Risk of Radiation Exposure during Endovascular Aortic Repair

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WHAT THIS PAPER ADDS

- This paper reports radiation exposure in a large cohort of patients after endovascular repair of the thoracic and abdominal aorta. Techniques including computer software modelling are used to evaluate the amount of exposure and confirm that the patient can receive high doses of irradiation, especially after complex repairs. We suggest that efforts to minimise irradiation and closer follow up of patients that have had high exposures are required.

A R T I C L E   I N F O

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A B S T R A C T

Objective: Exposure to radiation doses above 2 Gray (Gy) can cause skin burns. There is also a lifetime cancer risk of $\approx 5.5\%$ for every Sievert (Sv) of radiation. We assessed the radiation burden associated with endovascular treatment of the aorta.

Method: Thoracic (TEVAR), Infra-renal (IEVAR) and branched/fenestrated (BEVAR/FEVAR) endovascular aortic repairs were studied. The prospectively recorded dosimetric parameters included: fluoroscopy time and dose area product (DAP). Exposure films, placed underneath 10 patients intra-operatively, recorded skin dose and were used to calculate skin (Gy) and tissue (Sv) doses.

Results: The TEVAR cohort ($n = 232$) were younger ($p < 0.0001$) than BEVAR/FEVAR ($n = 53$) and IEVAR ($n = 630$). The median DAP was higher ($p = 0.004$) in the BEVAR/FEVAR group compared with IEVAR and TEVAR: 32,060 cGy cm$^2$ (17,207–213,322) vs 17,300 cGy cm$^2$ (10,940–33,434) vs 19,440 cGy cm$^2$ (11,284–35,101), respectively. The equivalent skin doses were BEVAR/FEVAR: 1.3 Gy (0.71–8.75); IEVAR: 0.71 Gy (0.44–13.7); TEVAR: 0.8 Gy (0.46–1.44). The whole body effective doses were BEVAR/FEVAR: 0.096 Sv (0.052–0.64); IEVAR: 0.053 Sv (0.033–1.00); TEVAR: 0.058 Sv (0.034–0.11).

Conclusions: The radiation exposure during endovascular aortic surgery is relatively low for the majority but some patients are exposed to very high doses. Efforts to minimise intra-operative exposure and graft surveillance methods that do not use radiation may reduce the cumulative lifetime malignancy risk.

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Introduction

Endovascular procedures play an increasingly important role in the treatment of vascular disease and have become the treatment of choice for the aorta. The radiation exposure involved can increase the morbidity associated with these treatments, by causing tissue damage and increasing the risk of malignancy. Transient skin erythema may be seen within hours of exposure to peak radiation doses over 2 Gy, with higher exposures risking temporary epilation and tissue necrosis. The biological effects of radiation on the whole body are measured in sieverts (Sv). With every Sv of radiation absorbed by the body there is a 5.5% detriment-weighted lifetime risk of induced cancer. The long term risk associated with radiation exposure following endovascular aortic procedures, is often dismissed with the notion that the life expectancy of the typical patient is relatively short, coupled with the fact that there is a latent period of around 10 years for malignant transformation following radiation exposure. Improved standards of care, however, mean that life expectancy is increasing and significant radiation exposure in the younger patient is of particular concern.

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lifetime follow up with imaging modalities such as computed tomography (CT) can significantly add to the burden of radiation after the initial repair.

Intra-operative radiation exposure during endovascular procedures should be accurately quantified and attempts made to minimise this exposure should be a priority. We used validated techniques to quantify the amount of radiation to which patients were exposed during repairs of the thoracic and abdominal aorta.

Methods

Prospective data collected on all consecutive Infra-renal aortic repairs (IEVAR), thoracic endovascular aortic repairs (TEVAR) and branched/fenestrated endovascular repairs (BEVAR/FEVAR) between 2003 and 2010 was analysed retrospectively. All repairs were carried out in an interventional radiology suite. Indirect measurements recorded by the fluoroscopy equipment were Dose Area Product (DAP) and the fluoroscopy time. Dose Area Product is a crude estimate of radiation exposure which reflects the radiation dose and the area of tissue that has been irradiated and does not reflect the peak dose received by one particular area. We therefore made direct measurements of peak skin radiation exposure for a cohort of procedures and used software modelling to accurately quantify the amount of radiation absorbed by the body.

