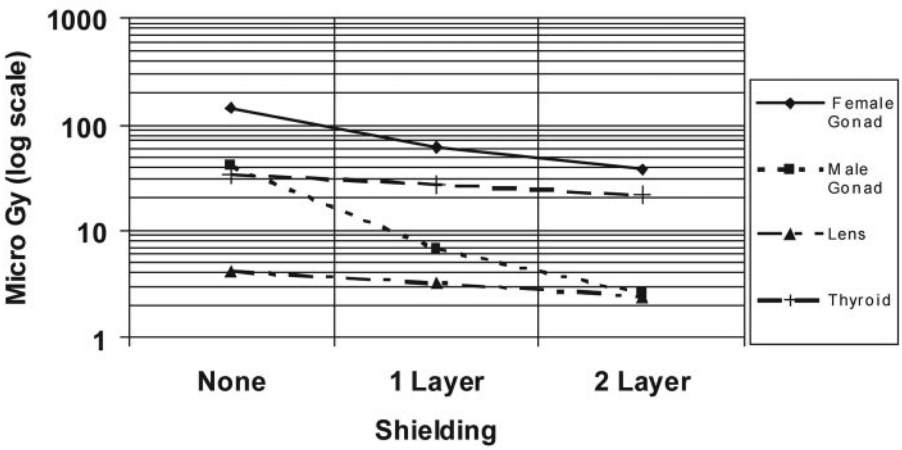

Figure 4. Logarithm scale: the decrease of scatter radiation to the phantom patient during celiac artery image acquisition as described in **Table 2** with use of single and double layers of the tungsten antimony shielding device in the patient.

for male gonads, and 35% for the thyroid gland (**Fig 4**).

The scatter radiation to the same organs was also measured during arterial visceral fluoroscopy at the same level at different times (**Table 4**). At 2 minutes with a two-layer shield, the following dose reductions were observed: 41% for female gonads, 60% for male gonads, 100% for the lens, and 45% for the thyroid (**Fig 5**). After 10 minutes of radiation exposure with the two-layer shield, a dose reduction of 39% was seen in the female gonad and thyroid gland. At 10 minutes, the lens remained 100% protected, and the male gonad showed a dose reduction of 57% with shielding.

Operator

Several factors influence doses to the operator during any interventional procedure, including the distance from the radiation source (ie, center of the image intensifier), which is generally approximately 25–50 cm in angiography procedures. In our study, an abdominal angiographic image acquisition was tested with and without placement of the shielding device between the phantom and the operator (**Table 5**). Recorded scattered radiation to the operator demonstrated dose reductions of 87% and 84%, respectively, with a single-layer shield at 25 cm and 50 cm. In addition, maximum reductions in scattered radiation of 90% and 96% were registered at the same distances with use of a double-layer shield (**Fig 6**).

During fluoroscopy, use of the shielding device was also associated with a remarkable decrease of radiation dose to the operator. Without the tungsten antimony protection, scatter radiation was detected even at 2 meters from the radiation source (**Table 6**). However, with use of only a single-layer shielding device, no scatter radiation was measurable in the phantom operator beyond 1 meter from the radiation source. At 25 cm, 50 cm, and 1 meter, the dose reductions with a single layer of shielding material were 47%, 71%, and 95%, respectively. Conversely, when the double-layer shield was tested, no radiation was measured when the operator distance was more than 50 cm, and reductions of 58% and 89% were seen with operator distances of 25 cm and 50 cm, respectively (**Fig 7**).

DISCUSSION

Radiology procedures are not free of risk. Radiation affects not only the patient but also the radiologist and other health care personnel. In the past 30–40 years, there has been a decrease in the occupational radiation dose for radiologists and radiology personnel. However, an exception to this decrease includes radiologists and personnel in the area of interventional radiology (12). The cause is the development of new and more complex time-consuming procedures such as angioplasty, stent placement, transjugular intrahepatic portosystemic shunt procedures, chemoembolization, embolization, declotting, and thrombolysis, which may increase the x-ray dosage and require the physicians and staff to be near the patient and the x-ray tube for prolonged periods of time.

Radiologists should use radiation safety techniques to minimize the ionizing radiation. Even when a trained

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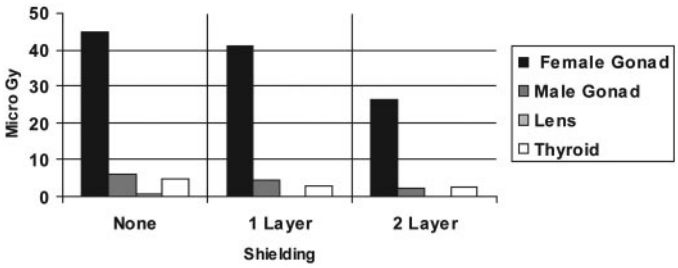

Figure 5. Decrease of radiation to specific organs of the phantom patient during 2 minutes of arterial fluoroscopy with and without the tungsten shielding device.

