HOW TO UNDERSTAND A PHANTOM?

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Abstract

Medical Physics students' theoretical training is currently not enough to allow graduates to work on expensive equipment, like those ones that are used in medical imaging, radiotherapy or nuclear medicine. Certainly, Physics Faculties from Romania have a moral obligation for society, to deliver graduates capable of facing current technology and challenges about patients and staff' safe. The aim of this paper is to propose a complementary approach for students' laboratory activities, using a didactic computed tomography (DCT) and some didactic phantoms (DC), to understand the role of quality assurance (QA) in the process of providing high-quality medical services for the patients' benefit. A phantom is not a ghost or a scary thing, it is a useful device, an object used as stand-ins for human tissues to ensure that used systems and methods for human body imaging are working properly [1]. QA of each CT used in simulation is essential in radiotherapy because it represents the starting point in the oncological patients' pre-planning work-flow. It is important to obtain a very good image quality and ensure that the dose received by the patient is as low as reasonably achievable. In the next years, a balance between theory and practice should be rethought for Medical Physics students to prevent possible accidents that may occur due their lack of experience. The difference between harm and benefits for Medical Physics students' progress is given by the instructors' creativity in finding new teaching and assessment methods, using some didactic equipment capable to simulate a professional environment.

Keywords: *medical imaging, didactic phantom, didactic computer tomograph, quality assurance, students training*

1. INTRODUCTION

There are serious difficulties related to the practical training for Medical Physics students in Romania, especially because they cannot develop in universities their practical abilities on some expensive equipment, like computed tomography (CT), magnetic resonance imaging (MRI), single photon emission (SPECT) and positron emission tomography (PET) gamma cameras. Besides this, a place with all these equipment is, in most cases, an environment with ionization radiation. There are two complementary solutions to improve this situation: 1. Students' internships to be performed in medical centers (medical imaging, radiotherapy, nuclear medicine); 2. Development of some creative didactic lab activities that allows students to 'learn by doing' and later to work in a professional environment using 'analogy', according to the similarity in some aspects of the used equipment.

It is obvious that didactic equipment can only simulate the conditions within a hospital up to a limited extent, with patients and medical staff. However, a creative hands-on activity might contribute to the students' progress, especially when the instructor has used methods such as learning by doing and analogy [2-5], students being familiar with the work procedures, the same with those ones from a professional environment. Besides this, a didactic equipment has a much lower price than any medical imaging equipment from hospitals, it is very safe from the perspective of working with ionization radiation and allows student to understand the interaction of radiation with some tissues and all procedures of QA. The practice in a medical imaging laboratory of the university can be performed at any time of the year and does not require hospital acceptance for access. If students understand the QA procedures and how to operate a didactic equipment similar to the real one, they might become capable to learn by analogy the procedures and use of a real equipment from hospitals, making a transfer from the original knowledge provided by the lab activities to the new knowledge given by the working environment. In this way, the learning difficulty for graduates will be reduced.

Of course, it remains mandatory to improve the relationship between universities and governmental hospitals or private medical centers. Also, it should be taken into account that in the medical imaging centers a large number of patients is scanned every day, the number of medical imaging units is still low at national level. This means that technical staff from hospitals does not have enough time to provide explanations to the students when they are in practice. The second solution requires a lot of creativity in designing laboratory activities on didactic equipment.

QA means a standardization of the medical protocols, planned and systematic actions implemented by the management of each medical center. The effect of QA implementation is that each equipment will produce high-quality images with minimum exposure of the patients and medical staff. The main goal of the QA is to maximize the efficiency of the imaging operation [6-7]. There are daily, monthly and annual QA procedures. In this framework, a lab activity for measuring the Hounsfiled units (HU) of some tissues is proposed, complementary to that one proposed by Phywe [8], a major European manufacturer of didactic equipment. The lab activity allows students to understand two real phantoms (RP), such as Gammex 467 (Tissue characterization phantom) and CatPhan 500 (Image quality phantom) [9-10] that are used in the monthly QA to a real CT. CT simulation is required in radiotherapy [11-14] for a reproducible positioning at each treatment session of each patient. There are some parameters [7] that are used for the QA of each CT system: slice thickness, patient alignment system, spatial resolution, displacement of the table, circular symmetry display system, spatial linearity accuracy and uniformity of the CT number (HU), contrast scale, calibration curve for radiotherapy planning, low contrast resolution, noise, fraction uniformity, artefacts, consistency in 3 dimensions.

