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Coronary Angiography - Physical and Technical Aspects

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1. Introduction

Diseases of coronary system and heart are the main reason of deaths in highly civilized population. Then the appropriate diagnostic methods and treating of early disorders are very important for a population health care. As the imaging techniques play a great role in good diagnosis they are intensively used and developed. Among the most commonly used methods is coronary angiography, which involves coronary vessels visualization during exposure to x-rays, after filling them up with contrast agents.
There are two versions of the procedure:
CCA – conventional coronary angiography, performed under control of x-ray unit with C-arm,
CTA - CT angiography, performed under control of computerized tomography (CT scanner).

2. CCA

2.1 Description of the procedure

A patient lies in a supine position on the table which is a part of the C-arm unit. The x-ray tube moves rotationally in two perpendicular planes (horizontal and vertical); it makes possible any needed type of projection. (The most common projections are: LAO, LAO/Cranial, LAO/Caudal, RAO). The principal current-voltage parameters are chosen automatically.
Good practice rules require keeping the x-ray tube under the table. This allows avoiding an unnecessary irradiation of the staff and makes the doses to a patient lower.
To visualize coronary vessels a contrast agent is administered intravenously. intravenously: first a thin catheter is introduced the brachial artery or the femoral artery (there are two alternative access routes) and its movement is traced by fluoroscopy and observed on monitor by the operator.
(Physiological parameters of a patient of patient are permanently monitored during the procedure.)
The operating team consists of 3 to 4 persons: usually there are an operator (with assistant if necessary), instrumenting nurse and anaesthetic nurse. All the staff remind around the patient table and thus may be exposed to quite high doses of radiation. (There are mainly scattered x-rays). The most exposed member of the team is the operator: the doses registered for such persons may achieve the highest level measured for occupational exposures [1,2].

Patient exposure results mainly from the primary x-ray beam which covers a part of the back surface (the area of left shoulder) by the most time of the procedure. The remaining parts of the patient's body are exposed rather to scattered radiation.

The images created during the procedure can be registered in three ways:

a. Real-time images (fluoroscopic images) observed only by the operator,
b. Some chosen moments of the procedure recorded in radiography mode (so-called acquisition),
c. Long periods of exposure can be recorded in so-called "cine-mode" (if this mode is implemented in the x-ray system).

The results of CCA procedure are analyzed by cardiologists during its performance and also retrospectively afterwards.

Most of x-ray units used nowadays in cardiology are equipped with the digital image recording system. They are two types of them: (1) image intensifier based systems and (2) flat-panel fluoroscopy systems.

The first one uses conventional technology: the output screen of image intensifier is projected in a video camera or a CCD camera to produce an electronic information. (In the previously used conventional image intensifier analogue system the output screen had been projected on the *film* by optical lens).

In the flat-panel systems signals created by x-rays are electronic and are thus recorded simultaneously.

(The fundamental difference between "analogue" and "digital" systems concerns to way of image *archiving* (i.e. film or electronic information). The *both* systems produce the "real-time" image, although the flat-panel systems create the image by dividing the primarily detected signal. That is why the modern x-ray system has much higher output capacity and thus higher doses are possible).

2.2 Technical requirements for x-ray systems used for CCA

X-ray system used for CCA procedures should be equipped as follows:

- constant potential generator of minimum 80 kW (in possibly rectangular pulses),
- x-ray tube focuses 1.2/0.5mm,
- overcouch image detector,
- distance between x-ray tube and image detector is tracked (minimum focus skin distance 30 cm),
- concave couch top for patient comfort (made from low-attenuating materials),
- dose-area product meter (display visible for operator),
- staff protective shielding.

The system should also have the following additional tools and fulfil the following requirements:

- display of fluoroscopy time, total dose-area product (fluoroscopy and radiographic) and estimated skin entrance dose,
- minimum two dose-rate options (Low-Medium-High or Low- Standard),
- additional filtration (Cu preferred) and collimators incorporating circular shutters,
- flexibility of pulsed fluoroscopy mode,
- image hold system,
- possibility of AEC mode choice by the user by the user (IMAGE or DOSE weighted).

Additionally in some x-ray systems there are also available partially absorbent contoured filters to control the bright spots produced by the lung tissue bordering the heart.