Quantification of peak skin dose

A sheet of Gafchromic XR-RV2 film (International Specialty Products, New Jersey, USA) was exposed to a series of known radiation doses, ranging from 0.06 Gy to 4.0 Gy as seen in Fig. 1a. The film was scanned and analysed using the image analysis software Image J (National Institutes of Health, USA) to obtain a calibration curve Fig. 1b.

Prospective data was then collected using a cohort of 10 patients (n = 9 IEVAR, n = 1 BEVAR/FEVAR). A sheet of Gafchromic XR-RV2 film was placed under the patient during interventions in order to make a direct measure of the maximum intra-operative skin dose received (Fig. 2). The film was placed in a protective bag, underneath the mattress, before the patient was positioned on the operating table. At the end of each procedure the film was scanned and analysed as described above. The mean pixel value in the darkest region of the film was used to estimate the peak radiation dose absorbed by the skin using the calibration curve. The largest possible rectangular region of interest that fitted inside each uniformly irradiated area of the film was used. This area typically measured greater than 10 cm².

The ratio of measured skin dose to DAP was found for all 10 patients. The mean value of this ratio was applied to the DAP value recorded for each of the 915 procedures in order to obtain an estimate of the peak skin dose for every patient.

Statistics

Spearman’s rank test was used to assess the correlation between DAP and fluoroscopy time, and Chi Squared test to compare proportion of patients exceeding 2 Gy skin dose in each group. All other variables were compared using a Mann Whitney T-test. Variables were expressed as median with range or mean with standard deviation. P values of <0.05 were regarded as statistically significant.

Results

The TEVAR cohort (n = 232, age 71, 15–89), which included patients treated for aortic transection and dissections, were younger (p = 0.004) in the BEVAR/FEVAR group compared with IEVAR and TEVAR: 32,060 cGy cm² [17,207–213,322] vs 17,300 cGy cm² [10,940–334,340] vs 19,440 cGy cm² [11,284–35,101], respectively (Fig. 3).

The recorded DAP for the 10 patients for whom Gafchromic film was used was 14,351 cGy cm² (12,438–20,812). The equivalent skin dose was 0.6 Gy (0.5–0.85). The mean ratio of the directly
measured skin dose (using film): DAP (recorded by machine) for the 10 patients was $4.1 \times 10^{-5}$ $(\pm 1.82 \times 10^{-5})$.

The volume of contrast used was significantly higher in the BEVAR/FEVAR when compared to the IEVAR and TEVAR, (180 ml [30–550] vs 105 ml [10–450] vs 140 ml [15–450], $p < 0.0001$ and 0.0003 respectively). The contrast volume was also significantly higher ($p = 0.0001$) in thoracic compared with infra-renal repairs.

There was a positive correlation between DAP and fluoroscopy time in the BEVAR/FEVAR and IEVAR, $R = 0.51, (p < 0.0001)$ and $R = 0.42, (p < 0.0001)$ respectively, but not TEVAR group (Fig. 4a). There was a positive correlation between contrast volume and fluoroscopy (screening) time (Fig. 4b) and also between contrast volume and DAP (Fig. 4c).

**Equivalent skin doses and whole body doses**

The skin doses derived using the conversion ratio of $4.1 \times 10^{-5}$ were 0.8 Gy (0.46–1.44) for TEVAR, 0.71 Gy (0.44–13.7) for IEVAR and 1.3 (0.7–8.7) for BEVAR/FEVAR.