2. MATERIALS AND METHODS

2.1. Equipment

The used equipment (shown in Fig. 1.) is a didactic computed tomography (DCT) with a dedicated software (Measure CT) and 3 phantoms provided by Phywe. The X-ray tube of the apparatus has a Wolfram anode, at 19° angle. The control panel of the didactic equipment indicates, using a light signal, the presence of X-rays inside of the equipment. By analogy, in a hospital, the room where the X-rays equipment is located has at entrance a lead door that is blocked when there are X-rays inside of the exposure room and a light warning that indicates when the equipment is in use (continuous or flashing light).

Also, if the leaded glass door is not blocked, the equipment will not start to produce X-rays. The equipment allows the students to see how X-rays are produced, to measure the dose of radiation inside the exposure room at different distances by X-ray source and different time intervals using an electrometer and a timer. It is also easy to check the level of the radiation outside of the equipment using a detector. The equipment has 3 DPs and an accessory kit. Two important components of the DCT are represented by a detector (direct digital image sensor) and a goniometric table rotated by a stepper motor.

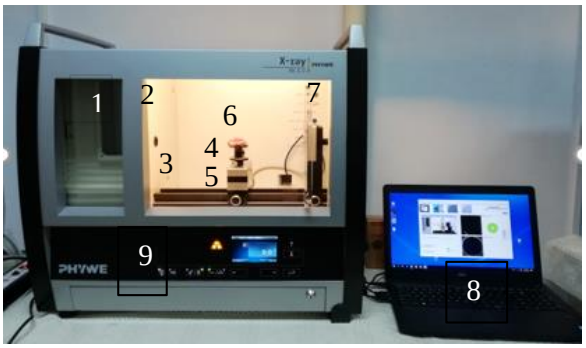


Fig. 1. Phywe XRI 4.0 equipment, X ray unit (1 - X ray source, 2 - slit, 3 - Aluminum track, 4- goniometer table, 5- stepper motor, 6- sample, 7 - digital detector, 8-computer with software for CT, 9- control panel with digital display)

2.2. Materials

The samples that are used in this experiment are represented by small pieces of pig tissues: liver, bone, lung, heart, kidneys, muscle, skin, fat and ice. The reason that pig tissues were chosen is that they are very close to the human ones. The set of 3 DPs provided by Phywe [8] contains 2 plastic rods that mimic water and bone. In a real phantom, materials are selected based of their mimic to human tissues in terms of proprieties like density, harness, stretching [9-10]. It should be emphasized that the human tissues absorb different doses of ionization radiation and have different sensitivities.

2.3. Methods

'Learning by doing' and 'Analogy' approaches have proved to be important methods of scientific cognition that allow students to realize the transfer of knowledge from a didactic lab to a real department of Medical Imaging and to make sense of their experiences in which they actively engage in making simple things and exploring some medical procedures [2-5]. Using these two methods, students will adapt easier after graduation to the medical reality in a professional environment because of the similarity between the equipment used (DCT&RCT, DP and RP) and know their responsibilities about QA procedures. For each hands-on activity that will be described further, the analogy with the real equipment will be made.

First step of each experimental measurement is to enter in the dedicated software of the DCT and to define a new experiment. Second step is to choose the distances between X-rays source and object (220 mm), between X-rays source and detector (400 mm) and the number of projections (200). The third step is to block the door and to apply the voltage on the tube to generate X-rays. The fourth step is to calibrate the equipment in the absence of any sample on the goniometric table. Only after these four steps have been performed, it will be possible for students to scan each sample, one by one, and in the end, using the software, to choose some sections of the sample, eventually finding the values of the absorption coefficient in each selected area. The scanning process and images that were obtained are shown in Fig. 2.



Fig. 2. a) b) c) d)

a) exposure room of the sample; b) scan process of a sample on a DCT; c) sections of a sample: axial, sagittal, coronal and 3D reconstruction, d) Coronal, sagittal and axial planes [15]

It is easy to understand at this moment what means axial section (any horizontal plan, a view looking through the body), sagittal section (any vertical plane parallel to the median plane/ any plan that divides the body into right and left parts), coronal section (any plane that divides the body into ventral and dorsal) and 3D reconstruction on a DCT. A suggestive image like that from Fig. 2. d) illustrates very well what means each section plan and stimulates students' spatial orientation.

Using a dedicated software, students can see hundreds of sections of each scanned tissue and find the attenuation coefficients, in different sections of each sample. This might be considered as being the fifth step and will become very important later, when the CT numbers (HU) are calculated.

