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MSCT and C-arm units: doses to patients in the chest angiography procedures

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Summary

Background: Since the late 1990's, computed tomography (CT) technique has become an alternative solution to "traditional" angiographies. Angio-CT (CTA) is most frequently used in cardiovascular procedures. Evaluation of patient doses in both CTA and "traditional" cardio-angiography was the aim of the presented study.

Material/Methods: The measurements were performed using three multislice CT scanners (MSCT) for exposures covering the chest area and three C-arm units for conventional coronary angiographies.

The patient was represented by a Rando Man phantom and organ doses were evaluated on the basis of readings from thermoluminscent dosimeters.

Results: Doses absorbed during CT angiography (CTA) were evaluated for eight exposures at "chest-angio" protocols and two exposures at "coronary" protocols. Doses absorbed during conventional coronary angiography were also evaluated for eight exposures on the three C-arm units.

Conclusions: 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 covered the chest are distributed more uniformly and are dependent on exposure pattern (i.e. configuration of projections). 3. The lowest doses in CTA covered the chest are higher then those measured at conventional cardio-angiography.

Key words: **Angiographies • multislice CT • C-arm units • patients • doses**

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Background

X-ray angiography procedures have been known and applied for years, especially in the "traditional" form, where contrast medium is inserted into blood vessels through a catheter. The imaging device is then a C-arm unit with high quality fluoroscopy. The principles of the method have not changed for the last 20 years, although the imaging equipment is better and better and obligatory requirements for it have been formulated.

The primary x-ray beam in the "traditional" angiography is focused on nearly the same area of the patient's body for most time of the procedure, and then very high local doses are possible. (Skin injuries and even of x-ray burn cases have been reported [1]).

Moreover, there is also a possibility to damage a vessel wall during catheter operations.

Patient entrance doses change with body thickness, required image quality (i.e. x-ray power option and image intensifier diameter) and distance to x-ray tube focus. As the medical staff have to work in the direct neighbourhood of the x-ray source and x-rays scattered on the patient's body, the doses to the staff are related to the doses received by the patient. Those may be higher when old x-ray equipment or low-quality monitors and no dose monitoring are used, and also when shielding is improper or the staff is not trained well enough.

That is the case because, despite a benefit from "traditional" angiographies, those procedures are still treated as invasive and risky both for patients and for the staff.

From the late 1990's, when advantages in computed tomography (CT) technique allowed to use multiclice scanners with their highly sophisticated software, a possibility to visualize thin vessel structures without invasion of catheters has been available. That created a solution alternative to "traditional" angiographies, referred to as angio-CT or CTA. Although "angio-CT" protocols were offered even in single-slice CT's, the first tests in real CT angiography (CTA) begun with the four-row scanners. Good spatial and temporal resolution of modern CT scanners are the reason for positive features of CTA in comparison to conventional angiography [2, 3, 4], i.e.:
– better detection of stenosed lesions,
– possibility to delineate a cross-sectional cut of the artery,
– non-invasive procedure in contrast to the conventional angiography or intravascular ultrasound.

Nowadays, when multidetector (sixty-four–row) CT systems offer a number of new possibilities, non-invasive visualization of vessels and other small anatomical structures is achievable in one-breath time and space-resolution of 0.4 mm. (The whole chest is visualized in 20 s.)

These challenges are most widely used in cardiology, as the cardiovascular procedures are the most frequent among all the angiographies [5].

The preferred implementations of CTA in cardiology are as follows:
– patients at high risk for heart disease due to standard risk factors (i.e. smoking, high cholesterol, etc.),
– patients after coronary bypass surgery, angioplasty, or stenting – for follow-up,
– patients who have had chest pains or other symptoms but normal cardiac tests,
– patients with no symptoms who have had abnormal cardiac testing.

In contrast to cardiac catheterization when only the cross-section (lumen) of a vessel is viewed, coronary CTA is the only test that can look at the wall of the coronary artery non-invasively, as high resolution of CTA allows to differentiate calcified plaque, fibrous calcified and non-calcified plaque. Due to these features, together with advanced image post-processing, CTA is playing an increasingly important role in x-ray coronary diagnostics. (Among others –[6]) Improvement in spatial and temporal resolution, short scan time and wide scan range have made CTA an excellent technique for quick (emergency) cardiac diagnosis and for qualification of patients for angioplasty.

Moreover, coronary CTA includes a complete evaluation of the lungs and chest. In contrast to the "traditional" angiography, in CTA staff is completely unexposed.

The only deficiency of CTA in comparison to cardiac catheterization ("traditional" angiography) is its only diagnostic character: any further interventions such as angioplasty are not possible in CTA technique. That necessitates continuing the treatment action in more "traditional" way – at C-arm unit control.

