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Low Dose Brain CT, Comparative Study With Brain Post Processing Algorithm

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Declaration

I certify that this thesis submitted for the degree of master, is the result of my own research, except where otherwise acknowledged, and that thesis has not been submitted for a higher degree to any other university or institution.

Signed :.....................

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Date: 21.1.2020

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Abstract

Computed tomography (CT) scanners and CT exams increase continuously. Researcher aims to minimize ionizing radiation dose by introducing new CT protocols, providing diagnostic CT images with lower radiation dose to patient. However, such studies encounter difficulties, when radiation dose is lowered, the quality of images becomes less and sometimes not diagnostic. In this study, the researcher aims to provide low dose brain CT protocol, and then determine if the images match quality criteria of Brain CT; and determine diagnostic appearance of the images. Then, the researchers will compare the result obtained from source Brain CT, and Brain post processing algorithm to determine which one of them provides better diagnostic image, and has a better match for quality criteria of Brain CT, by the Numerical criterion (1: weak, 2: moderate, 3:perfect) which used by expert medical imaging technologists, On a sample of 35 patients; the first brain CT was conducted by 22 milli-gray (mGy) volume computed tomography dose index ($CTDI_{vol}$); the resulting image was noisy, and has poor match for quality criteria, so more radiation needed to increase the quality of the images, here CTDIvol was raised to 25 mGy, then to 30 mGy, and finally to 33.8 mGy. At this point, the image was acceptable to complete the study. The researcher have engaged four radiologists to determine if the image provides diagnostic appearance, then six expert medical imaging technologists were involved to determine the quality criteria. These steps were followed for Brain CT before and after applying post processing algorithm. Then the results compared with the reference study for brain CT. the result for low dose brain CT was diagnostic and match quality criteria for brain CT, after applying brain post processing algorithm the images diagnostic appearance disturbed, the suggested protocol by the study provide 47%dose reduction,

from the standard protocol which use 63 mGy. The problem of signal reduction solved by, using iDose^4 (Fourth-generation hybrid iterative reconstruction algorithm introduced by Philips) which improve signal to noise ratio (SNR), increase slice thickness to 5 millimeter (mm), and the use of overlap increment to solve the problem of partial volume and increase number of acquired slices.

التصوير الطبقي للدماغ باستخدام جرعة شعاعية منخفضة, دراسة مقارنة مع خوارزمية تحسين التباين

إعداد: حمزه محمود عبد الرحيم العرجه

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الملخص

هناك ازدياد ملحوظ في عدد أجهزة التصوير الطبقي, وعدد الفحوصات التي يتم طلبها. يهدف الباحث في هذه الدراسة الى إضافة بروتوكول لتصوير الدماغ يستخدم كمية من الاشعة أقل من البروتوكول المعياري, مع إمكانية توفير صور تشخيصية, ولكن تواجه مثل هذه الدراسات صعوبات ، عندما يتم تقليل الجرعه الإشعاعية المستخدمة في التصوير ، تصبح جودة الصور أقل وأحيانًا لا تكون تشخيصية. في هذه الدراسة ، يهدف الباحث إلى إضافة بروتوكول يستخدم جرعة منخفضة من الاشعة مقارنة بالبروتوكول المعياري، ومن ثم تحديد ما إذا كانت الصور تطابق معايير الجودة لصور الدماغ؛ إضافة الى تحديد المظهر التشخيصي للصور. بعد ذلك سيتم عمل مقارنة للصور الطبقية الأولية, والصور الطبقية بعد تطبيق لوجاريتم تحسين التباين, لتحديد أي منها يوفر صورة تشخيصية أفضل ، ولديه تطابق أفضل لمعيار الجودة لصور الدماغ ،باستخدام المعيار العددي (1: ضعيف ، 2: متوسط ، 3:مثالي) وتم استخدام هذه المعايير من قبل فنيي أشعه ذوي خبرة ، تم عمل الصورة الأولى باستخدام 22mGy، كانت النتيجة صورة غير تشخيصية وبحاجة لكمية اكبر من الاشعة لتقليل التشويش, تم رفع الجرعة المستخدمة الى 25mGy ثم 30mGy وأخيرا 33.8mGy عند هذه النقطة كانت الصور ملائمة لإكمال الدراسة, وبعد فحص الصور والتأكد من إمكانية استخدامها في التشخيص قام الباحث بإشراك أربعة أخصائيين أشعة لتحديد ما إذا كانت الصور تشخيصية باستخدام المعيار الرقمي (1:تشخيصي,2:غير تشخيصي) ، تم اتباع هذه الخطوات قبل وبعد تطبيق خوارزمية تحسين التباين. ثم تمت

مقارنة النتائج مع الدراسة المرجعية لصور الدماغ, كانت النتائج صور تشخيصية متوافقة مع معيار جودة صور الدماغ، يوفر البروتوكول المقترح من الدراسة تخفيضًا بنسبة 47٪ للجرعة الاشعاعية, مقارنة بالبروتوكول المرجعي الذي يستخدم 63 mGy. تم حل مشكلة التشويش عن طريق استخدام $iDose^4$ (الجيل الرابع من الأنظمة الهجينة, لبناء ومعالجة الصور) لتحسين جودة الصورة، وتمت زيادة سماكة المقطع إلى 5 ملليمتر (مم) من اجل تخفيض التشويش ، واستخدمت المقاطع المتداخلة من اجل التغلب على مشكلة الحجم الجزئي وزيادة عدد الشرائح المكتسبة.

