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Investigation of Meningioma Physical Coefficients Pre- and Post-Contrast Using CT Technology

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Abstract: One of the most significant physical processes used in medicine is the computed tomography (CT) scan, which relies on the interaction of electromagnetic radiation energy (X-rays) with human tissue. In this research, a head CT protocol was used to image a patient (female, 40 years old) in two stages: before and after contrast agent injection. The mean values of Hounsfield unit (HU) for the images were extracted and analyzed by comparing the physical principles Linear Attenuation coefficient (LAC) and Half Value Layer (HVL) for both stages. Where a relatively small increase in the value of LAC was observed in the specific area of the left hemisphere of the brain compared to the corresponding area of the right hemisphere. This finding is matched by a decrease in the value of HVL for the same areas, and this means a relatively small increase in the density of the specific area of the left hemisphere, which indicates the discovery of an abnormal mass, but it does not appear prominently due to the iso-density. In post-injection stage, it was found that the difference between the values of LAC and HVL for both regions of each hemisphere of the brain became higher than in the first stage due to the absorption of the contrast agent by the detected mass (in the abnormal area) and showed a strong, homogeneous enhancement of it and became whiter than the rest of the surrounding normal tissue. A higher LAC value for this mass means an increase in hyper-density and thus a lower HVL value, all of which means a higher attenuation of the X-rays falling on the brain tissue. Based on the investigated coefficients, shape, and location of the mass, the case was diagnosed as a meningioma.

Keywords: Computed tomography (CT), Hounsfield unit (HU), Linear Attenuation coefficient (LAC), Half Value Layer (HVL), Iso density, Hyper density and contrast factor.

1. Introduction: CT technology has been ranked as one of the five most important inventions in medicine over the past 40 years because it provides a more accurate diagnosis than conventional imaging; It is the first medical imaging that was made possible by computer [1,2]. CT is based on the basic principles of the interaction of electrons with matter (bremsstrahlung) for the formation of x-rays in the x-ray tube, the interaction of x-rays with matter (photoelectric and Compton interactions); the gantry, which includes the X-ray tube, rotates and produces images in the form of sections of the body that are very clear. Because it enables us to see the human body from all levels in a feature called multi-planner reconstruction (MPR) to visualize and diagnose signs of disease with great accuracy and speed to help doctors identify the disease [3–5]. The principle of forming a CT image is based on the fact that the density of tissue passed by an X-ray beam can be measured by calculating LAC, then the density of the object is reconstructed by 2D section perpendicular to the axis of the acquisition system, and the cross-sections are reconstructed from measurements of the attenuation coefficients of X-ray beams passing through the volume of the investigated object using complex computer-generated mathematical algorithms. Attenuation of photons occurs from the primary X-ray beam as it passes through the tissue consisting of a line of individual blocks such that each block has a linear attenuation coefficient value (μ) that depends on the type of tissue and the energy of the X-ray photons that have penetrated this block; Therefore, the tissues of the body located along the path of the beam interact with this beam by absorbing or scattering it before it reaches the receiver (detector), which in turn receives the rays, converts them into electrical signals and sends them to the control unit. These analog electrical signals are processed and converted into a digital signal that is processed by Fourier transform and then reconstructed by inverse Fourier transform into images [6-9].

The number of x-ray photons (density) describes the quantity of the beam and is affected by the value of the x-ray tube current (mA), which determines the total number of x-ray photons present under the x-ray spectrum[6]. The quality of the beam is also determined by the distribution of the rays as a function of energy, and it determines the extent of penetration of the beam; It depends on the factors: kV_p, which is the factor that determines the highest energy in the x-ray spectrum in addition to filtration and also the atomic number of the target, and is not affected by the value (mA), and due to the effect of beam quality on image quality. The beam quality was assessed by measuring HVL, which is the layer Which works to attenuate the beam passing through the material by half [10,11]. The process of reconstructing a CT image is done first by calculating the attenuation coefficient value for each voxel and then converting it to a pixel value whose value is determined numerically by CT numbers, also known as Hounsfield units, which is a set of numbers that measure gray levels numerically by matter density or linear attenuation coefficients, water is used as a reference material to determine the numbers of the CT image, and in the reconstructed image each pixel is represented by a numerical value associated with the value of the linear tissue attenuation coefficient in each voxel [2,12].