### Table 1

<table>
<thead>
<tr>
<th></th>
<th>BEVAR/FEVAR (n = 53)</th>
<th>TEVAR (n = 232)</th>
<th>IEVAR (n = 630)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>76 (58–85)</td>
<td>71 (55–89)</td>
<td>76 (37–91)</td>
</tr>
<tr>
<td>Female (%)</td>
<td>13 (25%)</td>
<td>72 (31%)</td>
<td>67 (11%)</td>
</tr>
<tr>
<td>Screening time (mns)</td>
<td>58 (6.7–212)</td>
<td>10 (1.5–130)</td>
<td>18 (2.4–161)</td>
</tr>
<tr>
<td>Peak skin dose (Gy)</td>
<td>1.3 (0.7–8.7)</td>
<td>0.8 (0.46–1.44)</td>
<td>0.71 (0.44–13.7)</td>
</tr>
<tr>
<td>Whole body dose (Sv)</td>
<td>0.096</td>
<td>0.058</td>
<td>0.053</td>
</tr>
<tr>
<td>Skin dose &gt;2 Gy</td>
<td>17 (31%)</td>
<td>26 (11%)</td>
<td>69 (11%)</td>
</tr>
</tbody>
</table>

### Discussion

We report radiation exposures for a heterogeneous group of aortic endovascular procedures showing significant exposure to the skin but a low excess malignancy risk. As expected radiation exposure was consistently higher for BEVAR/FEVAR repairs with almost a third of patients exceeding the threshold of 2 Gy in this group. It is our practice to examine patients exposed to skin doses above 2 Gy in the immediate postoperative period for skin erythema and burns, however, we did not find any signs of skin damage at that time point even though some patients were exposed to doses higher than 2 Gy. A dose of 2G is recognised in the literature as a threshold that critically increases the risk factor of developing skin changes but immediate signs remain relatively uncommon and may be limited to subtle erythema. It should also be noted that manifestations of skin damage can be delayed and skin erythema, burns and hair loss can take up to 4 weeks to develop. The patients in the present study were not specifically examined for signs of radiation injury in outpatients and signs of delayed skin damage may have been overlooked. The International commission on radiological protection recommends that patients whose maximum cumulative absorbed dose exceeds 1 Gy should be counselled about the aforementioned effects of radiation exposure, their general practitioner notified and should be followed up in outpatients.

Routine dosimetric measures typically recorded include DAP, fluoroscopy time and contrast volume. Dose area product is a crude measure of exposure that doesn’t take into account the differences in X-ray beam quality or the size and position of the X-ray field. Although it reflects the dose and area of tissue irradiated, it provides no information regarding the spatial distribution of the entrance beam on the patient’s skin. The same DAP is therefore observed with a large field and low skin dose, compared with a small area and large skin dose. The use of Gafchromic film and specialist software phantom models provide a way for calculating the amount of radiation exposure at the skin level and the amount absorbed by the body during these procedures respectively. Weiss...
et al. reported peak skin doses of 0.75 Gy (0.27–1.25) for 12 infra-renal endovascular aneurysm repairs using a comparable method to the present study with Gafchromic film. We have reported a skin dose of 0.71 (0.44–13.7) the larger range may be explained by the larger sample size in the present study that includes technically challenging procedures needing prolonged fluoroscopy and multiple DSA runs and simple tube grafts that only necessitated the briefest exposures.

The fluoroscopy time correlated positively with the DAP for BEVAR/FEVAR and IEVAR. For thoracic repairs, fluoroscopy time did not correlate with DAP and there was a large exposure despite short fluoroscopy times in some cases. This may be due to the relatively high ratio of digital subtraction angiography (DSA) and/or digital acquisition runs to fluoroscopy during these thoracic repairs. The fluoroscopy time only includes X-ray exposures in fluoroscopic mode and would not, therefore, account for the DSA runs. Digital subtraction angiography allows clear visualisation of blood vessels in a bony or dense soft tissue environment, but this is at the expense of a high radiation dose. During some procedures (e.g. thoracic interventions) the C-arm would have been used more frequently in a lateral or oblique orientation which produces a relatively high DAP for short a screening times.