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list of abbreviations

Abbreviation	Definition	Page
CT	Computed Tomography	II
$CTDI_{vol}$	volume computed tomography dose index	II
mGy	Milli-Gray	II
$iDose^4$	Fourth-generation hybrid iterative reconstruction algorithm introduced by Philips	III
mm	Millimeter	III
DRLs	Diagnostic Reference Levels	1
DNA	Deoxyribonucleic acid	2
ED	Effective Dose	2
CNR	Contrast to nois ratio	2
MDCT	Multidetector Computed Tomography	2
ALARA	As Low As Resonably achievable	3
mSv	millisieverts	5
mAs	Milliampere-seconds	7
Kvp	Peak Kilovoltage	10
s	seconds	11
SNR	Signal to Noise Ratio	11
DLP	Dose Length Product	18
CSF	Cerebrospinal sluid	20
DICOM	Digital Imaging and Communications in Medicine	27
PRCS	Palestinian red crescent society	28

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Chapter I
Introduction

1.1 Introduction

X-ray is high electromagnetic radiation energy. It was discovered by William Rontgen in 1895. It consists of ionizing X-ray photons, which can penetrate through the human body to provide images and can often be used instead of surgery, which was previously used for medical diagnosis, while diagnostic surgery was associated with a lot of pain and risks for patients, X-ray machines are widely used and developing continuously tell this day(1).

The number of CT scanners is dramatically increasing with continuous and wide improvements in quality, resolution, accuracy, and speed. Therefore, the number of CT examinations has increased with lots of patients being exposed to ionizing radiation (1).

CT scan is considered to be the highest contributor to the total population dose, with more than 60 million CT scans obtained in the US annually. In 2006, CTs were responsible for 70% of medical radiation exposure, the CT dose has potential future or lifetime cancer risks for the patient. Ionizing X-ray beams can cause DNA damage and mutations of cells, which then may grow to form tumors. Therefore, the dose from CT examinations has become a global public health issue (1).

The potential radiation risks on the human body are attributed to the absorbed dose levels in CT exams. Diagnostic Reference Levels (DRLs) and specific European Guidelines on quality criteria were established and distributed globally for CT-procedures, dose optimization and assessment. These guidelines aimed to ensure that all CT doses are within the acceptable ranges for each examination, which allows an estimation of the possibility of stochastic and deterministic effects of radiation exposure. Any increase in the absorbed dose will increase the potential changes in cell growth and DNA composition (cancer risk) by ionizing radiation. The effective Dose (ED): describe the amount of radiation received, the magnitude of ED is related to the stochastic radiation risks of cancer induction and the production of a genetic effect.

This study aims to reduce the patient dose, by introducing a low dose protocol, the amount of radiation less than the standard protocol for brain CT. Also, the study will determine the efficiency of two algorithms in improving the quality of brain CT, one of these algorithms improves SNR and the other improves the contrast to noise ratio (CNR).

1.2 Computed tomography

The intervention of computed tomography was in the 1970s. Its technology depends on an X-ray tube which rotates in a closed circle of detectors, connected to a computer to process and produce an image of all body tissues. It produces a high-quality radiograph better than X-ray in contrast resolution, and spatial resolution, and has the ability to cover a large area of the patient's body (1).

The development of multidetector computed tomography (MDCT) scanners lead to an increase in the number of clinical examinations of CTs for the diagnosis. However, MDCT, if not used correctly, may deliver high doses to patients without benefits and, therefore, a potential radiation hazard. So clinical justification and technical optimization are important to maintain the highest benefits and lowest risk ratio (2).

Computed tomography is the main cause of radiation exposure to patients. The significant probability accompanying with radiation risk estimates long delays between exposure to radiation and cancer manifestation, and the fact that carcinogenesis is proved by statistical inference rather than by direct observation tend to reduce the perceived urgency to reduce the radiation dose delivered by CT(3).

Head Organ dose from 64 slices multidetector computed tomography (MDCT) after applying 57.7 mGy $CTDI_{vol}$ was as follows: cranium, 25.7–34.7 mGy; brain, 23.4–37.8 mGy; lens, 25.1–50.3 mGy; mandible 1.7–4.8 mGy; and thyroid, 0.3–2.8 mGy (4).

1.3 Problem statement

Low dose CT is an important research done to reduce patient dose, to match ALARA (as low as reasonably achievable) principle, the biggest problem in CT when reducing radiation dose to the patient is the disturbance of image quality, due to reduction in the number of photons in each pixel.

1.4 Justifications

The ALARA principle concludes that all medical exposure for diagnostic purposes shall be as low as reasonably achievable. It is based on the radiation assurance recommendations of various international expert committees and organizations to form the cornerstone of radiation protection (3).

When lenses are exposed to radiation during brain (CT) exams, there is an important concern because this may lead to cataract formation. Recently, the estimations of the threshold dose are lower than what was previously thought. So avoiding unnecessary brain CT examinations or other ionizing radiation examinations is important for patient protection. Therefore, there are some methods to avoid or decrease lens radiation exposure (5). Also the Repeated brain CT is associated with the risk of cataract (6).

The radiation risk per brain CT exam equals to 1 cancer case per 11×10^{-3} Brain CT exam. So there needs to be an improvement in the Brain CT protocol and the training of medical imaging employees (7).

1.5 Study objectives

The main objective of this study is to protect the patient, and reduce patient dose by introducing new a protocol for brain CT, provide a diagnostic radiograph with a lower radiation dose to the patient. Also, the study aims to determine the efficiency of the brain post-processing algorithm and $iDose^4$ in improving the quality of brain CT.

2 Chapter II
Literature Review

2.1 Risks from Ionizing Radiation

The radiation doses from radiological examinations by means of computed tomography (CT) are usually in the range of 1–24 millisieverts (mSv) per CT examination for adults and 2–6.5 mSv for children. The effective doses of CTs are classified as low, although they are invariably larger than that observed, using conventional diagnostic radiology. The immediate question which comes to the mind is whether or not these low doses carry risks for the patient (3,8).