It should be noted that the first CT scan of the brain was performed in 1971 by the British engineer Hounsfield Godfrey, but the CT scan device was officially presented to the public in 1972. Surprisingly, the American physicist Cormack Allan also invented a similar device. As for imaging the rest of the organs of the human body were not common until 1980 [1,8]. When performing a CT scan of the brain using old and slow devices, the patient is asked about his illness history and previous examinations are reviewed before imaging the patient. In the event of suspicion of the presence of head injuries or tumors, the patient is directly injected with a contrast injection[13]. However, using current modern devices, the patient is always photographed first without injecting the contrast agent, then determining whether the condition requires injections, as in cases of tumors, and it often does not require significant preparation for the patient except in the case of anesthesia or injection of the contrast agent, as it is preferable for an adult patient to fast for about 6 hours [13–17]. One of the most important types of brain tumors is meningioma, which is the most common type of primary brain tumor in adults[18,19]. Most of them are usually benign and are found on the outer surface of the brain, at the top of the brain or at the base of the skull [20–22]. Meningiomas begin in the layers of tissue that surround the outside of the brain and spinal cord (meninges), and they

account for about 1 in 3 primary tumors of the brain and spinal cord. The risk of developing these tumors increases with age. It occurs approximately twice as often in women [20,21].
The main objective of this research is to calculate the linear attenuation and half-value layer of the tissue using Hounsfield units calculated from the normal and abnormal areas of the image produced by the CT device of the patient's brain organ first without using contrast media agent and then after using contrast media in order to detect the lesion (tumor e.g.) and their exact size and position in specific details

2. Materials and methods:

2.1 Materials:

The CT device used is SOMATOM Emotion 16-slice configuration from SIEMENS, Software Versions: (Syngo CT 2009E) [23]. The device generally consists of a gantry, which contains most of the components of the device, such as X-ray tube, filters, detectors, collimators, etc. The device also contains a patient table; All of this is designed in a special room surrounded by walls made of lead to protect workers from radiation. There is also a control room outside, which contains a computer to control the process of imaging, processing, and outputting images (Figure 1). Iohexol Injection USP (Contrapaque* 350) is a sterile solution of Iohexol in water for Injection. It contains NL T 95.0% and NMT 105.0% of the labeled amount of Iohexol ($C_{19} H_{26} I_3 N_3 O_9$) as organically bound iodine.

Figure 1: 16 Slice Computed Tomography

2.2 Methods: The patient was prepared for the head imaging position, where the patient lies in a supine position, resting his arms on the body, and we fixed his head well in the head holder to ensure that the head area is placed in the center of the scanning field. Using the computer, we selected the protocol for the medical examination of the head, which is: A set of parameters that specify specific scanning and contrast requirements [16,24,25] For example: Head-Routine, then we click the (Load) button, and the device begins scanning, and after completing the scanning, we click the (Recon) button to reconstruct the scanned sections. The resulting image data is automatically stored in the computer and the image clips appear on the screen and can be processed. Then we choose the appropriate clips to show the varying details in the organ and highlight the locations of the disease or lesion shown in the image. Then we begin analyzing the resulting images by calculating the linear attenuation coefficient and the half-value layer HVL using the Hounsfield numbers obtained from the normal and abnormal areas of the medical image and comparing them. After that, we injected the patient with a contrast injection into one of the patient's veins and re-imaged him immediately after the injection to obtain images with higher contrast that highlight the lesion more clearly. We repeated the calculations in the same way for the images after the injection. Then we analyze the findings to reach the conclusion and diagnosis of the case, and then we write a report on the most important details, which explains the abnormal condition in several points to the specialist doctor.

3. Results and calculations:

3.1 The first stage: Without using a contrast media: CT procedures using a head CT protocol were performed for a patient (female, 40 years old) with abnormal brain symptoms and obtained a set of CT images (Figure 2). Table (1) shows the values that were used from the brain protocol for this case.

Table 1: Tag Text

Body Part Examined	HEAD
KV_p	130 KV
Gantry Detector Tilt	-2°
Scan time	1.5 s
X Ray Tube Current	180 mA
Exposure	270 mAs
Focal Spots	0.95 mm
Kernel	H30s
Window Center	40\700
Window Width	80\3200
Slice Thickness	4.8 mm

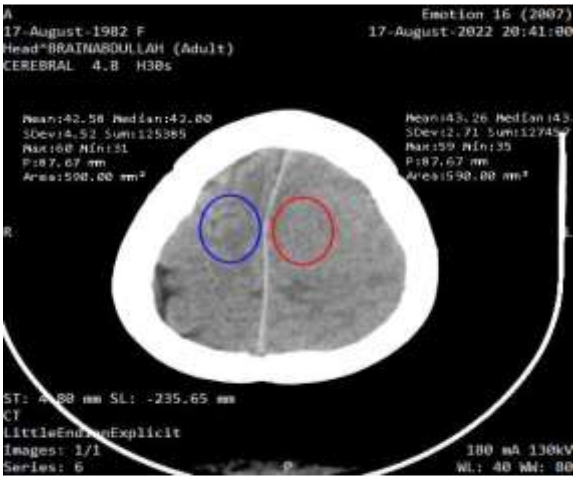

Figure 2: The detected area without contrast factor

Calculations of the first stage:

