Radiation Dosimetry in Pulmonary Embolism Detection

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The current discussions regarding the relative benefits and problems of CTPA vs V/Q scanning for diagnosis of pulmonary embolism revolve around two main questions Which provides the better diagnostic value, and what radiation dose is delivered to the patient in the process? This note covers the latter issue, although neither should be seen in isolation.

Dosimetry Factors

For V/Q scanning, the dosimetry is relatively uncomplicated, and is affected mainly by administered activity in each phase. The radiopharmaceutical used has a role, but given that the macroaggregates all have similar dosimetry and use ^{99m}Tc , the variations then come from the ventilation agents – Technegas, aerosols and gases. The main biological factor we need to consider is whether a female patient is pregnant or not. The dosimetry is independent of the imaging device.
The situation with CTPA is very different. There is a wide range of factors which can be varied. Some of these, and a brief effect for each, are:

- kVp – lower kVps can reduce dose
- mAs – a simple linear relationship with dose
- scan slice width – thin slices can increase dose
- whether CT automatic exposure control (AEC) is used – "on the fly" variation in tube current can reduce dose
- number of slices, or scan volume – again, a simple relationship, but also will determine which organs are irradiated
- scan pitch – lower pitch can increase dose
- number of scan runs – pre- and post-contrast runs will effectively double the dose
- breast shielding – use can decrease breast dose
- the CT scanner – doses vary with manufacturer and model

This all means that accurate prediction of CTPA doses is difficult if not impossible, and the reader of the literature needs to be aware that stated doses can vary widely.

For both modalities, the dose to the patient can be expressed as organ absorbed dose (in mGy), and as effective dose to the body as a whole (in mSv). The effective dose is the product of (absorbed dose x tissue weighting factor) summed over all irradiated organs. Strictly speaking, it is equivalent dose in mSv rather than absorbed dose which should be used in this calculation; however for photons the two are numerically equal. In its 1976 recommendations (1) the ICRP introduced the term "tissue weighting factor WT" to describe this. The weighting factors are used when calculating a person's effective dose from exposures to individual organs or tissues.

WT for the breast was 0.15, based on assumed risk factor for fatal cancer of 2.5 x 10^{-3} Sv-1. The highest weighting factor of 0.25 was for the gonads, based on assumed risks of hereditary effects as well as tumour induction and fertility impairment. Only 6 organs were allocated specific weighting factors at that time.
The sum of all factors was 1 by definition. All factors including breast are gender-averaged.

The 1990 recommendations of the ICRP (2) added 6 further organs to be allocated WT values, resulting in a reduction in the values for gonads and breast to 0.20 and 0.05 respectively. These values are still being used for radiation protection purposes at the present time.

Last year, the ICRP issued a draft revision of it Recommendations. These do not suggest any fundamental change in the system of radiation protection, but do take into account knowledge gained in the last 20 years. Although there has been no evidence that radiation exposure to the parent causes excess hereditable disease in the offspring, the ICRP continues to believe that radiation can cause mutations to reproductive cells but that the risk of hereditable diseases has been overestimated. As a result, the tissue weighting factor for gonads could be considerably reduced.

In January 2007, ICRP released their draft recommendations (3), which may be a final draft after a public comment period on an earlier draft in 2006. In this document, the weighting factors for gonads and breast have been changed to 0.08 and 0.12 respectively.

What are the implications of this? Firstly, breast now becomes the highest weighted organ, along with red marrow, colon, lung, stomach and "remainder tissues". Gonads have the second highest weighting. This has the effect of more than doubling the contribution of breast dose to the effective dose, and will particularly affect cases where breast exposure is a significant component. Two good examples of this will be in cardiac

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diagnosis and treatment, and diagnosis of pulmonary embolism.discussed the potential impact of the increase in tissue weighting factor for breast tissue recently agreed to by the International Commission on Radiation Protection (ICRP).

In the following table of doses, we will consider two CTPA protocols – one that might be called "standard" and as used in my hospital, the other using low kVp. Breast dose reduction by use of breast shields is considered separately. No CT AEC is included in any of the CTPA dosimetry (i.e. constant mAs).

