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Technical note

Patient doses and occupational exposure in a hybrid operating room

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ABSTRACT

Purpose: This study aimed to characterize the radiation exposure to patients and workers in a new vascular hybrid operating room during X-ray-guided procedures.
Methods: During one year, data from 260 interventions performed in a hybrid operating room equipped with a Siemens Artis Zeego angiography system were monitored. The patient doses were analysed using the following parameters: radiation time, kerma-area product, patient entrance reference point dose and peak skin dose. Staff radiation exposure and ambient dose equivalent were also measured using direct reading dosimeters and thermoluminescent dosimeters.
Results: The radiation time, kerma-area product, patient entrance reference point dose and peak skin dose were, on average, 19:15 min, 67 Gy·cm^2, 0.41 Gy and 0.23 Gy, respectively. Although the contribution of the acquisition mode was smaller than 5% in terms of the radiation time, this mode accounted for more than 60% of the effective dose per patient. All of the worker dose measurements remained below the limits established by law.
Conclusions: The working conditions in the hybrid operating room HOR are safe in terms of patient and staff radiation protection. Nevertheless, doses are highly dependent on the workload; thus, further research is necessary to evaluate any possible radiological deviation of the daily working conditions in the HOR.

1. Introduction

X-ray imaging development is leading to a transformation not only in diagnostic radiology but also in the fields of cardiology, neurosurgery and vascular surgery. Currently, in particular, the endovascular procedures guided by radiological imaging represent a proportion up to 80% of vascular interventions [1] being used in many institutions in preference to open surgical repair [2]. Conversely, a new concept in operating room design allows vascular surgery patients to receive multiple levels of care within a single operating room. The new hybrid operating rooms (HORs), equipped with robotic angiography systems and several high-definition monitors, enable physicians to perform the most advanced vascular and surgical procedures with a high level of sterility and virtually unrestricted freedom-of-movement radiological images.

These interventional procedures, in addition to other diagnostic imaging modalities (such as CT) contribute significantly to man-made exposure of the population. The overall complexity of these types of studies (which usually require the extended use of fluoroscopic guidance with high-quality and low-noise images), high number of studies per day and large number of medical staff involved lead to relatively high occupational exposures of the members of the medical team [3], as well as lead to higher exposures to patients [4], than other imaging procedures.

The potential risk of patient radiation damage must be viewed in the context of the general benefit of these procedures and the likelihood of greater trauma associated with brain or heart surgical interventions and perhaps with imminent death if the intervention were not performed. This potential radiation damage can be divided into stochastic and deterministic effects. Patient exposure to high-entrance surface doses (up to several Gy) during these types of procedures can lead to well-documented deterministic effects, such as skin erythaema, necrosis, and even ulceration [5]. The skin, however, is not the only tissue exposed to possible deterministic effects. The eyes can, for example, be very close to the examined region during neurological procedures. Although

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deterministic effects are generally well known, the potential long-term risk associated with ionizing radiation (such as cancer and genetic effects) is usually more difficult to assess [6,7].

The direct measurement of radiation exposure to the patient can be performed with certain types of dosimeters, such as thermoluminescent dosimeters (TLDs), optically stimulated luminescence dosimeters (OSLs) or radiochromic films; however, these strategies are usually impractical. Despite these problems, radiation exposure can be estimated by indirect patient dose monitoring system from direct measures of X-ray output using a Kerma-Area Product (P_{KA}) [8] meter, based on a transparent ionization chamber mounted in the X-ray tube assembly. Spanish legislation [9] has required all fluoroscopes installed in Spain to be capable of displaying the value of P_{KA} and the cumulative air kerma (calibrated free in air) at the patient entrance reference point for each intervention. For isocentric fluoroscopic systems such as C-arm fluoroscopes, the patient entrance reference point is located along the central X-ray beam at a distance of 15 cm from the isocentre in the direction of the focal spot [10].

The Kerma-area product, as well as patient entrance reference point dose (D_{PERP}) or fluoroscopy time (FT), is now reported by newer fluoroscopy units in Radiation Dose Structured Reports (RDSRs). Although direct measures are more accurate, they cannot be routinely obtained; thus, indirect estimations are recommended as proxies for the clinical setting [11]. Unfortunately, there is no real-time indicator of the patient skin dose that can be observed during a fluoroscopically guided intervention, but the patient entrance reference point dose roughly correlates with patient's skin dose during a procedure [12].