The doses obtained by patients undergoing CTA procedures are also differentiated, although not so widely as in "traditional" angiography. The reason results mainly from the protocols used: if dedicated cardio-protocols (i.e. coronary CTA, calcium score, etc.) have not been installed by producers, the user of the scanner will try to find some substitutes of those. In practice, this can be achieved by combination of protocols providing high-resolution images of the chest area (angio-chest, chest HRCT) and then visualizing coronary vessels. Thus, CTA examination can collect one to three "phases" (with and without contrast medium) which results in a difference in dose values.

To summarize, coronary CTA is a very valuable technique from the diagnostic point of view, but besides all its benefits, a charge of the patient with radiation dose exists. The evaluation of that for both the techniques (CTA and "traditional" angiography) of coronary procedures is the aim of the presented study.

Materials and methods

The measurements were performed using multislice CT scanners (MSCT) for exposures covering the chest area and coronary angiography procedures and conventional coronary procedures using C-arm units.

The patients referred for these procedures were represented by a Rando Man phantom (manufactured by Alderson, USA). For C-arm units exposures, the current voltage settings were chosen by AEC system appropriately for the phantom. Due to that, the exposure parameters were selected for the standard object every time and differences in settings were related mainly to the x-ray system in use. The doses absorbed by organs were evaluated on the basis of readings from thermoluminescent dosimeters (TLDs) (MTS-N type, INP Krakow, Poland). The number of TLDs put into the space of phantom interior corresponding to the particular organ was constant for all the phantom exposures analyzed here.

Taking into consideration the difference in high voltage settings for C-arm units and MSCT, the TLDs for both devices were calibrated separately.
The doses were evaluated for thirteen soft organs and nine parts of the skeleton (excluding the extremities). On this basis, the effective doses were estimated according to ICRP Publ. 60 recommendations.
Fluoroscopy times in particular projections were chosen as the mean examination times recorded for real adult patients of standard body construction.
In case of MSCT tube, voltage and the other scan parameters were determined by the imaging protocol in use. Tube loading was stated adequately to the phantom by automatic anode-current modulation system of the scanner.

Table 1. Doses to patients in conventional coronary angiography: results for eight exposures carried out with C-arm units designed by three manufacturers.

Organ	Range (*) of absorbed doses [mGy]	Averaged doses per 100 mAs (mean value ± S.D.)	Mean absorbed dose [mGy] (**)
Lungs	2.95 – 23.68	1.15 ± 0.52	11.04
Stomach	0.07 – 59.76	0.55 ± 0.79	5.28
Upper Large Intestine	<0.1 – 10.73	0.12 ± 0.13	1.15
Red Bone Marrow	1.75 – 23.90	0.80 ± 0.31	7.66
Thyroid	0.13 – 2.03	0.15 ± 0.21	1.44
Heart	0.52 – 27.15	1.00 ± 0.75	3.84

The results with high coefficient of variation are shaded: (S.D./ mean) > 100%. (*) evaluated at the tube-loading ranged from 270 mAs to 2800 mAs per procedure; mean value ± S.D. is (960 ± 950) mAs. (**) averaged dose per mAs multiplied by the mean tube-loading.

Table 2. Doses to patients in conventional coronary angiography: results for four exposures carried out with C-arm units of the same type (made by the 1st manufacturer).

Organ	Range (*) of absorbed doses [mGy]	Averaged doses per 100 mAs (mean value ± S.D.)	Mean absorbed dose [mGy] (**)
Lungs	2.95 – 5.64	1.28 ± 0.26	3.99
Stomach	0.22 – 0.75	0.17 ± 0.07	0.53
Upper Large Intestine	0.10 – 0.37	0.08 ± 0.05	0.25
RBM	1.75 – 3.30	0.73 ± 0.13	2.28
Thyroid	0.13 – 2.03	0.25 ± 0.27	0.78
Heart	1.39 – 3.75	0.91 ± 0.30	2.84

The results with high coefficient of variation are shaded: (S.D./ mean) > 100%. (*) evaluated at the tube-loading ranged from 270 mAs to 360 mAs per procedure; mean value ± S.D. is (312 ± 37) mAs. (**) averaged dose per mAs multiplied by the mean tube-loading.

Table 3. Absorbed doses [mGy] to patients in CT chest angiography.

Organ	Sixteen-slice CT scanners		Sixty-four-slice CT scanner of the 1st manufacturer (values for 2 exposure patterns)
	of the 1st manufacturer(range for 5 exposure patterns)	of the 2nd manufacturer (values for 2 exposure patterns)	
Lungs	19.1 – 46.4	19.1; 93.4	37.1; 56.0
Stomach	10.8 – 33.5	16.0; 39.5	14.2; 23.7
Upper Large Intestine	1.7 – 5.0	3.6; 6.4	2.6; 4.0
Red Bone Marrow	9.8 – 25.2	8.42; 40.0	21.1; 24.2
Thyroid	4.2 – 20.6	13.0; 24.5	29.0; 32.8
Heart	16.3 – 53.6	22.4; 98.5	40.2; 63.2

Results

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.