Deleterious health effects induced by ionizing radiation have conventionally been separated into two different categories: deterministic effects and stochastic effects. Exposures to high acute doses in excess of one or two grays may cause substantial levels of cell killing, which is expressed as organ and tissue damage and, soon after exposure, as deleterious clinical effects. These effects are called deterministic, and the dose-effect relationships exhibit a long threshold dose, with no observable effect, after which the effect increases in severity as the radiation dose increases. The possibility of deterministic health effects, such as radiation sickness, arising from low doses are used with computed tomography can be dismissed (3).

At lower doses, deleterious health effects such as cancer or hereditary disease which may take years to be revealed from can occur as a consequence of molecular damage to the nucleus of a single cell. These effects are called stochastic effects, and the probability for their occurrence increases as the dose increases, but the severity of the effect is unrelated to the dose (3). The possibility of ionizing radiation to induce cancer mostly occurs in a stochastic manner: here, there is no threshold point and the risk increases proportionally with the dose.

Deterministic effects occur if a threshold of exposure to radiation has been exceeded. The severity of this effect increases as the dose increases. Because of an identifiable threshold level, proper radiation protection and occupational exposure dose limits must be followed to reduce the possibility of these effects occurring. Deterministic effects are caused by cell damage or death. The physical effects occur when the cell death burden is large enough to cause obvious functional impairment of a tissue or organ (9).

The possibility of ionizing radiation to induce cancer is most likely to occur in a stochastic manner: here, there is no threshold point and the risk increases proportionally with the dose.

2.2 Previous study

Specific $CTDI_{-vol}$ has been used for specific CT examinations, $CTDI_{-vol}$ for different protocols, deferent CT manufacturer has different values of a milli-gray for the same CT exam (10).

Many comparative studies between low dose CT scan protocols and standard protocols that use 63mGy $CTDI_{vol}$ have been done. Some recent studies show that the radiation dose was given to patients in comparison to the diagnostic gain in the head, chest and body of

CT studies. All results from studies showed that it is possible to obtain diagnostic performance in a pathological case (11).

Sohaib et al. 2001 has a comparative study of four different imaging protocols which found out that the difference in the protocol was just in mAs (200, 250, 100, 50 mAs (milliampere second)). The study aimed at acquiring a perfect normal anatomical detail of bone and sinuses components. The authors concluded that the normal anatomy of the facial bones can be seen with a significant reduction in the radiation dose (50 mAs) (12).

Cohnen et al. 2000 concluded that when a dose reduction of 40% is acquired by lowering mAs, and kVp (kilovoltage peak), it will produce a diagnostic brain image similar to those of the standard technique; (13) however, any decrease in the radiation dose would lead to a disturbance in SNR. This problem can be solved by increasing slice thickness to improve the SNR; 5mm is adopted in brain CT. Also, iterative reconstruction allows for a 30% dose reduction.

In some selected cases of the study; Low-Dose Brain CT Sensitivity: A Comparative Study with a Conventional Technique, Aprile et al. 2012 aimed at determining whether the low-dose protocol can be used instead of a standard protocol. Patients with 51 brain lesions had an image with both protocols. Compared with the standard protocol, the low-dose protocol was edited with a mAs reduction by 25%. Even if images have a poor SNR, the low-dose protocol that visualized all the lesions was shown by the standard protocol except for three chronic vascular lacunar infarcts. The study concluded that the low dose protocol can be used instead of the standard CT scans. Table 1 shows that all selected pathological cases were detected by low dose protocols except three Chronic lacunar strokes. (11).

Table 1: Lesions studied both with conventional and low-dose CT techniques (11).

Type of lesion	Lesions detected with conventional CT scan	Lesions detected with the low-dose CT technique
Chronic lacunar stroke	8	5
Acute ischaemic stroke	5	5
Subacute ischaemic stroke	6	6
Hemorrhagic stroke	1	1
Porencephalic cyst	4	4
Subarachnoid haemorrhage	2	2
Parenchymal haemorrhage	4	4
Subdural haematoma	3	3
Subdural hygroma	2	2
Epidural haematoma	1	1
Cerebral contusion	2	2
Metastasis	6	6
Intra-axial tumour	3	3
Extra-axial tumour	4	4

The study results show that low dose brain CT can detect all lesions, as conventional protocol, but its sensitivity is less in lacunar stroke, and standard Brain CT is not the true choice for ischemic infarction detection, the best CT protocol to detect ischemic infarction is CT perfusion. Figure 1 shows that chronic lacunar infarction is detected by the standard protocol, and is missed by the low dose protocol which has a reduced mAs by 25% (14).

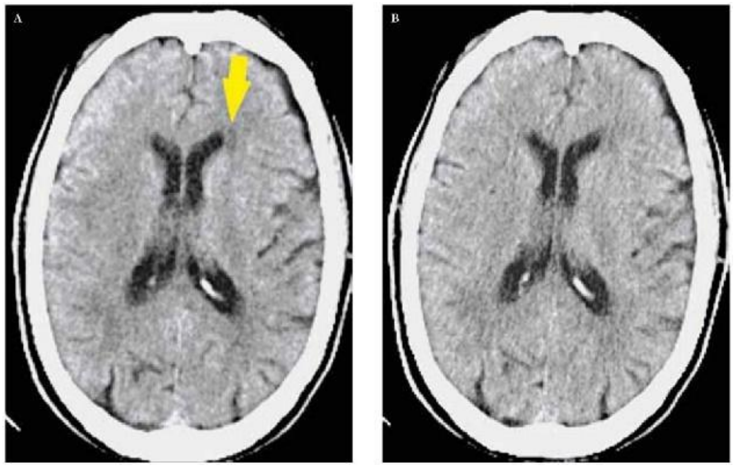

Figure 1: standard (A) and low dose (B) CT scans. Chronic lacunar infarct (yellow arrow): the lesion is well seen only with the standard technique (A) (11).