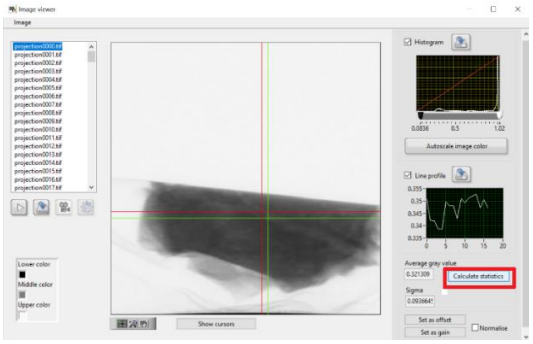


Fig. 4. Finding the attenuation coefficient in the area between red and green reticular lines

At this point, an analogy between a DCT and a RCT should be made. Students have to identify components part of a RCT from **Fig. 5.** a), especially: rotating X-ray tube, row of detectors placed in the gantry (to measure X-ray attenuation by different tissues inside the body) and cooling system. Meanwhile, they should recognize all sections from an image given by a RCT such those ones from **Fig. 5.** b).

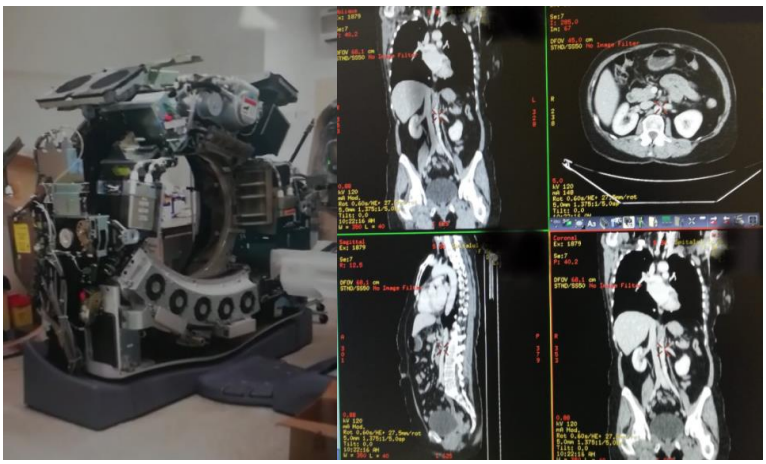


Fig. 5. a) **b)**

a) RCT components (1-row of detectors placed in the gantry, 2-data acquisition system, 3-power unit, 4-high voltage generator, 5-rotation control unit, 6-oil tank, 7-cooling system, 8-pacient table); b) RCT Scan Sections (oblique, axial, sagittal, coronal)

A DCT has a set of 3 didactic phantoms (DP), 2 equivalent to Catphan (up, right side and down) and one to Gammex (up, left side), as can be noticed in **Fig. 6.** a).



Fig. 6. a) b)

a) Components parts of the didactic phantoms (DP) equivalent with Gammex and CatPhan; b) phantoms placed one on top of the other as in the experiment proposed by Phywe

By analogy, real phantoms are made of hard, soft and digital materials that mimic the responses of human tissues under specific conditions. Tissue Characterization Phantom (Gammex 467) is used to provide accurate corrections for tissue inhomogeneities [9]. Using Gammex (**Fig.7.)**, it is established the relationship between electron density of different tissues and their corresponding CT number (HU) [16]. Gammex is a matrix of 16 holes in a disk that hold interchangeable rods. These rods are made of various tissues and water simulating materials. The physical density (gm/cm^3) and electron density relative to water of the rod materials are provided by each manufacturer. Monthly phantom scan provides data useful for the QA program of both the CT scanner and treatment planning system (in radiotherapy).

