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PROCEEDINGS

APPLICATION OF MATERIALS USED IN EVERYDAY LIFE TO CREATE RADIOLOGICAL MODELS OF HUMAN TISSUES

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ABSTRACT

Radiological physical models (phantoms) are used for quality control, for evaluation and analysis of a given X-ray device. They are easily available, providing the X-ray technicians with consistent results and safety compared to using a live subject. Phantoms must respond in the same or similar way to human tissues and organs when exposed to radiation, and therefore must be manufactured from materials with the same or similar X-ray properties (1). The purpose of this report is to study materials from everyday life as suitable substitutes for human tissues in quality control tasks. In daily life, everything we come in contact with could be used as a material for a physical phantom: plastic, wood, glass, water, salt, sugar, gelatin, paraffin, and others. Due to the advantages of plastic—cheap, flexible, waterproof, and easy to manufacture, it becomes a reliable material in many fields, including 3D printing. After the physical model is printed, it should be checked whether or not it is the same or similar to the real human tissues. All results are processed by using the DICOM processing program (Digital Imaging and Communication in Medicine) by comparing the density using the Hounsfield units scale to determine to what extent the physical radiological model is approaching real human tissue.

Keywords: *radiological model, phantom, 3D printing, plastic, density, Hounsfield units, computed tomography*

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INTRODUCTION

Radiology models, also called phantoms, are specially designed objects that are used to evaluate, analyze, or even adjust an X-ray machine. This is necessary for quality and dosimetry control, for example, in the case of new X-ray equipment or such after repair. A phantom is more readily available and provides more consistent results than using a live subject or a cadaver, and likewise avoids subjecting a living organism to direct risk. Initially, phantoms were used in two-dimensional (2D) X-ray-based imaging techniques, such as radiography or fluoroscopy, but later, phantoms with desirable imaging characteristics were developed for three-dimensional (3D) techniques, such as SPECT, MRI, CT, PET, and other imaging methods (2).

The phantoms we use for quality and dosimetry control must respond in the same or similar way to human tissues and organs in a single exposure. Therefore, the radiological model (phantom) must be printed from materials whose X-ray properties are the same or close to those of human tissues and organs. For example, when using computed tomography, our radiological model, for instance, a breast, must contain enough radiocontrast reagents to resemble the adipose tissue (ρ=0.95 g/cm^{-3}), to adjust the contrast of the device, or to modulate the dose with which we irradiate the patients.

AIM

The aim of this report is to investigate materials from everyday life and to come to a conclusion about the most suitable ones.

MATERIALS AND METHODS

Materials

A material from our everyday life that can be used is plastic. Plastic is made of synthetic or semi-synthetic compounds and has the ability to change its shape. Most plastics on the market are completely synthetic. However, with the growing general concern for the environment, there is also the presence of plastics derived from renewable materials, such as polylactic acid (PLA), used in 3D printing. Thanks to its low cost, easy production process, flexibility, and water resistance, plastic is a material used in many fields, including the sphere of medicine.

The most popular and affordable 3D printing process is fused deposition modelling (FDM)—modelling by molten material deposition. In FDM, 3D parts are produced by extruding plastic filaments. An extruder, a machine similar to a meat grinder, is used. It also heats the plastic, forming pellets, otherwise known as filaments. These filaments are used in the 3D printing process.

Acrylonitrile butadiene styrene (ABS) is a flexible and resistant thermostatic polymer commonly found in the industry. It is used in car bodies, appliances, and mobile phone cases. Acrylonitrile butadiene styrene is used in 3D printing when heated between 230°C and 260°C. Thanks to its resistance, it can withstand temperatures from -20°C to 80°C. However, ABS is not biodegradable and shrinks when exposed to air. To prevent warping, the print platform must be preheated. When working with ABS, it is best to use a 3D printer with a closed chamber to limit particle emissions.

Table 1. Investigated materials.

Materials	Density (ρ, g/cm^{-3})
Paraffin	0.96
Wood (walnut)	0.8
Plexiglas	1.18
ABS-E (100% ABS)	1.03
PLA-E (100%PLA)	1.21
PLA-W (60%PLA + 40%wood)	1.2
PLA-S (50%PLA + 50%stonefil)	1.7
PET-G (85%PET + 15%C)	1.19
PC	1.20
Silicone rubber	1.24
Resin (epoxy)	1.2
Glass	2.5
Gelatin	1.27
Olive oil	0.9
Egg white	1.03
Water	1
Sugar	1.6
Salt	2.16
Au (gold)	19.3
Al (aluminium)	2.7

Polylactic acid (PLA) is biodegradable and is produced from renewable raw materials. It is one of the easiest materials to print on, although there is some slight shrinkage after printing. Unlike ABS, PLA does not require a heating platform. The temperature at which this plastic can be processed in 3D printing varies between 190°C and 230°C. The peculiarity of PLA, compared to ABS, is that this material is more difficult to process, due to its tendency to rapidly cool and harden. There is also danger that the models will be damaged in contact with water.

The advantage of PLA is that it is an easy-to-use plastic that is available on the market in a wide variety of colors, making it a suitable material for FDM 3D printing.

Polyethylene terephthalate (PET) is suitable for making plastic containers, bottles, and utensils intended for contact with food. This material has good chemical resistance, does not emit any odors during printing, and is 100% recyclable. For optimal results, the printing temperature should vary between 75°C and 90°C. Polyethylene terephthalate can be found on the market as a translucent filament.