2.3 A standard protocol for brain CT

The reference study for brain CT published by Calzado. Et all 2000, determined the standard protocol for brain CT which used 63mGy $CTDI_{vol}$, this protocol is ensured by other studies, performed by the likes of Hatzhoannou. Et all 2003(15). It is also determined by the European guideline for quality criteria of brain CT (16). The standard protocol from different manufacturers comes to be around 63mGy $CTDI_{vol}$, and the used CT scanner uses 65mGy $CTDI_{vol}$ as the standard protocol for brain CT.

3 Chapter III
CT Scan Parameters

3.1 Peak Kilovoltage Kvp

CT scanners allow the radiographer to edit the tube voltage. These are referred to as kilovolt peak, or (kVp), settings. This parameter does not change the contrast in CT as directly as it does in film-screen radiography. Compared with mA selection, choices of kVp are more limited. Increasing the kVp beam's ability to penetrate a thick section. Usually, Routine body CTs for adult patients is done with 120 to 140 kVP (17).

The proper selection of mAs and kVp is critical to optimize image quality and reduce patient dose. The mAs reduction while fixing the kVp reduces the radiation dose of the patient. The radiation dose of the patient also decreases if kVp is reduced while the mAs is fixed. However, lowering the kVp results in a dramatic increase in an attenuated X-ray to the patient, consequently the X-ray photons will be weak and unable to penetrate through the patient (17).

The best common practice to reduce the mAs, rather than the kVp, when editing the radiation dose is displayed in two choices. First, the choice of mA is more flexible, with available settings ranging from 20 to 800 mA. Also the practical advantage of editing the mA instead of kVp is that its effect on image quality is more straightforward and can be predictable (17).

3.2 Milliampere-Seconds mAs

It consists of two parameters milliamperes (mA) and time (s) and becomes milliampere-second (mAs). Increasing the product of tube current and scan time (mAs) leads to an increased SNR, decreased image noise, and increased patient exposure. In general, the relationship between tube current and patient dose is essentially linear, with increases in mAs resulting in an increase in patient dose. In this study, the low dose protocol depends on mAs reduction, and the disturbance in SNR will be compensated by increasing slice thickness from 3mm to 5mm, adopted in brain CT (18).

3.3 Reconstruction slice thickness

Increasing the slice thickness improves the signal to noise ratio due to an increase in the number of photons for each voxel, and disturbs spatial resolution, as appeared in left side image in figure 2, and reduces reconstruction slice thickness. Improved spatial resolution, a cause of disturbance in signal to noise ratio due to less numbers of photons in each voxel, as appeared in the right side image in figure 2, so there should be a tradeoff in slice thickness in order to get the best SNR, spatial resolution, and a less radiation dose to the patient.

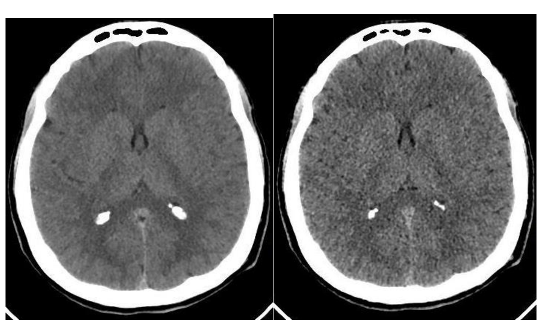

Figure 2: On the left is an image by reconstruction slice thickness 5mm, and on the right is an image by 1.25 mm.

3.4 Increment

Helical data allows the slice incrementation to be changed, retrospectively. This allows the creation of overlapping slices, without increasing the radiation dose. In some situations, reducing the slice incrementation can reduce the partial volume effect. There are three types of increment, contiguous, which exhibits a slice beside another without any gap between them, overlap exhibits slice to overlap with another slice, and a gap that relieves a gap between slices, and this method is not preferred. The most used contiguous which provides a less number of a slice, and less used disk space on a computer, overlap provides a double number of slices and needs more disk space, this type has been used in our new protocol, figure 3 shows slices shaped according to the selected increment (17).

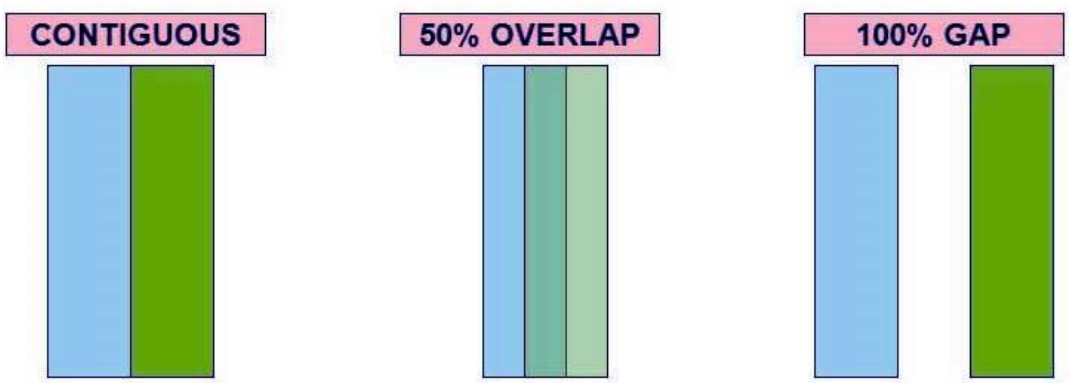

Figure 3: increment type and slices shape in CT.