2.3 X-ray dosimetry in CCA

The quantities used to assess radiation risk in interventional radiology are following:
Entrance air kerma (EAK), surface dose , dose-area product (DAP), absorbed organ dose, effective dose.
EAK, surface dose and DAP are available for measurements. The remaining can be evaluated experimentally or theoretically.
EAK and surface dose can be measured directly (using appropriately calibrated devices) or indirectly (by thermoluminescence (TL) dosimeters or film badges). The indirect methods need a calibration of dosimeters by the comparison to a reference meter for the standardized exposure (in a competitive laboratory). These methods are routinely applied to individual dosimetry of occupationally exposed persons, but are also used for patients in radiological procedures. (TL dosimeters are preferred for the staff in interventional procedures.)
X-ray systems used for CCA are obligatory equipped with a DAP-meter to summarize the emission in all modes of work (i.e. fluoroscopy, radiography, cine). (Dose Area Product= DAP [$mGy.cm^2$]). Measurements are performed by the transmission chamber placed on the x-ray tube output.
Absorbed organ doses are necessary for evaluation of a possible effect for an exposed human. They can be estimated theoretically or experimentally. Theoretical evaluation relies on Monte Carlo simulation performed for mathematical human phantom at assumed exposure conditions. In the experimental method the physical anthropomorphic phantom is used which is exposed at assumed exposure conditions while the dosimeters are placed inside. (TL dosimeters are used usually for this purpose.)
On the basis of the absorbed organ doses the evaluation of the equivalent dose and the effective dose are possible [3,4].

Equivalent dose (in an organ or body part)

$T_i=w_R.D_i$ [Sv] where w_R-the radiation weighting factor (w_R=1 for x-rays, γ-rays and electrons), D_i- the dose absorbed in "i" organ (or body part).

Effective dose (whole body)

$E_{ff}= \sum w_i.D_i$ [Sv] had been implemented to evaluate overall risk for health resulted from exposure to ionizing radiation. This value is fully justified if irradiation of the body is uniform enough: if opposite deterministic effects can appear despite the very low value of the E_{ff} .
Both quantities (T_i and E_{ff}) are used for the dose limits applied for occupational exposure.

2.4 Doses to patients

The doses obtained by the patients undergoing CCA procedures are dependent on:
- patient architecture (BMI-body mass index),
- emission effectiveness of the x-ray system,
- applied dose-rate mode,
- total exposure time,
- mode of work (number of acquisitions -radiographic or cine).

The entrance surface dose to patient dramatically increased when the focus-to-skin distance becomes too short.
The patient doses are significantly higher when the high dose-rate mode is activated or if pulsed fluoroscopy of high number of pulses per second is chosen. These doses are also

inversely proportional to the diameter of the image intensifier. The entrance dose to skin may locally achieved values exceeding the threshold of deterministic effects and the skin injuries of patients undergoing interventional procedures are reported [5].
Generally, exposure of the patients during CCA procedures is extremely non-uniform:high doses are received on a small are of the back while the remaining parts of the body practically stay out of the primary beam. Although effective dose is not a good measure of radiation risk for that, this quantity is used after all. The measurable quantities, i.e. entrance surface dose (or air kerma) and DAP, have more practical meaning. These quantities are proportional to each other:

$$DAP = EAK_c . S$$

where EAK_c –the entrance air kerma in the centre of the beam, S – mean value of incident x-ray beam are (on patient's skin).
(Both values are averaged over the total exposure time, because their varies from one projection to another.)
DAP (and EAK_c) values have to be displayed on the monitors of x-ray system and should be registered in the patient record. (Especially when EAK_c>1Gy and exceeds the threshold of deterministic skin effects.)
As the doses to patients in CCA are affected by a number of factors the range of their values is very wide. The examples are presented in Table 1 and Table 2.
To keep the radiation risk to patients on an acceptable level and control it the reference levels are introduced also for interventional cardiology procedures (like for another radiological procedures).