We obtained mean values of Hounsfield units (Table 2) for the regions marked in figure (2) and performed several calculations according to the following equations [2,12]:

The linear attenuation coefficient is symbolized by ($\boldsymbol{\mu_{tissue}}$):

Its unit of measurement is (cm^{-1}) based on the following equation:

$$\mu_{\mathrm{tissue}} = \frac{\mu_{\mathrm{water}}[\mathrm{HU}_{\mathrm{tissue}} + 1000]}{1000} \dots (1)$$

When the linear attenuation coefficient of water is equal to:

$$\mu_{\mathrm{water}} = 0.18\ \mathrm{cm}^{-1}$$

Half-Value Layer (HVL): A unit of measurement based on the following equation:

$$\mathrm{HVL}_{\mathrm{tissue}} = \frac{\ln 2}{\mu_{\mathrm{tissue}}} \dots (2)$$

Table 2: Result of stage 1

$\mathbf{HU_{tissue}}$ (**Mean Value**)		$\boldsymbol{\mu_{tissue}}$ ($\mathbf{cm^{-1}}$)		$\mathbf{HVL_{tissue}}$ (**cm**)	
Normal	Abnormal	Normal	Abnormal	Normal	Abnormal
42.58	43.26	0.1876644	0.1877868	3.69354	3.69113

3.2 The second stage: With using a contrast media:

After we performed the CT procedures in the first stage without injecting the contrast agent, we repeated the work but after injecting the patient with the contrast agent and a set of CT images obtained (Figure 3).

Calculations of the second stage:

The average values of the Hounsfield units were obtained for this stage for the regions marked in Figure 3 and repeated the calculations according to the equations (1) and (2) as in the first stage (Table 3).

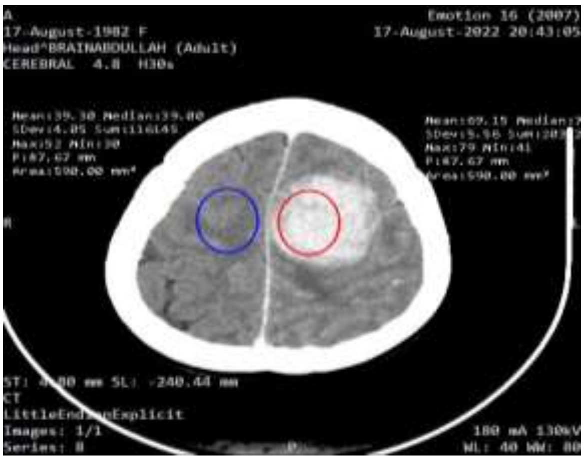

Figure 3: The detected area with contrast factor

Table 3: Result of stage 2

$\mathbf{HU_{tissue}}$ (Mean Value)		$\mu_{\mathbf{tissue}}$ (cm^{-1})		$\mathbf{HVL_{tissue}}$ (cm)	
Normal	Abnormal	Normal	Abnormal	Normal	Abnormal
39.30	69.15	0.187074	0.192447	3.705203	3.601756

4. Discussions: In the first stage, through the values obtained from the previous results presented in table (2) and from figure (3), we found the following:

1. The mean value of the Hounsfield units that we obtained in the region indicated by the red circle in figure (2) is greater than its value in the region indicated by the blue circle; We have indicated-as in table (2)-the area marked with the red circle as abnormal, and we have indicated the area marked with the blue circle as the normal area.

2. When we compared the values of the linear attenuation coefficient between the normal and abnormal regions, we found that the linear attenuation coefficient in the abnormal region slightly larger than the linear attenuation coefficient in the normal region.

3. Also, when we compared the half-value layer between the two regions, we find that the half-value layer in the abnormal area is slightly lower than the half-value layer in the normal area.

4. The comparisons in points (2 and 3) above indicate that there is a mass density (tumor) in the abnormal area (in the left hemisphere of the brain) greater than that in the normal area in the right hemisphere of the brain.

5. Although the mass density detected in the left half of the brain does not appear clearly, it appears-anatomically-through the appearance of some mass effects resulting from the following:

- Slight deviation of the cerebral falx to the right hemisphere of the brain.
- Pressure on the suprasellar parts of the left parietal lobe.
- Pressure on the upper part of the left lateral ventricle.
- The lesion is closely associated with the superior sagittal sinus venosus.

In the second stage, in order to make seeing the tumor clearer and easier, we injected the patient with a contrast agent and then re-imaged him. We obtained the results shown in Table (3) and noted the following:

1. When comparing the values of the linear attenuation coefficient for the normal and abnormal areas, we find that its value in the abnormal area (marked by the red circle) is greater than its value in the normal area (marked by the blue circle) as a result of the abnormal soft tissues absorbing the contrast agent medium, unlike the normal areas that do not absorb it. Therefore, the half-value layer values of the abnormal region are lower than those in the normal region.