3.5 Pitch

It is a CT scan parameter that describes table movement speed. It is equal to slice thickness, which is divided by table movement per X-ray tube rotation 360^{o}. When the table movement equals slice thickness, the pitch will be equal to one and no gap in data will appear. However, when the pitch is less than one, it will not be a preferred high dose and slices will overlap. When the pitch is more than one, it is also not preferred as less radiation, but the gap in the data would affect the quality of the image. The new pitch definition is as follows: pitch = (table movement per rotation/(n · T)) where n: number of detectors, T: detector thickness.

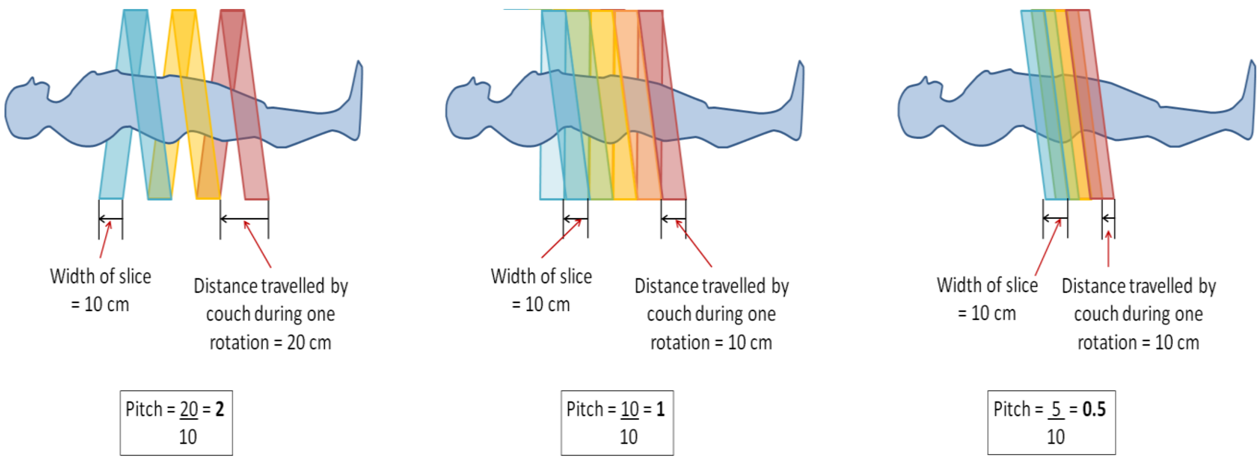

Figure 4: Deferent pitches describe deferent shape slices.

3.6 Reconstruction Algorithms

Different CT scanners use different reconstruction algorithms (filter, or kernel) depending on the manufacturer (17). Each of these algorithms allows a range of radiation dose reduction, the optimal protocol uses an optimal filter with a less radiation dose depending on the tissue type. The widely used iterative reconstruction algorithm which, uses an ideal image and repeatedly compares the resulting image with ideal image, improves image quality and allows for more radiation dose reduction that may reach 30% (18). The statistical iterative reconstruction provides better image quality than the filter back projection technique (19). The CT scanner used in this study contains three filters shown in figure 5 for brain CT imaging: Brain smooth filter, Brain standard filter that is used in the study, and Brain sharp filter.

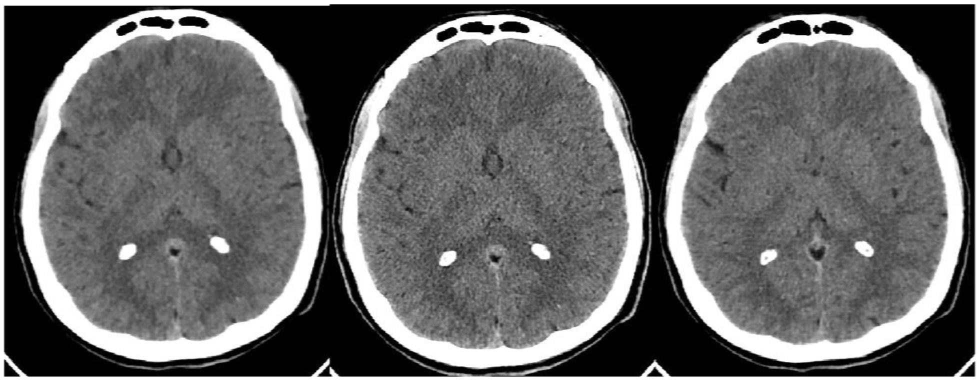

Figure 5: Philips ingenuity 64 slice reconstruction filters: On the Left smooth filter, in the middle sharp filter, on the right standard filter used by the study.

3.7 Window Level

The window level or window center determines the center point of the window Width. The terms for the window center and window level are often used interchangeably. The window level selects which CT numbers are viewed on the image, and an increase in the window center leads to a reduction in brightness and vice versa, the typical center for brain CT is 40 (17).

3.8 Window Width

The window width determines the number of CT numbers displayed on a specific image. The viewer software specifies shades of gray to CT numbers that are within the range selected. Any values higher than the range would appear bright, and any value less than the range would appear dark. Increasing the width will reduce contrast while reducing width would increase image contrast, the typical width for brain CT is 80 (17).