Number of patients	DAP [Gy.cm²]	Time of fluoroscopy [min]	Number of frames	Reference
130	72 +/-55	0.35+/-0.25	1550+/-775	[7]
78	73	9.9	1079	[8]
100	60.6	-	412	[9]
117	1.1 – 11.3	0.3 - 22	-	[10]
8	22 - 93	2 - 21	Doctor 1	[11]
3	14 - 44	1 – 4	Doctor 2	
106	35 - 160	4.8+/-3.5	39+/-11	[12]
62	37-190	4.2+/-3.0	30+/-10	
90	3.1-57.2	1.5-5.1	639	[13]
76	44.5	6	10	[14]
194	64 - 281	0.4 - 33	200-1911	[6]

Table 1. The doses to patients in CCA procedures (according to [6])

Effect of pulsed fluoroscopy on the patient dose in CCA were investigated by [16]:
X-ray systems with pulsed fluoroscopy (5 vendors): 10 units; average surface dose rate: 22.52+/-4.5 mGy/min, (25, 30 and 50 pulses/sec);
X-ray systems with conventional fluoroscopy (3 vendors): 3 units; average surface dose rate: 23.93+/-2.77 mGy/min.

X-ray system	DAP [Gy.cm^2]		Time of fluoroscopy [min]	
	median	range	median	range
CCD	30.0	1.1-135.2	3.8	1.1 – 57.0
FP	31.0	14.7-75.9	4.0	0.8- 39.4

Table 2. Median and range of DAP and fluoroscopy time in CCA for different x-ray systems [15]

2.5 Doses to staff

The main inconvenience of CCA procedures (generally – interventional radiology) is the necessity to work standing near the patient during exposure, i.e. in the radiation field. Thus the staff is also exposed mainly to scattered radiation, but primary x-rays are also possible. The factors affecting staff dose are as follows:

- relative position with respect to patient,
- patient body typ (BMI),
- irradiated patient volume,
- x-ray tube position,
- time of exposure,
- effective use of protection shielding.

Thus, staff and patient doses are partially linked: higher exposure for patient means higher irradiation to staff. This is especially true for an operator and the person standing nearby him (an assistant or instrumenting nurse). Additional factor determining the doses to staff is an professional experience and good training in the procedure performance: good manual skills make the exposure time shorter.

Patients with high BMI need a high dose-rate to produce the diagnostic image and then the scattered x-rays also achieve high intensity (especially near the patient).

X-ray tube in undercouch position allows to reduce the doses (mainly for eyes and thyroid of the operator) and also allows avoiding the contact with primary x-rays. (The old x-ray systems had the tube in overcouch position which caused very high doses to operator's hands).

The problem of radiation risk to staff in interventional cardiology had been widely discussed many times. The resulting essential conclusions are the recommendations concerning performance of the interventional procedures and elaboration of the methodology for evaluation radiation risk for the staff [1,17].

The main recommendations concerning the proceeding of the staff during CCA can be summarized in the three points:

- time of exposure possibly short,
- distance to patient possibly long,
- protection shield used effectively.

The recommendations concerning radiation risk rely upon evaluation of the doses to the staff.

Because of the spatial distribution of x-rays affecting staff exposure the special dosimetric requirements are introduced for this group of workers: they should have been equipped with minimum two dosimeters, one under the protective apron (at the chest level) and the second over the apron at the collar level. The first dosimeter is used to evaluate the effective dose and the second can be used to evaluate the equivalent dose to the eyes. (Also for the thyroid if it is not shielded.) Additional dosemeter(s) can be use to evaluate the equivalent

dose(s) to the hands. The protective aprons used by the staff in interventional procedures should have Pb-equivalent of 0.35mm.
As the doses to staff in CCA are affected by a number of factors the range of their values is very wide (the same concerns patients) and many studies were performed to evaluate them.
The range of the doses shows the results given in the paper from the USA [18], where on the basis of the rich collection of published data the exposure for operators in cardiovascular procedures from the early 1970's through the present was analyzed. The range of effective doses from 0.02μSv to 38 μSv per one cardiac diagnostic catheterization procedure was found.
Another survey had been performed by European research group SENTINEL in a sample of European cardiac centres and the results have been published recently [19]. According to this study the results for the first operator are as follows:

a. annual effective dose: median 1.3mSv, third quartile 1.4mSv,
b. equivalent dose over the apron: median 11.1mSv, third quartile 14mSv.

Although the above values are rather low it should be underlined that they may be many times higher (even up the annual limits) , especially for inexperienced staff or in a case of clinically difficult patient.