Doses absorbed during conventional coronary angiography were evaluated for eight exposures:

- four of them were carried out using C-arm units of the 1st manufacturer,
- two of them were carried out using C-arm units of the 2nd manufacturer,
- two of them were carried out using C-arm units of the 3rd manufacturer.

Doses absorbed during CT angiography (CTA) were evaluated for eight exposures at "chest-angio" protocols and two exposures at "coronary" protocols.

"Chest-angio" protocols were performed for:

- sixteen-slice CT scanner of the 1st manufacturer (five times, at different configurations of projections),
- sixteen-slice CT scanner of the 2nd manufacturer (at two configurations of projections),
- sixty-four-slice CT scanner of the 1st manufacturer (at two configurations of projections).

Special "coronary" protocols were available only in case of the scanners of the 1st manufacturer and these were performed for sixteen-slice and sixty-four-slice scanners. The results are presented in details in Tables from 1 to 5.

Discussion

Behind of the constant "patient" (represented by Rando Man phantom), the doses for the particular organs registered during the eight coronary angiographies by C-arm units differed over two orders of magnitude.

Table 4. Absorbed doses [mGy] to patients in CT coronary protocols (both CT scanners made by 1st manufacturer).

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

This resulted from:
- differences of x-rays intensity given by C-arm units,
- variations in exposure time for particular projections (at different directions of x-ray primary beam) caused by both the diagnostic needs of the particular patients and by routine performance of the procedure by particular operation teams.

The first factor is excluded when the procedure is repeated using only one C-arm unit. This was proved by results obtained for the C-arm unit of the 1st manufacturer.

For the CT scanners, chest angiography protocols were analyzed because these are used for diagnosis of coronary vessels if the appropriate software is lacking. In case of these procedures, the doses vary several times from one configuration of projections to another, and between the scanners. A special coronary protocol was available for the scanners of the 1st manufacturer. The doses measured for the 64-slice scanner were higher up to eight times in comparison to these for the 16-slice scanner.

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 primary x-ray beam to about zero in quite near vicinity. In all the phantom examinations, the doses for both lungs and the doses for elements of skeleton differed significantly depending on the configuration of projections.
That was not observed for CTA procedures, when the magnitude of doses inside the scanned volume was similar.

A great difference in surface dose values for patients undergoing "traditional" coronary angiography was reported everywhere, and similarly differences concerning the absorbed organ doses [7]. Because evaluation of the absorbed dose is much more complex, the European Community has sponsored a scientific project aiming to evaluate the radiation risk and to establish the reference levels in interventional cardiology [8].

The doses received by patients undergoing CTA procedures are also differentiated, although not so widely as in "traditional" angiography. This results mainly from the protocols used: if specific cardio-protocols (i.e. coronary CTA, calcium score, etc.) have not been installed by the manufacturers, the scanner users try to find some substitutes of those. In practice, this can be achieved by combination of protocols providing high-resolution images of the chest area (angio-chest, chest HRCT) and then visualizing coronary vessels. Thus, CTA examination can collect one to three "phases" (with and without contrast medium) which results in a difference in dose values. "Proper handling of the contrast bolus" is indicated by specialists [9] as another reason: an adjustment of contrast and image acquisition is found more valuable for diagnosis than scan speed rise. That suggests the necessity of optimization (or rather standardization) of exposure patterns on order to obtain maximum information through appropriate combination of CT protocols.

Conclusions

1. In coronary angiography carried out using C-arm units, the doses received by patients are highly differentiated and distributed non-uniformly inside the patient's body. Therefore, a low effective dose does not mean the low absorbed doses at all.

2. Doses received by patients in CTA procedures covering the chest are distributed in the patient's body more uniformly. Their values are dependent on exposure pattern (i.e. configuration of projections) applied during the examinations. (A number of phases, HRCT mode, thin slices and low pitch make these doses definitely higher.)

3. The lowest doses in CTA are higher than those in conventional angiography. The doses received by patients examined with sixty-four-slice scanners, very effective in diagnostics of coronary vessels, are higher than in case of sixteen-slice scanners as well as C-arm units.

Table 5. Effective doses to patients in coronary procedures[mSv].

Coronary angiography by C-arm units	CTA procedures	
	Chest angiography	Coronary angiography
of the 1st manufacturer:	16-slice of the 1st manufacturer:	16-slice of the 1st manufacturer:
1.4 ± 0.1	6.3 ± <0.1	5.4 ± 0.1
0.9 ± <0.1	17.1 ± 0.1	
0.9 ± <0.1	7.7 ± <0.1	
1.0 ± 0.1	15.9 ± <0.1	
of the 2nd manufacturer:	13.3 ± <0.1	
1.3 ± 0.3	64-slice of the 1st manufacturer:	64-slice of the 1st manufacturer:
3.2 ± 0.6	13.9 ± <0.1	23.1 ± <0.1
of the 3rd manufacturer:	12.3 ± <0.1	
6.2 ± 0.1	16-slice of the 2nd manufacturer:	
18.8 ± 0.7	27.6 ± 0.1	
	7.9 ± <0.1	

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