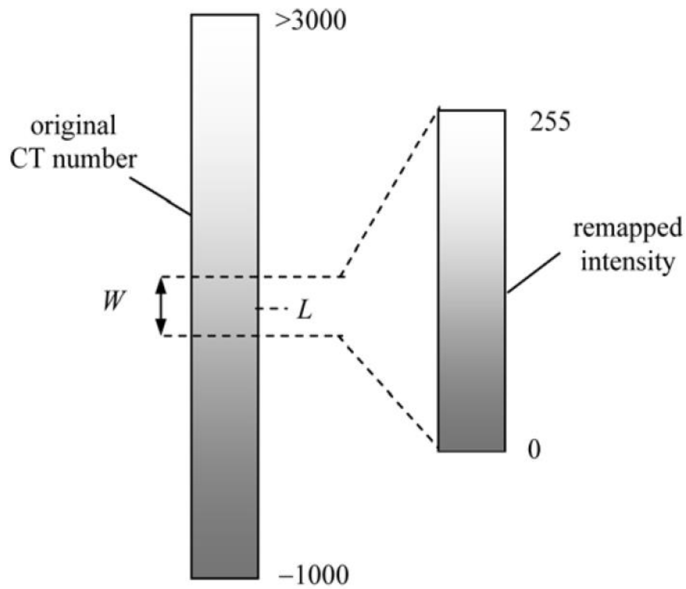

Figure 6: Window level, window center (17).

3.9 Helical (Spiral) Scanning

Many recent technical developments allowed the introduction of a continuous acquisition scanning most often called helical or spiral scan. This type of scan, which allows continuous table movement and continuous X-ray tube rotation, would lead to less scan time and less radiation dose for the patient (17). So, the introduced low dose protocol by the study has been used.

3.10 Axial scan method

An axial acquisition, where the slice increment per X-ray tube rotation is selected by the number of slices acquired. If the increment equals thickness, slices are contiguous. If the increment is less than slice thickness, slices overlap (17). The next figure shows the difference in the data shape according to acquisition type.

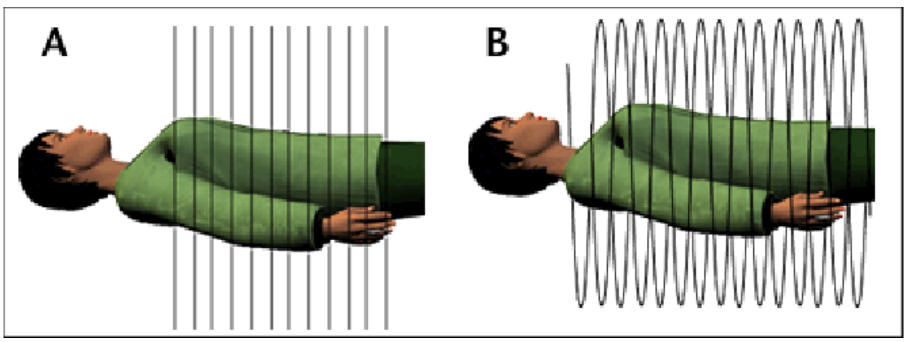

Figure 7: acquisition type in CT, A: axial, B:spiral (20)

3.11 Dose modulation

This technique automatically increases the mAs in the body part with the greatest attenuation and decreases mAs in the body part with lower attenuation. Depending on the amount of attenuation on the scout image as shown in figure 8, the automated tube current modulation can be selectively used or canceled from CT protocol, mostly this technique lowers the patient's dose, and reduces the photon starvation artifact (17). In Philips CT scanners, its name, Dose-Right index and it is used in standard CT scanner protocols for brain CT, but when it comes to brain CT, it is preferred to be turned off in Brain CT protocol(10). Later on, in chapter 6 the importance of turning dose modulation while imaging the Brain will be discussed.

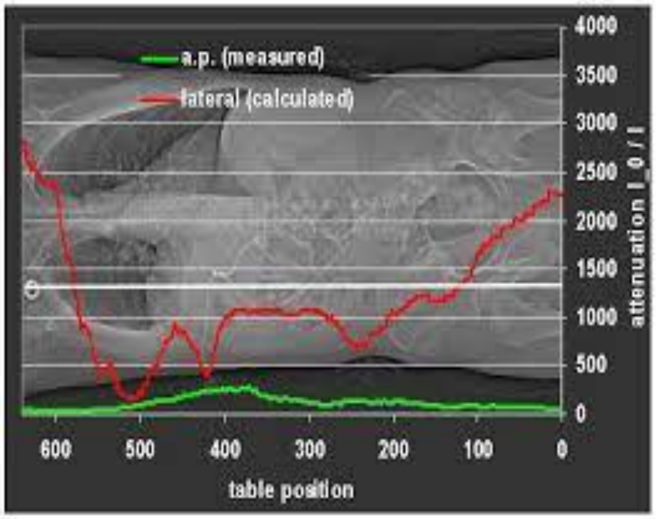

Figure 8: Dose modulation curve, radiation dose increased, or reduced according to the amount of attenuation in the scout image.

3.12 Rotation Time

Gantry rotation time describes the required time for the X-ray tube to rotate 360°. It affects patient radiation dose because the less the rotation time, the less radiation dose is given to patients, in this study the rotation time is 4s per 360° (3). Reducing rotation time leads to a reduction in the scan time and an elimination in the motion artifact, and however increases streak artifact and image noise (21).

3.13 Scan angle

While the tube rotates around the patient, X-ray passes through the patient's body and carries information for the image, any slice would usually need 360° for a complete data collection. Some scan protocol suggests 180° scan angle, which provides images with less resolution, but it is still diagnostic and acceptable for some CT exams.

3.14 $CTDI_{vol}$ & DLP:

The patient's actual absorbed dose in CT is hard to be measured, but CT scanner manufacturer is used to describe the output of the scanner for each image by $CTDI_{vol}$, and dose length product (DLP) which is measured by milli-gray centimeter (mGy*cm), and $CTDI_{vol}$ which, depends on Kvp, mAs, and pitch. In CT scanners, usually specific $CTDI_{vol}$ value used for specific examination. The standard protocol in the used CT scanner by this study uses 65 mGy $CTDI_{vol}$ for brain CT but the use of dose modulation increases it in some exams and decreases it in others. $CTDI_{vol}$ multiplied by scan length equal to DLP, the scan length differs from one patient to another due to different body habitus, so $CTDI_{vol}$ is equal for all patients when imaging the same body part (without the use of dose modulation) while the DLP has a different value for each patient (22).