3. CTA

A very dynamic development computerized tomography (CT) Which occurred during last decade creates quite new possibilities for this imaging method. The rotation time below one second together with a rich software allow applying CT to diagnostics of dynamic physiological processes and quickly moving objects (organs). On the other hand, increasing frequency of heart diseases in population linked the health needs With technological achievements in the CT technique to implement this imaging method to cardiology.
Although traditional (conventional) coronary x-ray diagnostics remain a gold standard these procedures are invasive and resulted in high radiation doses both to patients and to staff. Therefore CT procedures became an alternative and comfortable method for heart diagnosis.
For technological reasons the possibilities of CT are limited to diagnostics, without further therapeutic activity (i.e. angioplasty). However, cardiovascular CT plays an increasingly important role in planning for cardiovascular interventions (those are performed under C-arm x-ray units).
Improvements in spatial and temporal resolution, scan time, scan range and advanced image postprocessing (very important in clinical practice) have made *CT angiography* (CTA) an excellent tool for identifying patients in need of invasive therapy and for mapping out the best percutaneous or surgical approach. In some cases CTA provides complementary information to conventional angiography (CCA).
As coronary disease is jointed with calcification of coronary arteries evaluation of this process is a good indicator of pathology. CTA gives possibility to display calcifications (3D) and to assess them quantitatively: it is so-called "calcium scoring".
Although history of CTA had begun with four-slice scanners, the real development came with 64-slice scanners with appropriate combination of spatial and temporal resolution.
Generally, the heart can be imaged well if its structures do not move significantly during the scanning time. This condition is fulfilled during the diastolic phase of cardiac cycle. For

selection of the proper phase for CT images recording ECG gating (triggering) is applied. Additionally, to collect sufficient image data the table speed should not exceed v= SC . f_H and pitch should not exceed p=f_H. t_{rot},
where SC- total collimation width (CT primary beam), f_H- frequency of heart, t_{rot}- rot1ation time. (For example: if t_{rot}=0.5sec and f_H=60bpm then p≤0.5)
The main benefit from CTA is the evaluation of cardiac structure and function. That concerns coronary anomalies, right and left ventricular function, left ventricular ejection fraction and myocardial viability assessment, when the results of other modalities are inadequate [1,2].
According the American College of Cardiology Foundation (ACCF) the principal indications to cardiac CT are as follows [3]:

- low and intermediate pretest probability of obstructive coronary artery disease (CAD),
- noncontrast CT calcium scoring for patients at intermediate risk of coronary heart disease, and for low-risk patients with a family history of disease,
- coronary CT is especially recommended for patients with reduced left ventricular ejection fraction at low or intermediate pretest probability of disease,
- preoperative CT angiography for both heart surgery and noncoronary indications in the setting of risk of CAD.

3.1 Description of the procedure

General rules for exposure parameters:
Slice thickness <1mm, pitch<1, t_{rot}≤0.5sec, kilovoltage U≥100kV, mAs and physical filtration are dependent on the CT scanner, ECG-gating.
The main stages of CT study protocol are as follows:

- The heart rate control and regulation (if necessary: should have been lower than 65bpm),
- Calcium scoring,
- i.v. injection of contrast agents,
- CT angiography.

Ad.1. The required heart rate is dependent on the scanner software: at the high cardiac rate the registered imaging data also have to be reconstructed very quickly (practically immediately). This is possible only with the newest scanners. Lowering the heart rate is achieved pharmacologically.
Ad.2. Calcium scoring is performed on the basis of pre-contrast images. The high attenuation of x-ray in calcified structure allows to differentiate them from the soft tissues.
Ad.3. Contrast agent (iodine compound) is injected automatically in the rate adapted to data acquisition.
Ad.4. CT coronary angiogram: the data acquisition starts automatically when the signal in the descending aorta reaches a predefined threshold (usually 100 HU). The entire volume of the heart is scanned during a few seconds: the newest versions of CT scanners (≥64-slice) do it during one breath-hold (<10sec) under ECG control. The tube voltage, anode current and gantry rotation time are dependent on the scanner type and model and version of software.
After completing acquisition of primary data, elaboration of them (post-processing) begins.
The software dedicated to coronary procedures is necessary for that. Such software is offered by the vendors on user's requirement.