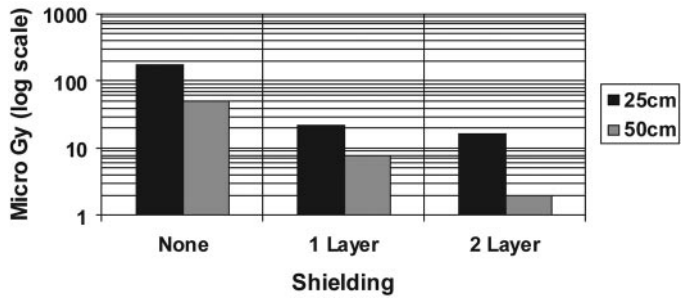

Figure 6. Logarithm scale: scatter radiation reduction to the operator during celiac artery image acquisition with use of single and double layers of the tungsten antimony shielding device.

Table 4
Scatter Radiation to Phantom Patient with and without Shielding During Arterial Fluoroscopy (mGy)

Area of Phantom	Time: 15 Seconds	30 Seconds	1 Minute	2 Minutes	3 Minutes	5 Minutes	10 Minutes
Male Gonad							
No shield	0.733	1.486	2.984	6.003	9.033	15.04	30.04
One layer	0.55	1.12	2.277	4.593	6.87	11.49	23.19
Two layers	0.306	0.578	1.153	2.375	3.596	6.19	12.64
Female Gonad							
No shield	5.407	11.06	22.28	44.85	67.24	112.2	224.5
One layer	5.087	10.25	20.5	41.1	61.65	102.7	205.6
Two layers	3.291	6.338	12.9	26.48	40.1	67.89	137.1
Lens							
No shield	0	0	0	0.696	1.338	2.71	6.083
One layer	0	0	0	0	0	0	0
Two layers	0	0	0	0	0	0	0
Thyroid							
No shield	0.6	1.168	2.338	4.747	7.14	11.97	23.54
One layer	0.395	0.755	1.532	3.168	4.818	8.24	16.8
Two layers	0.347	0.663	1.377	2.799	4.241	7.162	14.43

Table 5
Scattered Radiation to the Operator with and without Shielding During a Celiac Artery Image Acquisition (μGy)

Distance (cm)	Shielding: None	One Layer	Two Layers
25	172.3	21.47	16.31
50	49.97	7.753	2.014

Table 6
Scatter Radiation to the Operator with and without Shielding during Arterial Access Fluoroscopy (μGy)

Distance (cm)	Shielding: None	One Layer	Two Layers
25	16.24	8.684	6.782
50	8.942	2.566	1.029
75	4.769	1.194	0
100	2.721	0.135	0
125	1.766	0	0
150	1.192	0	0
175	0.917	0	0
200	0.515	0	0

operator uses modern fluoroscopic equipment with dose-reducing technology, a significant percentage of procedures can result in radiation doses to the patient and operator that can potentially have future clinical consequences (13). With this in mind, a safe and efficient use of radiation should be used in therapy, diagnosis, and research.

A study of risk of cancer development from exposure to medical radiologic tests (14) estimated it to be 0.6%–3% of all cancers, with Japan leading in risk secondary to major use of radiographic medical imaging. In the United States, the Nuclear Regulatory Commission controls the occupational and nonoccupational radiation exposure limits to prevent deterministic and stochastic effects. The deterministic effects could be avoided using a radiation exposure less than 500 mSv per year, and to prevent the stochastic effects, the radiation should not exceed 50 mSv per year (15). The Biologic Effects of Ionizing Radiation report number 7 (16), the most recent and comprehensive publication concerning radiation health effects, reviewed the available biologic and biophysical data supporting the Linear No-Threshold risk model: that the risk of cancer proceeds in a linear fashion at lower doses without a threshold and that the smallest dose has the potential to cause a small increase in risk to humans. Biologic Effects of Ionizing Radiation report number 7 (16) defines low radiation between zero and approximately 100 mSv. For example, people in the United States are exposed to annual background radiation levels of approximately 3 mSv; 58% of the man-made radiation dose to patients comes from medical x rays; fluoroscopy exposure from a whole-body computed tomography scan is approximately 10 mSv; and exposure from a chest radiography procedure is approximately 0.1 mSv. Exposures at low