3.15 Brain CT protocol:

Brain CT protocol for adults can be performed with a slice thickness of 5mm, standard brain filter, 300 mAs, 120_140 Kvp, and the acquisition may be axial or helical, but the helical needs a less radiation dose than axial (10,23,24)

3.16 Quality Criteria for Brain CT

Calzado, et al. 2000 determined 5 points for image quality without contrast, adapted by the European Guidelines on Image quality criteria for CT, and determined as a reference study for brain CT, as well as the standard protocol determined in this study. The next points and figures (9_14) describe brain CT criteria, introduced by the reference study (25).

1. Visually sharp reproduction of the border between white and grey matter.

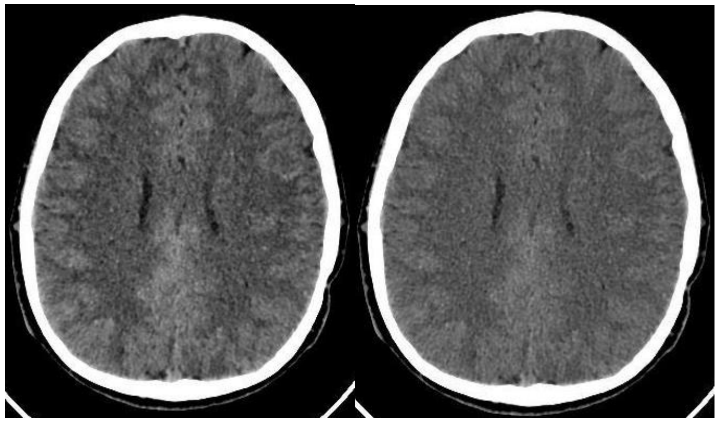

Figure 9: The left-hand side with the brain processing algorithm, the right-hand side without it, this image shows a clear difference between white and gray matter, but the brain processing algorithm increases the deference in a clear way.

2. Visually sharp reproduction of the basal ganglia.

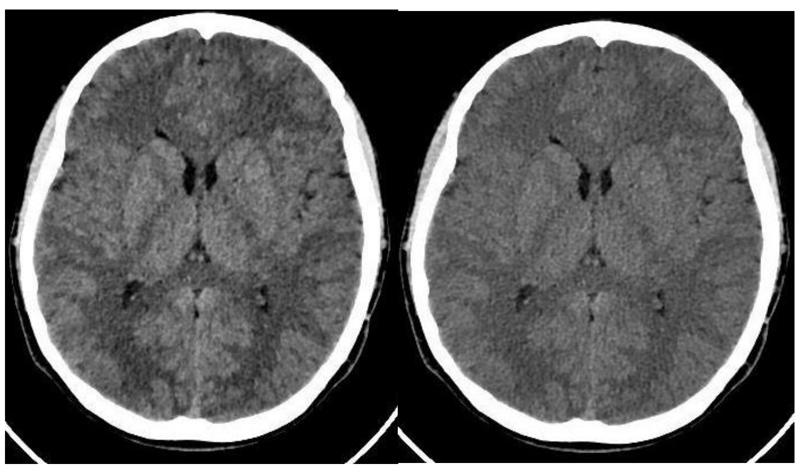

Figure 10: The left-hand side with the brain processing algorithm the right-hand side without it, here, the caudate nucleus is shown clearly, and more clearly with a brain processing algorithm.

3. Visually sharp reproduction of the ventricular system.

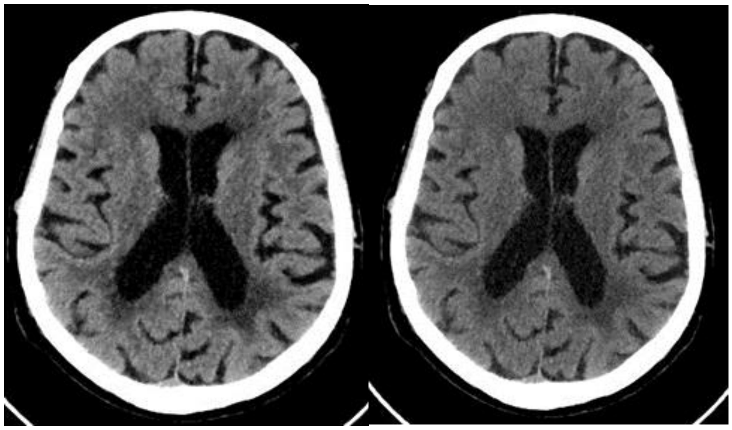

Figure 11: The left-hand side with the brain processing algorithm, the right-hand side without it, both lateral ventricles will visualized, more obvious with the algorithm.