It should be underlined that imaging possibilities of each CT scanner are determined by its technical configuration (number of detectors, generator, etc.) but even more by the installed version of software.
The principal algorithms for image post-processing are [4]:
- curved and multiplanar reformats (MPR),
- shaded-surface display (SSD),
- maximum intensity projection (MIP),
- volume rendering (VR).

The axial images produced by hardware (so-called row data) are essential and should be used but reformatted images may improve lesion detection and classification (particularly coronal and oblique views). The axial images and MPRs are used for diagnosis and the SSD and MIPs are for display purposes.
The results of CTA are evaluated or consulted by a cardiologist.

3.2 Dosimetry in CT

Because of special exposure system CT needs the special dosimetry quantities, i.e.: dose-length-product (DLP) and computed-tomography-dose- index (CTDI).
CTDI is treated as an estimation of mean absorbed dose to the whole scanned volume. This quantity also evaluates the level of radiation risk for given procedure at assumed exposure parameters.
CTDI is calculated *automatically by scanner* software on the basis the selected exposure parameters and is displayed on CT monitor. The DLP is then computed as a product of CTDI (averaged over the whole scan length) and the scan length: such value is displayed on CT monitor after the examination is completed.
Independently, *CTDI can be computed* on the basis of measurements performed for particular dosimetric phantoms. For that purpose DLP is measured using special pencil-shaped chamber (external probe) to summarize the dose from incident photons during the tube rotation on the whole length of scanned object. (This is also performed during the acceptance or constancy Quality Control (QC) tests for CT scanner.)
Final evaluation of risk to patient in CT procedures is based on the effective dose. As in the other radiological techniques this quantity can be estimated theoretically (Monte Carlo simulation) or experimentally (TL dosimeters inside the anthropomorphic phantom). Additionally – the effective dose obtained in the particular procedure can be estimated indirectly:

$$E_{ff} = k \cdot DLP$$

where DLP – value for the procedure, k – transition coefficient for the examined body part (computed theoretically). The above evaluation is applied for adult patients only.
For coronary examinations the transition coefficient $k=0.014\ mSv.mGy^{-1}.cm^{-1}$ is used which corresponds to the chest as the examined region [5].
The problem of doses in CTA is considered only for patients as the staff is out of radiation area.

3.3 Doses to patients and radiation protection in CTA

Because of exposure conditions in CTA (thin slices and low pitch) the doses to patients are relatively high, especially at 64-slice scanners. It was an inspiration to implement the methods of dose reduction without loss of image quality.

The doses can be reduced by lowering of current-voltage parameters, implementation of x-rays intensity modulation (for three axis) and shortening of scanned body length.
The special solution for dose reduction being dedicated to cardiac CT examinations is change of image acquisition technique from RGH to PGA [6].
RGH = Retrospectively Gated Helical: the patient and table move through the gantry at a steady speed. A low pitch (0.2 to 0.4) is needed to cover the entire cardiac volume, especially to compensate for any ectopic beats, which can result in misregistration and gaps in coverage. Thus, the same anatomy can be exposed to the x-ray beam many time (up to five) to ensure enough coverage, causing the high absorbed doses.
PGA= Prospectively Gated Axial: the table is stationary during PGA image acquisition, then moves to the next location for another scan that is initiated by the next normal cardiac cycle. The x-rays emission is then dynamically predicted on the basis of ECG signal.
Diagnostic values of images obtained for PGA protocol were not found to be lower for RGH while the doses where substantially lower [6]. In the same study including 203 CTA exams (82 with routine RGH and 121 with the PGA) the doses were evaluated for protocol including scout images, low-dose calcium scoring scans, test-bolus scan and CT coronary angiogram. The exams were performed by using 64-slice CT scanner (LightSpeed VCT XT, GE). The effective doses were as follows:
RGH: (8.7-23.2) mSv, mean: 18.4 mSv;
PGA: (0.75-6.67) mSv; mean: 2.84 mSv.
For comparison, the results of the big study involved nearly 2000 patients examined (CTA) in 50 hospitals in 2007 in Germany and US show the range of effective dose (8-18) mSv with median 12 mSv. The reduced 100 kV tube voltage was used in 5% of patients, with sequential scanning in 6%. ECG gating was applied in 73% exams [7].
The influence of lower tube voltage is illustrated also by the results CTA performed using 320-MDCT for anthropomorphic phantom (ECG gating was simulated) [8].
The results are given in Table 3.