V/Q scan administered activities used are a general average.

Doses are from published sources, or calculated using references shown. Dose length product (DLP) values for the "standard" CTPA are measured at Westmead.

Modality	Agent and Administered Activity	CT Protocol	DLP mGy.cm	Breast Dose (mGy)	Foetal Absorbed Dose (mGy) -3 months	Effective Dose (patient) mSv
V/Q - Perfusion	^{99m}Tc MAA 150 Mbq	NA	NA	0.8 [2]	6.3 [11]	1.7 [2]
V/Q - Ventilation	Technegas 400 MBq	NA	NA	0.3 [2]	Uterus <0.01 [10]	0.6 [2]
V/Q - Ventilation	^{81m}Kr gas - 100 MBq	NA	NA	Negligible	Negligible	0.08 [3]
V/Q - Ventilation	^{99m}Tc DTPA aerosol 600MBq	NA	NA	0.23 [4]	0.5 [11]	0.7 [12]
CTPA - Full lung fields	NA	135 kVp,150 mAs, 1mm slices, pitch1, no breast shielding used, no AEC single phase, full lung fields Toshiba Aquilion 16	652 [6]	30 [6]	Uterus 0.04 [6]	11 [6]
CTPA - Full lung fields + breasr shields	NA	135 kVp,150 mAs, 1mm slices, pitch1, breast shielding used, no AEC, single phase, full lung fields Toshiba Aquilion 16	652 [6]	12.6 [6,8]	Uterus 0.04 [6]	11 [6]
CTPA - Limited lung fields	NA	135 kVp,150 mAs, 1mm slices, pitch1, no breast shielding used, no AEC, single phase, scan length 160mm, Toshiba Aquilion 16	425 [6]	29 [6]	Uterus 0.025 [6]	8.7 [6]
CTPA - Limited lung fields + low kVp [7]	NA	120/100 kVp,100 mAs, 0.75 mm slices, pitch1.157,single phase, no AEC, scan length 160mm, Siemens Sensation 16	114.7/39.2 [7]	5 [6]	0.005 [6]	2.44/1.37 [7] 2.4/1.5 [6]

Notes and References

1. The activity placed in the Technegas unit or nebuliser. The patient will receive less than this – 20% for aerosols and 10% for Technegas have been assumed here.
2. International Commission on Radiological Protection, ICRP Publication 80 "Radiation dose to patients from radiopharmaceuticals", Pergamon, 1999
3. Christian PE, Bernier DR, Langan JK. "Nuclear Medicine and PET – Technology and Techniques", Mosby 2004
4. International Commission on Radiological Protection, ICRP Publication 53 "Radiation dose to patients from radiopharmaceuticals", Pergamon, Oxford, 1988
5. Calculated by scanner (Toshiba Aquilion 16)
6. ImPACT CT Patient Dosimetry Calculator Version 0.99x, ImPACT, St Georges Hospital, London (uses ICRP60 tissue weighting values)
7. Heyer CM, Mohr PS, Lemburg SP et al. "Image quality and radiation exposure at pulmonary CT angiography with 100- or 120-kVp protocol: Prospective randomised study" Radiology 245:2, 577-583, November 2007
8. McLean ID et al, "Radiation safety report – breast dose and effects of shielding", internal report, Medical Physics Dept. Westmead Hospital 2005 (showed 42% dose reduction for medium breast)
9. Ell PJ, Gambhir SS (eds). "Nuclear Medicine in Clinical Diagnosis and Treatment", Third Edition, Churchill Livingstone, 2004
10. "Notes for Guidance on the Clinical Administration of Radiopharmaceuticals and Use of Sealed Radioactive Sources", Administration of Radioactive Substances Advisory Committee (ARSAC), UK Health Protection Agency, 2006
11. Russell JR, Stabin MG, Sparks RB et al. "Radiation absorbed dose to the embryo/fetus from radiopharmaceuticals" Health Physics 73(5):756-769, 1997
12. International Commission on Radiological Protection, ICRP Publication 80 "Radiation dose to patients from radiopharmaceuticals – Addendum to ICRP 53", Pergamon, Oxford, 1999