2. By looking at image (3) of the second stage (after injection) and comparing it to image (2) of the first stage (before injection), and by comparing the two abnormal areas (indicated by the red circles in both images 2 and 3) for both stages with each other, we noticed the appearance of a bright color. The abnormal area of the second stage is whiter than the same area of the first stage; This is because this area absorbs the contrast agent, resulting in a lesion that shows strong, homogeneous post-contrast enhancement.

5. Conclusion: In this study, physical laws were used to analyze the medical CT image of a case photographed using computed tomography in two stages before and after contrast injection. This was done by extracting the mean values of HU for the images and analyzing them by comparing the physical principles LAC and HVL for both stages. In the first stage, due to the closeness of the linear attenuation coefficient values and the half-value layer values in the normal and abnormal areas, the contrast between the two areas decreased, which led to the location and size of the lesion being unclear. Where a relatively small increase in the value of LAC was observed in the specific area of the left hemisphere of the brain compared to the corresponding area of the right hemisphere of the brain, and this is matched by a decrease in the value of HVL for the same areas, and this means a relatively small increase in the density of the specific area of the left hemisphere, which indicates the discovery of an abnormal mass, but it does not appear prominently due to the iso-density. Therefore, it was necessary to re-image the patient after injecting him with the contrast agent in order to raise the value of the attenuation coefficient in the diseased tissues to highlight these tissues and be able to diagnose them accurately. In the post-injection stage, it was found that the difference between the values of LAC and HVL for both regions of each hemisphere of the brain became higher than in the first stage due to the absorption of the detected mass (in the abnormal area) of the contrast agent and showed a strong, homogeneous enhancement of it and became more whiter than the rest of the surrounding normal tissue. A higher LAC value for this mass means an increase in density (hyper-density) and thus a lower HVL value, all of which means a higher attenuation of the X-rays falling on the brain tissue. From the analyzed coefficients, shape and location of the mass, the case was diagnosed as a meningioma causing the mass effects mentioned previously.

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دراسة المعاملات الفيزيائية للورم السحائي قبل وبعد التباين باستخدام تقنية التصوير المقطعي

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الملخص: يعد التصوير المقطعي المحوسب (CT) من أهم العمليات الفيزيائية المستخدمة في الطب، والذي يعتمد على تفاعل طاقة الإشعاع الكهرومغناطيسي (الأشعة السينية) مع الأنسجة البشرية. في هذا البحث، تم استخدام بروتوكول التصوير المقطعي المحوسب للرأس لتصوير مريضة (أنثى، 40 سنة) على مرحلتين: قبل وبعد حقن عامل التباين. تم استخراج القيم المتوسطة لأرقام CT والتي تسمى بوحدات هاونسفيلد (HU) للصور وتحليلها من خلال مقارنة المبادئ الفيزيائية لمعامل التوهين الخطي (LAC) وطبقة نصف القيمة (HVL) لكلا المرحلتين. حيث لوحظت زيادة طفيفة نسبيًا في قيمة LAC في المنطقة المحددة من النصف الأيسر من الدماغ مقارنة بالمنطقة المقابلة في النصف الأيمن. ويقابل هذه النتيجة انخفاض في قيمة HVL لنفس المناطق، وهذا يعني زيادة طفيفة نسبيًا في كثافة المنطقة المحددة من النصف الأيسر من الدماغ، مما يشير إلى اكتشاف كتلة غير طبيعية، لكنها لا تظهر بشكل بارز بسبب الكثافة المتساوية تقريبًا؛ أما في مرحلة ما بعد الحقن وجد أن الفرق بين قيم LAC وHVL لكلا المنطقتين لكل من نصفي الدماغ أصبح أعلى مما كان عليه في المرحلة الأولى وذلك بسبب امتصاص عامل التباين بواسطة الكتلة المكتشفة (في المنطقة غير الطبيعية) وأظهر تعزيزًا قويًا ومتجانسًا لها وأصبحت أكثر بياضًا من بقية الأنسجة الطبيعية المحيطة بها. تعني قيمة LAC الأعلى لهذه الكتلة زيادة في الكثافة المفرطة وبالتالي انخفاض قيمة HVL، وكل ذلك يعني توهينًا أعلى للأشعة السينية التي تسقط على أنسجة المخ. وبناءً على المعاملات التي تم فحصها وشكل وموقع الكتلة، تم تشخيص الحالة على أنها ورم سحائي.

الكلمات المفتاحية: التصوير المقطعي المحوسب (CT)، وحدات هاونسفيلد (HU)، معامل التوهين الخطي (LAC)، طبقة نصف القيمة (HVL)، الكثافة المتساوية، الكثافة المفرطة، عامل التباين.