Heart rate= 60bpm	100kV	120kV	135kV
Midbreast	13.4±3.6	21.7±4.1	29.3±5.2
Breast	11.8±0.6	18.9±1.1	24.8±1.5
Lung	12.2±2.6	19.1±3.2	26.5±5.0
Thyroid	0.4±0.1	0.7±0.1	0.9±0.2
Heart rate=75bpm	100kV	120kV	135kV
Midbreast	38.3±2.0	59.7±3.1	77.8±3.7
Breast	26.2±1.7	44±1.1	52.8±4.1
Lung	38.0±1.6	58.9±1.7	78±2.9
Thyroid	0.8±0.2	1.0±0.2	2.2±0.5

Table 3. The effect of tube voltage and heart rate on absorbed doses [mGy] in CTA (according to [8]).

4. Comparing CCA and CTA

Primary x-ray beam in the CCA is focused on nearly the same area of a patient's body by most time of the procedure, and then very high local doses are possible. (Skin injuries and even of x-ray burn cases were reported in the paper [9]).
Moreover, a possibility to destroying the vessel wall during catheter operations also exists.
Patient entrance doses change with body thickness, required image quality and distance to x-ray tube focus. Because medical staff have to work in direct neighbourhood of x-ray source and x-rays scattered on a patient's body, the doses to the staff are related to the patient doses.
Thus, the procedures are still treated as invasive and risky for both patients and the staff despite the benefit from "traditional" angiographies.
Good spatial and temporal resolution of modern CT scanners is the reason of positive features of CTA in comparison to conventional angiography [10,11,12], i.e.:

- better detection of stenosed lesions,
- possibility to delineate a cross-sectional cut of the artery,
- non-invasive procedure contrary to the conventional angiography or intravascular ultrasound.

All of the above reasons have made CTA an excellent technique for quick (emergency) cardiac diagnosis and for qualification patients for angioplasty. Moreover, coronary CTA includes a complete evaluation of the lungs and chest. Contrary to to conventional cardiac angiography (CCA) the staff are completely unexposed in CTA.
The only deficiency of CTA in comparison to CCA is its exclusive diagnostic character: any further intervention as angioplasty is not possible in CTA technique. That needs continuing of treatment action in more "traditional" way – at C-arm unit control.
For comparison of doses to patients in both imaging techniques techniques the measurements were performed using multislice CT scanners (MSCT) and C-arm units.
The measurements were performed for

- two sixteen-slice CT scanners (made by two manufacturers),
- one sixty-four-slice CT scanner,
- three C-arm units of different manufacturers.

For each controlled C-arm unit the organ doses in "traditional" coronary angiography were distributed extremely non-uniformly: from up to 100 mGy in the area of the primary x-ray beam interaction to about zero in quite near vicinity of that. For that in all the phantom examinations doses for both lungs and doses for elements of skeleton differed significantly in dependence on the composition of projections.
That was not observed for CTA procedures, when the magnitude of doses inside the scanned volume was similar.
The detailed results were published [13]. Below the most important values of are presented in the Tables 4 to 6.
To summarize of the presented results:

1. In coronary angiography carried out by C-arm units patient organ doses are distributed non-uniformly inside patient body (from up to 100 mGy in area of primary x-ray beam to about zero in quite near vicinity). Therefore, a low effective dose does not mean the low absorbed doses at all.

2. Doses to patients in CTA procedures covering the chest are distributed more uniformly and are dependent on the scanner configuration and protocol of the procedure.

CCA	CTA
1st manufacturer: 0.9 – 1.4	16-slice scanner: 5.4
2nd manufacturer: 1.3 – 3.2	64-slice scanner: 23.1
3rd manufacturer: 6.2 – 18.8	(The both scanners made by 1st manufacturer.)