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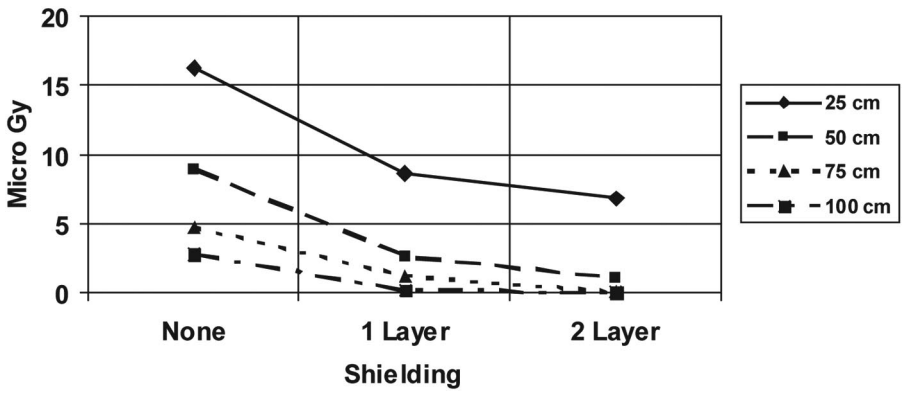

Figure 7. Scatter radiation dose reduction to the operator during arterial access fluoroscopy with use of single and double layers of the tungsten antimony shielding device. No scatter radiation was found for the operator at 100 cm (1 m) from the radiation source for single and double shielding layers.

levels of ionizing radiation (approximately 100 mSv) are responsible for approximately 1% of cancers (solid cancers or leukemia) in humans, whereas approximately 42% result from other causes like dietary, genetic, and environmental factors such as natural background radiation (16).

Although actual exact low-dose radiation risk is unknown, radiologists should be aware of different techniques, methods, and devices that can be applied synergistically to diminish scatter radiation. Available shielding methods include gloves, glasses, aprons, and floor- and ceiling-mounted barriers. This concept of attenuating scattered radiation from patient to operator is not new and has been studied previously with the use of lead (8). The density of a radiation shielding material determines its penetration by x rays. The denser the material, the more x-ray intensity is reduced (17). Lead has a very high density property; it has been used to provide shielding from x rays for many years and still is an effective protection. But other elements like tungsten, tantalum, and bismuth have more density than lead and consequently provide a more valuable barrier to x rays. The use of bismuth as a radiation shield has been reported and has shown valuable protection from scatter radiation (18). We have found that tungsten antimony shields are ergonomic and reduce occupational exposure without increasing staff workload or apron weights.

One possible limitation of our study was the sensitivity threshold and the digital rounding of the dosimeter we used. Obviously, extrapolation of the study results to real procedural dosages requires unvalidated assumptions related to procedure simulations. It is also possible that our simulation underestimated the doses required when extremely difficult procedures are encountered or with inexperienced operators.

With the lead-free, lightweight, and disposable one- or two-layer tungsten antimony shielding used according to the technique described herein, the protection from scatter radiation for the patient and operator is simple, affordable, and effective.

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Errata

In the March 2006 letter to the Editor entitled "Sloughing of Intraductal Tumor Thrombus of Hepatocellular Carcinoma after Transcatheter Chemoembolization Causing Obstructive Jaundice and Acute Pancreatitis" J Vasc Interv Radiol 2006; 17:583–585, there is an error in the name of the eighth author. The corrected author list is as follows:

Takao Hiraki, MD, Jun Sakurai, MD, Hideo Gobara, MD, Hirofumi Kawamoto, MD, Takashi Mukai, MD, Soichiro Hase, MD, Toshihiro Iguchi, MD, **Hiroyasu Fujiwara, MD,** Nobuhisa Tajiri, MD, Yasushi Shiratori, MD, and Susumu Kanazawa, MD

In the June 2006 article entitled "Midterm Follow-up of a Single-center Experience of Endovascular Repair of Abdominal Aortic Aneurysms with Use of the Talent Stent-Graft" J Vasc Interv Radiol 2006; 17:973–977, there is an error in the name of the seventh author. The corrected author list is as follows:

Dare Mutiyu Seriki, MRCP, FRCR, Raymond J. Ashleigh, FRCS, FRCR, J. S. Butterfield, MRCP, FRCR, Andrew England, BSc, Charles N. McCollum, FRCS, Nasim Akhtar, MD, FRCS and **Mark Welch, FRCS**

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