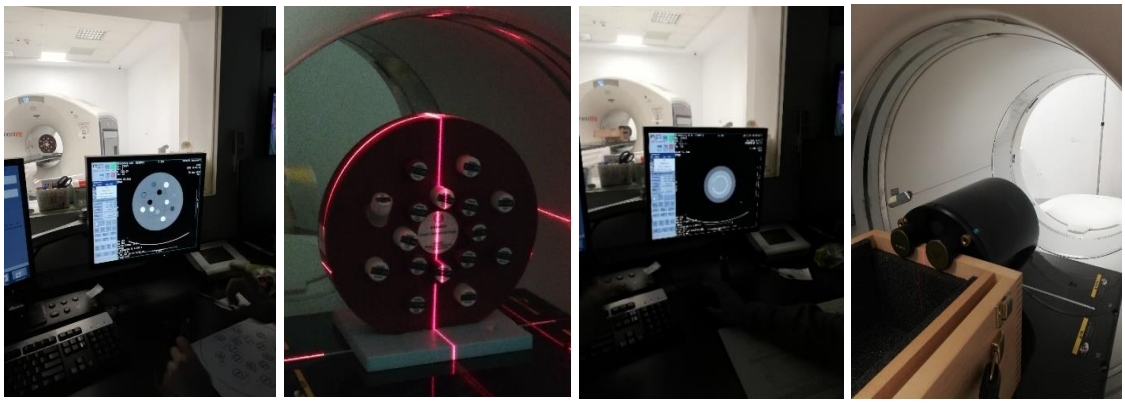


Fig. 7. a) Gammex phantom b) Catphan phantom

Catphan 500 is a plastic cylinder with insertions of different densities. The main purpose of this phantom is to test CT image reconstruction quality. It has three modules: one for pixel value stability and contrast-to-noise ratio, two for high and low contrast resolution tests. The aluminum contrast figures are cast intro position on the radial octagonal pattern (resolution section ranging from 1 to 30 lines pairs per cm). This resolution gauge pattern reduces the possibility of obtaining artifacts from other test objects. A combination of the octagonal design and the rotating mount with 45° indices enable all gauge segments to be measured either aligned with the x or y axis, or at 45° or 90° angle [10]. A disadvantage of a DCT is obviously at this point, there is no laser for position verification as has any RCT.

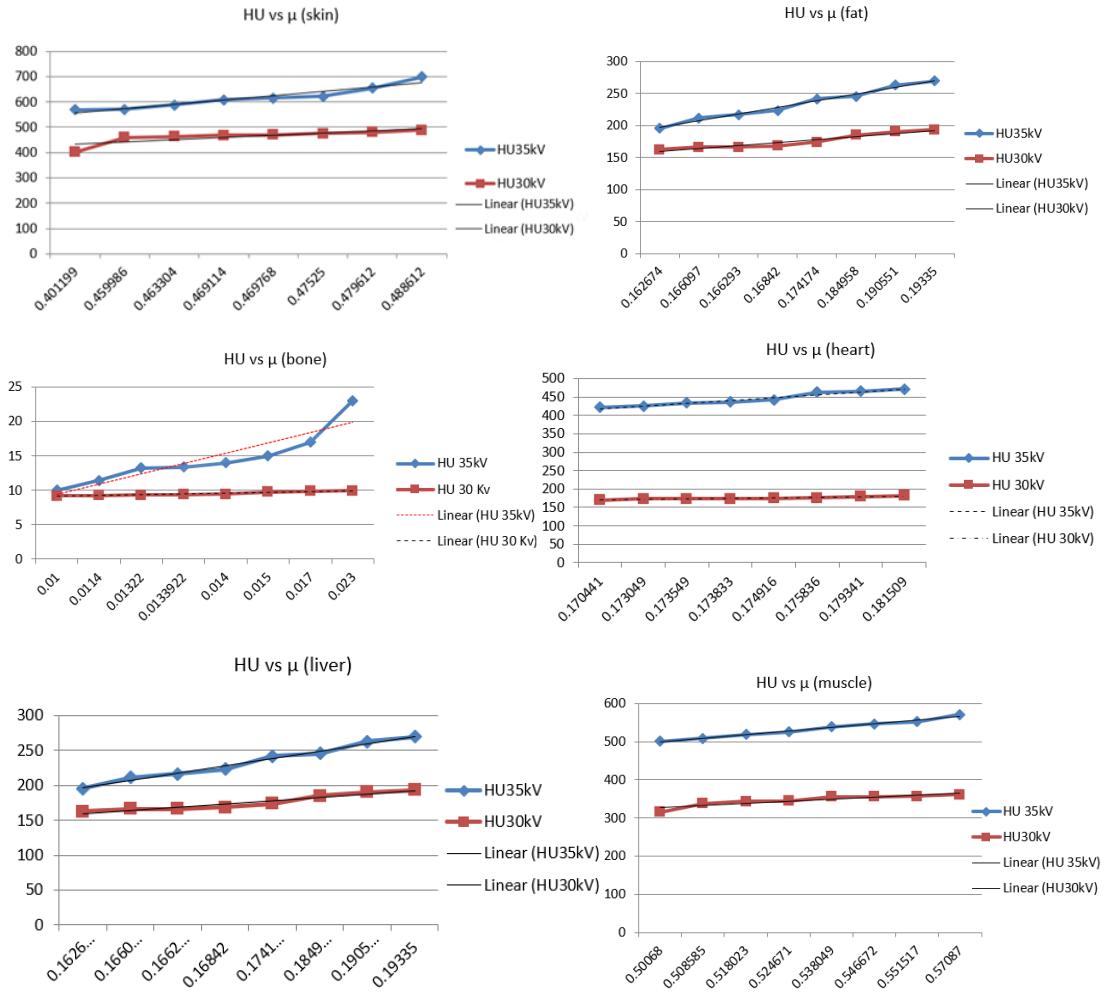
Data are collected over a lab activity, on a DCT, for each pork tissue CT scan, at two different voltages 35 KV and 30 KV, choosing one or more sections where the attenuation coefficients (μ) are calculated using the following formula:

$$HU_{tissue} = 1000 \times \frac{\mu_{tissue} - \mu_{H_2O}}{\mu_{H_2O} - \mu_{air}},$$

where the value of μ_{H_2O} is considered as being 0 and the value for air, μ_{air}, is taken -1000. For each tissue, at the same voltage were taken eight values. As is shown in **Table 1**., for the scan tissues, the following results were obtained:

Tissue	KV	$\overline{\mu_{tissue}}$	$\overline{HU}$	Rel.dev. *HU*	Tissue	KV	$\overline{\mu_{tissue}}$	$\overline{HU}$	Rel.dev. *HU*
skin	35	0.615	633.474	7.103	liver	35	0.233	233.398	8.997
	30	0.463	444.905	6.967		30	0.176	178.012	6.741
fat	35	0.686	688.663	2.758	muscle	35	0.532	535.775	4.106
	30	0.378	378.770	17.688		30	0.346	338.310	4.729
bone	35	0.013	16.5	24.242	kidney	35	0.433	440.482	5.448
	30	0.01	9.539	0.295		30	0.103	120.174	12.481
heart	35	0.444	446.471	4.255	ice	35	0.235	235.414	40.91
	30	0.175	175.975	1.704		30	0.282	282.761	4.59

Table 1. HU values for all used tissues



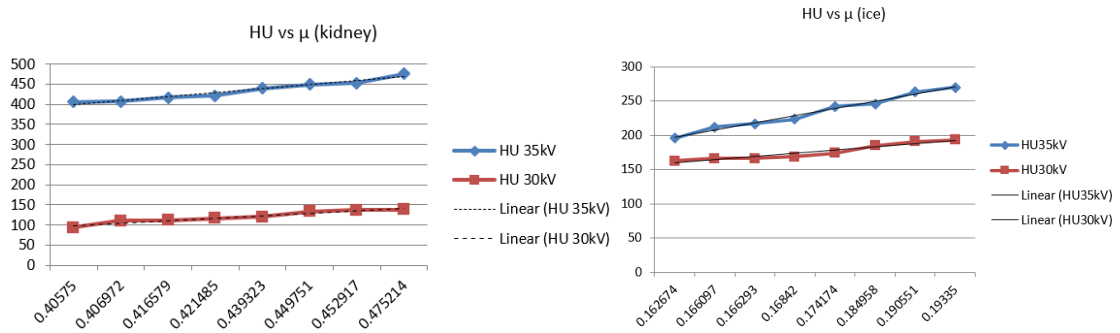


Fig. 8. Graphical representation of HU vs. μ for different tissues and different voltages

3. RESULTS AND DISCUSSIONS

Even if the values obtained for low voltage on X-ray tube are different than those given by a RCT and a RP, students will learn how to calculate HU for any sample and will understand the reasons for which their values are different (voltage, pork tissues). It is well known [11] that in medical imaging, very low energies of an X-ray spectrum are removed prior to an interaction with the patient by using a thin metal plate which is placed between the patient and the X-ray source. The most important part of the low energy photons is absorbed by the patient; thus, the patient dose increases without a substantial improvement of the image quality. Unfortunately, in the proposed lab activity, only low energies were used. Results suggest that HU may provide usable information of tissue issues, especially when are interpreted in relation with the voltage on X ray tube and used pork tissues and as a component of complex analysis tailored for education. The results are nevertheless subject to the inherent limitations of the approaches employed, like the meaningfulness of the used DCT scan and didactic phantoms (e.g., in relation to the real CT and QA procedures) or that the HU definition (e.g., as relevant for the Medical Physics students' training).

4. CONCLUSIONS

This proposed hands-on activity allows students to understand the importance of each phantom in QA, using a very safe and compact equipment. If students take into account that was used a low voltage and pork tissues, they will understand better the factors that occur at such results. The principle according to which a phantom works is the same both in hospital and laboratory. Certainly, there are differences related to the measurements performed in the laboratory compared to the real ones. A variety of experiments can be performed on a DCT: determination of Hounsfield units for different samples, significance of the high- and low-resolution tests. How to understand a phantom? The answer is very simple, using a toy, a didactic equipment!

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