Table 4. Effective doses to patients in coronary procedures [mSv]

Organ	Eight exposures carried out by C-arm units designed by three manufacturers.	Four exposures carried out by C-arm units the same type (made by the1st manufacturer)
Lungs	2.95 – 23.68	2.95 – 5.64
Stomach	0.07 – 59.76	0.22 – 0.75
Upper Large Intestine	<0.1 – 10.73	0.10 – 0.37
Red Bone Marrow	1.75 – 23.90	1.75 – 3.30
Thyroid	0.13 – 2.03	0.13 – 2.03
Heart	0.52 – 27.15	1.39 – 3.75

Table 5. Range of absorbed doses [mGy] in CCA

Organ	Sixteen-slice CT	Sixty-four-slice CT
Lungs	25.8	64.5
Stomach	5.7	44.2
Upper Large Intestine	1.5	8.1
Red Bone Marrow	10.9	31.4
Thyroid	6.8	11.7
Heart	29.0	77.7

Table 6. Absorbed doses [mGy] to patients in CTA (both CT scanners made by 1st manufacturer)

5. References

5.1 References for CCA

[1] International Commission on Radiological Protection, Publication 85, Avoidance of Radiation Injuries from Medical Interventional Procedures, 2001.

[2] Vano E, Gonzales L, Guibelalde E, et al:Radiation exposure to medical staff in interventional and cardiac radiology. Br.J.Radio., 71,954-960,1998.

[3] International Commission on Radiological Protection, Publication 60, Recommendations of the International Commission on Radiological Protection, 1991.

[4] International Commission on Radiological Protection, Publication 103, The 2007 Recommendations of the International Commission on Radiological Protection, 2007.

[5] Vano E, Arranz L, Sastre JM, et al: Dosimetric and radiation protection considerations based on some cases of patient skin injuries in interventional cardiology. Br.J.Radiol., 71, 510-516, 1998.

[6] Bor D, Olgar T, Toklu T, et al.: Patient doses and dosimetric evaluations in interventional cardiology. Physica Medica, 25,31-42, 2009.

[7] Maccia C: An optimization study of cardiac interventional radiology procedures: an experience in France. ERPET in Madrid, p.113-119, 1997.

[8] Hansson B, Karambatsakidou A: Relagtionships between entrance skin dose, effective dose and dose area product for patients in diagnostic and interventional cardiac procedures. Radia.Prot.Dosimetry. 90: 141-144, 2000.

[9] Van de Putte S, Verhaegen F, Taeymans Y, et al.: Correlation of patient skin doses in cardiac interventional radiology with dose-are product. Br.J.Radiol. 73: 504-513, 2000.

[10] Clark AL, Brennan AG, Robertson LJ, et al.:Factors affecting patient radiation exposure during routine coronary angiography in a tertiary referral centre. Br.J.Radiol. 73: 184-189, 2000.

[11] McFadden SL, Money RB, Shepherd PH: X-ray dose and associated risks from radiofrequency catheter ablation procedures. Br.J.Radio. 75: 253-265, 2002.

[12] Delichas MG, Psarrakos K, Molyvda Athanassopoulou E, et al.:Radiation doses to patients undergoing coronary angiography and percutaneuos transluminal coronary angioplasty. Radiat.Prot.Dosimetry.103(2):149-154, 2003.

[13] Sandborg M, Fransson SG, PetterssonH: Evaluation of patient and staff absorbed doses during coronary angiography and intervention by femoral and radial artery access routes. Eur.Radiol. 14(4):653-658, 2004.

[14] Leung KC, Martin CJ: Effective doses for coronary angiography. Br.J.Radiol. 69:426-431, 1996.

[15] Tsapaki V, Kottou S, Kollaros N, et al.: Dose performance evaluation of a charge coupled device and a flat-panel digital fluoroscopy system recently installed in an interventional cardiology laboratory. Radiat.Prot.Dosimetry. 111(3): 297-304,2004.

[16] Chida K, Fuda K, Saito H, et al.: Patient skin dose in cardiac interventional procedures: conventional fluoroscopy versus pulsed fluoroscopy. Catheter Cardiovasc Interv.69(1):115-121, 2007.

[17] International Commission on Radiological Protection, Publication 75, General Principles of Monitoring for Radiation Protection of Workers, 1997.

Kim KP, Miller DL, Balter S, et al.: Occupational radiation doses to operators performing cardiac catheterization procedures. Health Phys. 94(3):211-227,2008.