The majority of patients undergoing EVAR are elderly and may outlive the stochastic effects of radiation exposure before they manifest. The TEVAR subgroup are, however, younger and the risk in this cohort may be higher. Use of annual surveillance CT scans, for example in the case of a patient in their 30’s following TEVAR for aortic trauma, would significantly add to the radiation burden. Walsh et al. reported the lifetime risk of CT related cancer in an 80 year old, having yearly CT follow up as 1 in 3000 which rises to 1 in 140 for a 20 year old. A CT scan of the thoracic and abdominal aorta exposes the patient to an effective dose of 11 mSv which is equivalent to 4.5 years of background radiation and gives an increased cancer risk of 1 in 1700. The radiation burden associated with follow up imaging in our patient cohort would be the subject of another study but it seems sensible to use graft surveillance methods, such as Duplex ultrasound, that do not require radiation. We have adopted a policy of using duplex imaging for follow up of infra-renal aortic repairs if the initial follow up CT scan shows a satisfactory repair.

Awareness of the amount of radiation exposure to both the surgeon and patient is becoming imperative with the increasing use of fluoroscopy guided endovascular procedures. The vascular surgeon has a vital responsibility to monitor and minimise exposure where possible. Strategies to minimise this risk include intermittent use of fluoroscopy where possible and adjusting the table position to reduce the air gap between the fluoroscopy detector and the patient. A smaller air gap reduces radiation scatter and consequently reduces radiation exposure to both the patient and the operator.

Figure 4. (a) There was a positive correlation between the screening time (ST) and the dose area product (DAP) in the BEVAR/FEVAR and IEVAR group but not in TEVAR. There was a positive correlation between contrast volume and ST (b) as well as between contrast volume and DAP (c) for all categories.

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Branched and fenestrated repairs necessitate higher doses of radiation. Identification and cannulation of target vessels may need prolonged fluoroscopy, several DSA runs and the use of large doses of contrast. Techniques such as “image registration” are being developed to aid identification of aortic branches and their ostia, thereby reducing fluoroscopy time and contrast usage. This technique relies on computer software to construct a 3 dimensional representation of the aorta and its branches from a preoperative contrast CT. This 3D image is overlaid onto intra-operative fluoroscopic images allowing continuous visualisation of the position of target vessel ostia to aid graft positioning and vessel cannulation.

Limitations of the study

Only ten patients, largely IEVAR, were examined using Gaf-chromic film to determine peak skin dose. This inevitably introduces a margin of error for the conversion factor and therefore on the extrapolated for the entire cohort of mixed endovascular procedures. The data obtained is very valuable in the setting of infra-renal aortic repairs but skin exposure values obtained in the BEVAR/FEVAR and TEVAR cohort using this methodology need to be interpreted with caution.

Errors in the film calibration may have resulted from variation between individual films, the radiation beam quality, accuracy of the dosimeter used for calibration and the consistency of the tube output. The patient’s sex, body habitus, individual anatomy, part of body irradiated, radiation field size and radiation source to skin distance are just some of the other factors that would affect the dose of radiation absorbed by the body. These were not taken into account when applying the conversion factors in the present study. In addition, variations in operator technique such as field size, number and length of DSA runs and tube angulation will also affect the skin and whole body effective doses.

Finally, the study would benefit from long term follow up of patients to determine the long term incidence of malignancy in this population and whether exposure to higher doses of radiation does indeed lead to a higher incidence of malignancy.

Conclusions

The risk associated with radiation exposure during endovascular aortic surgery is relatively low for the majority but some patients are exposed to very high doses. Graft surveillance methods, such as duplex and MRI, that do not use radiation are important in reducing the cumulative lifetime malignancy risk.

Conflict of Interest Statement

None of the authors have any conflict of interest that would bias this work.

Funding

None.

Ethics Statement

The work detailed in this manuscript has been approved by the appropriate ethical committees related to our institution and the subjects involved gave informed consent to the work.

References