Ionizing radiation is also potentially dangerous for workers. Since the advent of HORs and the proendovascular approach in many indications, radiation exposure of vascular surgeons and interventional radiologists has increased significantly [13]; thus, the evaluation and monitorization of staff radiation doses in HORs is an important subject to consider for the safety of professionals [14].

Lead aprons, thyroid collars and protective shields are used within the HOR to protect the staff. Personal dosimeters are also used to ensure that staff radiation doses remain below the limits established by the current legislation in our country [15], according to the International Commission on Radiation Protection [16]. This global analysis does not allow, however, a case-by-case distinction; thus, it is complicated to recognize individual physician practices that may result in higher doses for patients or staff. The identification of these variables would allow the improvement of radiation protection and minimize the dose for all of them.

Despite the increasing caseload for many vascular surgeons and interventional radiologists [17,18], there are few studies that have specifically investigated the radiation exposure to the entire operating team. Radiation exposure to the medical staff is highly dependent on their position with respect to the patient couch. Thus, even if values of the P_{KA} are low, members of the medical staff positioned closer to patients during fluoroscopy could receive high occupational doses, unlike those who are further away. Thus, nurses and technicians usually receive doses lower than those received by the chief or accompanying operators [19].

In September 2015, an HOR opened at the Hospital Clínico Universitario de Valladolid (Spain) to perform vascular surgery studies. Interventions that require the use of X-ray imaging within the HOR cover procedures such as arteriopathy interventions or endarterectomy, where a few angiographies are sufficient, to complex interventions such as coil embolization, Sten-Graft or endoprosthesis placement. However, not all HOR patients need X-ray imaging: there are some procedures, such as chemotherapy reservoir removal or member amputation, which require only a sterile environment. The aim of this work was to characterize the patient doses and occupational exposure during the first year of use of the HOR. This evaluation will allow us to estimate the radiation protection conditions of both professionals and patients to take appropriate actions if necessary.

2. Materials & methods

2.1. Hybrid operating room

The HOR is equipped with Siemens Artis Zeego (Siemens Healthcare, Erlagen, Germany), a multi-axis robotic X-ray imaging system with flat panel detector. The X-ray tube has power ratings from 40 to 125 kV, providing pulsed imaging with four different pulse rates—7.5, 10, 15 and 30 pulses per second (pps)—both for fluoroscopy and acquisition radiation modes. Examinations in the HOR are usually performed under automatic exposure-rate control (AERC) in which the tube potential and tube current are automatically adjusted.

The system is equipped with a P_{KA} measurement chamber permanently installed on the fluoroscopy unit that provides the P_{KA} and D_{PERP} measurements of each intervention. Chamber quality control measurements based on the Spanish Protocol of Quality Control in Diagnostic Radiology [20] are periodically carried out using an RTI Barracuda electrometer with a solid state detector R100B (RTI Electronics AB, Mölndal, Sweden). In the last measurement performed in late 2015, the deviation founded was ≈8% in P_{KA} and ≈12% in D_{PERP} for the entire range of clinical filtrations and voltages, being lower than 20%, the limit value set by the Spanish protocol.

The HOR is also equipped with two movable ceiling-mounted lead glass shields (0.5-mm Pb equivalent) and all the HOR staff wear lead aprons (at least with a 0.25-mm Pb equivalent) and thyroid collars during the use of X-rays.

2.2. Patient doses

Two hundred sixty procedures (22% female, 78% male) required the use of X-ray guidance during the first year of use of the HOR. Interventions without the use of X-ray imaging or irradiation times below 30 s were rejected in our study. No cases of pregnancy or allergy to iodine were presented during the study.

A summary of the type and ratio of the 260 procedures under study can be seen in Table 1. As a general rule, all the procedures are performed by two vascular surgeons, to which must be added a third, usually a resident. During the intervention, the HOR staff also includes an anesthetist, sometimes also one anesthesia resident, two nurses, one nursing assistant and one diagnostic imaging technician.

The RDSR of each intervention was retrieved using CARE Analytics, a tool provided by Siemens that collects the dose report of the procedures and shows the associated main radiation parameters, such as the radiation time, P_{KA}, D_{PERP} and peak skin dose ($D_{skin,max}$).

The value of the patient $D_{skin,max}$ included in the RDSR and retrieved by CARE Analytics is computed by CARE Monitor [21], a

Table 1
Type and ratio of the 260 procedures carried out in the HOR during the year under study.

Type of intervention	Ratio
Angioplasty (femoropopliteal stent)	44%
Angioplasty (iliac stent)	25%
Aortic endoprosthesis	15%
Angioplasty (distal stent)	8%
Other procedures	8%