[18] Padovani R: Optimisation of patient and staff exposure in interventional radiology. In: Radiation Protection in Medical Physics, edited by Y.Lemoigne and A.Caner, Springer in Cooperation with NATO Public Diplomacy Division, The Netherlands, 2011.

5.2 References to CTA

[1] Korosoglou G, Mueller D, Lehrke S, et al.: Quantitative assessment of stenosis severity and atherosclerotic plaque composition using 256-slice computed tomography. Eur.Radiol 20:1841-1850,2010.

[2] Rutten A, Meijs MFL, de Vos A, et al.: Biphasic contrast medium injection in cardiac CT: moderate versus high concentration contrast material at identical iodine flux and iodine dose. Eur.Radiol. 20: 1917-1925, 2010.

[3] Taylor A, Cerquiera M in Journal of the American College of Cardiology, October 2010: according to AuntMinnie.com (November 1,2010): New cardiac CT guidelines expand use for low-risk patients.

[4] W.A.Kalender: Computed Tomography. Publicis MCD Verlag, Munich 2000.

[5] Bischoff B, Hein Fm Meyer T, et al.: Impact of a reduced tube voltage on CT angiography and radiation dose: results of the PROTECTION I study.JACC Cardiovasc Imaging 2:940-946, 2009.

[6] AuntMinnie.com February 15, 2007: Radiation dose slashed in 64-slice coronary CTA (by Eric Barnes)

[7] AuntMinnie.com February 3, 2009: JAMA study finds wide variation in cardiac CTA dose (by Eric Barnes)

[8] Nikoito D, Khosa P, Lin PJ, et al.:Absorbed radiation dose in radiosensitive organs during coronary CT angiography using 320-MDCT: effect of maximum tube voltage and heart rate variations. AJR.195(6):1347-1354, 2010.

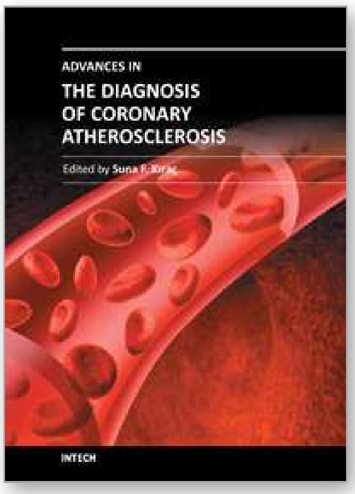
[9] Vano E, Gelcolea J., Galvan C et.al. Skin radiation injuries in patients following repeated coronary angioplasty procedures. The British Journal of Radiology 2001; 74: 1023-1031.

[10] De Backer G, Ambrosioni E, Borch-Johnson K, et al. European quidelines on cardiovascular disease prevention in clinical practice. Eur.J.Cardiovasc.Prev. Rehabil. (2003), 10(4):S1-10.

[11] Nieman K, Cademartiri F, Lemos PA, et al.Reliable non-invasive coronary angiography with fast submillimeter multislice spiral computed tomography. Circulation 2002, 106: 2051-2054.

[12] Ropers D, Baum U, Polite K, et.al. Detection of coronary artery stenoses with thin-slice multi-detector row spiral computed tomography and multiplanar reconstruction. Circulation 2003. 107:664-666.

[13] Staniszewska MA, Jazwinski J: MSCT and C-arm units: doses to patients in the chest angiography procedures. Pol.J.Radiol. 73(1):43-49, 2008.



Advances in the Diagnosis of Coronary Atherosclerosis
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Coronary artery disease (CAD) and its consequences are most important morbidity and mortality reasons in the developed and developing countries. To prevent hard end-points, early definitive diagnosis and optimum therapy play significant role. Novel advanced diagnostic tests which are biomarkers of inflammation, cell adhesion, cell activation and imaging techniques provide to get the best result in the detection and characterization of calcified or uncalcified atherosclerotic plaques. In spite of last developments in the imaging methods, coronary catheterization is still frequently performed. Following the first cardiac catheterization performed in 1844, date by date historical developments and the mechanics of cardiac catheterization techniques, risks associated with coronary angiography, and also, preventions and treatments of possible complications have been presented in this book. Other important issue is radiation exposure of patients and staff during coronary angiography and scintigraphy. Radiation dose reduction techniques, general radiation protection principles have been discussed in related chapters.

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