Polycarbonate (PC) is a high-strength material that is mainly intended for engineering applications. It can withstand any physical deformations requiring high temperatures—up to about 150°C. However, PC tends to absorb moisture from the air, which can affect the quality and durability of the print. To avoid this, it is advisable to store the material in hermetically sealed containers. Polycarbonate's strength and transparency make it a highly valued material in the additive manufacturing (AM) industry. Since it has lower density than glass, it is suitable for designing optical parts, protective screens, or decorative objects (3).

Building parts using resin results in highly detailed models with remarkably smooth surfaces. However, the limitation of the color range when working with such material can be noted as a disadvantage. Standard 3D printing resin has properties similar to ABS. There are also more advanced resins for technical applications in dentistry, engineering, and other sectors. There are other types of resin that offer more flexibility and can be used to make jewellery.

Other types of materials used in our everyday life are **paraffin**, **gelatin**, **egg white**, **salt**, and **sugar**. They all have different densities that can resemble human tissue. Gelatin or jelly at first resembles adipose tissue. The egg white consists mostly of 90% water and its main purpose is to protect the yolk in the egg. That is why one of its functions is protection. These characteristics closely resemble the characteristics of the connective tissue of the human body, but to know whether their densities are close, a study should be conducted.

When selecting the materials for investigation, a question arose such as why we do not also use harder materials, or in other words—metals, such as aluminium, gold, etc. As materials, however, they are too dense, very expensive compared to plastic, and will result in reconstruction artefacts.

Methods

The phantoms of different types of plastic were arranged in a certain order according to their type and density. They were scanned on a SIEMENS computed tomograph at St. Marina University Hospital in Varna, using different protocols defined for each area of the human body.

The results of the study were processed using the DICOM (Digital Imaging and Communication in Medicine) program. With the program we formatted the medical images with which we exchanged the data and quality needed for clinical uses and research.

The breast phantom provided to us by Prof. K. Bliznakova was made of materials at hand that we encounter mainly in our everyday life, with the exception of resin. The radiological model was three-dimensionally printed with a resin whose density was 1.2 g/cm^{-3}, with a thickness of 0.8 mm. The resin was placed in a cast of a female breast. The inner part was filled with balls, swollen after being soaked in water. The density of the balls was 0.99. As an outer layer over the resin, we used a latex glove to enclose the balls in the cast. The glove was resistant to external mechanical movements. The resin is also elastic and durable, but under pressure the integrity of the balls is low.

RESULTS

The Hounsfield unit (HU) scale is a linear transformation of the original linear attenuation coefficient measurement into one where the radiodensity of distilled water at standard pressure and temperature is defined as 0 HU, while the radiodensity of air is defined as 1000 HU.

A change of one HU represents a 0.1% change in the attenuation coefficient of water since the attenuation coefficient of air is almost zero.

Hounsfield unit calibration tests can be done against water and other materials to ensure a standardized response. This is particularly important for computed tomography (CT) scans used in radio-

Table 2. Measured HU values for the plastic materials (4).

Materials	HU (Hounsfield Units)	
ABS-E (100% ABS)	63.79 ± 1.68	
PLA-E (100% PLA)	204.39 ± 0.71	
PLA-W (60% PLA + 40% wood)	65.608 ± 0.58	
PLA-S (50% PLA + 50% stonefil)	844.24 ± 3.84	
PET-C (85% PET + 15% C)	62.66 ± 1.75	
Water	0	

therapy treatment planning, where HU is converted to electron density. Variations in measured values of reference materials of known composition and variations between and within sections may be used as part of the test procedures.

Hounsfield-unit-based material differentiation applies to medical-grade dual-energy CT scans, but not to cone-beam computed tomography (CBCT) scans, as CBCT scans provide unreliable HU readings.

Table 3. HU values of human organs and tissues (5).

Tissue/Organ	HU (Hounsfield Units)
Air	-1000
Fat	-120 to -90
Soft tissue on contrast CT	+100 to +300
Subdural hematoma first hours	+75 to +100
Subdural hematoma after 3 days	+65 to +85
Liver	+60 ± 6
Lung	-700 to -600
Urine	-5 to +15
Unclotted blood	+13 to +50
Clotted blood	+50 to +75
Cortical bone	+500 to +1900
Cancellous bone	+300 to +400
Water	0

The values given here are approximate. Different dynamics are reported from one study to another, as shown in Table 3.

The exact HU dynamic may vary from one CT acquisition and reconstruction parameters (kV, filters, reconstruction algorithms, etc.). The use of contrast agents also modifies HU, depending on the part (mainly blood).

The materials that approach a tissue/organ of the human body on a CT scanner are summarized in Table 4:

CONCLUSION

In conclusion, according to the results, plastic is the most suitable material from our everyday life to represent human soft tissue. Using 3D FDM printing, we can transform the plastic filament into any shape, thus forming a physical phantom, which is suitable for daily quality control of the X-ray machines. The plastic filament PLA-W, which is made of 60% PLA and 40% wood comes closest to subdural hematoma after 3 days, the ABS-E (100% ABS) comes closest to the liver, PLA-E (100% PLA)—to soft tissue on contrast CT, while the material PLA-S, which is made of 50% PLA and 50% stone fill—to cortical bone.

Table 4. Matching suitable materials to human tissues.

Materials	Tissue/Organ
PLA-W (60%PLA + 40%wood)	Subdural hematoma after 3 days
ABS-E (100% ABS)	Liver
PLA-E (100%PLA)	Soft tissue on contrast CT
PLA-S (50%PLA + 50%stonefil)	Cortical bone

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