4. Visually sharp reproduction of the cerebrospinal fluid space around the mesencephalon.

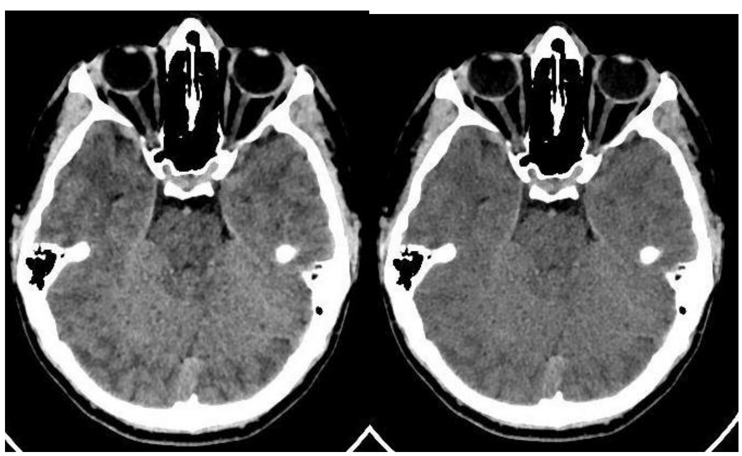

Figure 12: The left-hand side with the brain processing algorithm, the right-hand side without it, cerebrospinal fluid (CSF) around mesencephalon will be visualized, more obvious with the algorithm.

5. Visually sharp reproduction of the cerebrospinal fluid space over the brain.

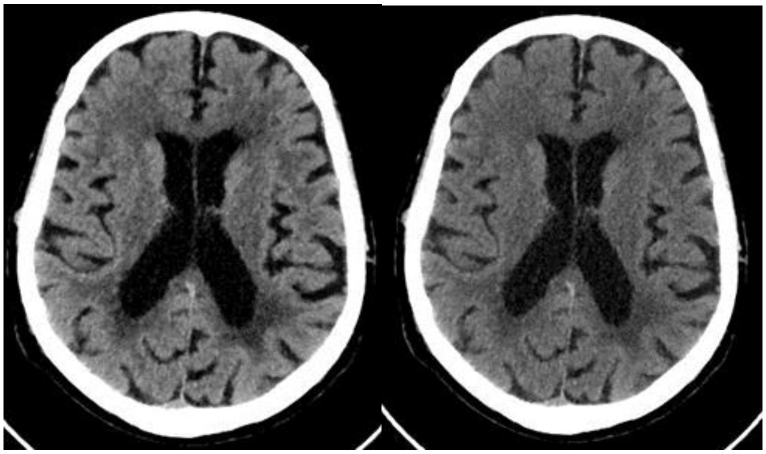

Figure 13: The left-hand side with the brain processing algorithm, the right-hand side without it, CSF over the brain will be visualized in both, more with the algorithm.

3.17 Brain post-processing algorithm (CNR improvement algorithm)

A new software icon is used by Philips to enhance the contrast of brain tissue. The improved brain contrast function allows medical imaging technologist or radiologist to select one of three levels of contrast enhancement: soft, medium, and strong (26). Figure 14 brain post-processing icon and figure 15 show this as follows.

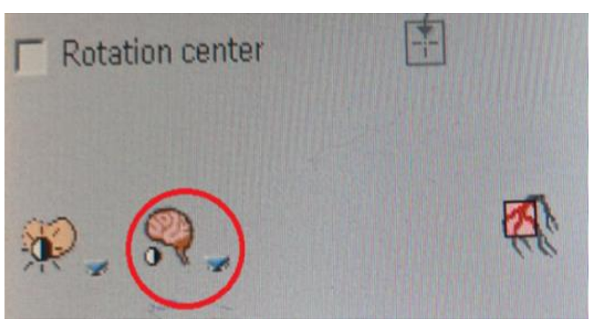

Figure 14: Brain processing algorithm icon circulated by a red line

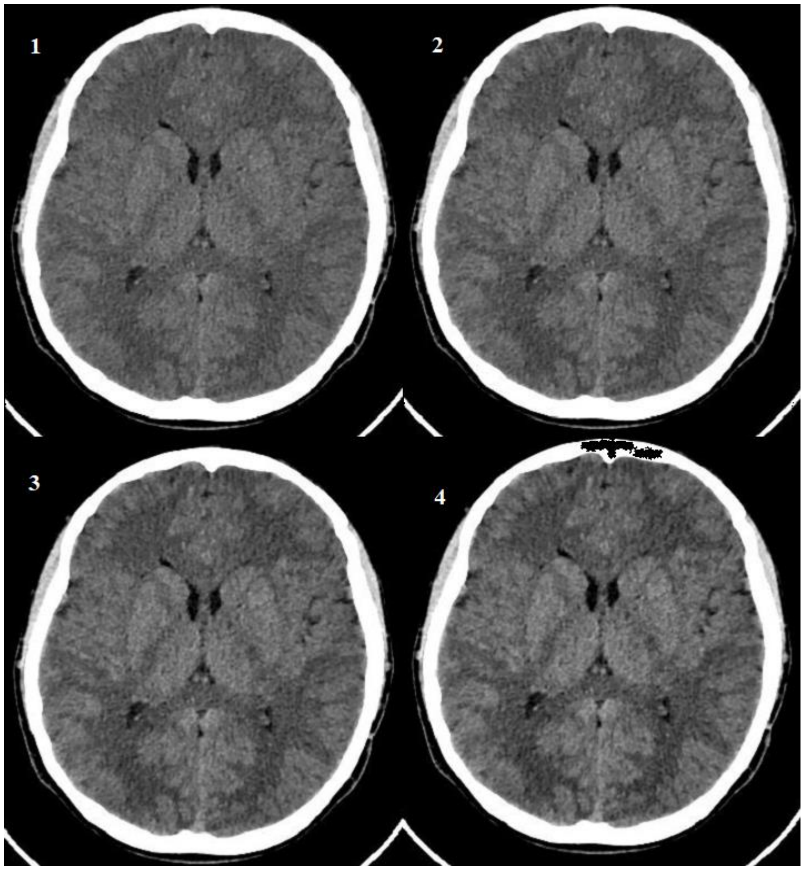

Figure 15: The first image is the source image, the second image used the algorithm at a soft level, the third image used a medium level and the fourth used a strong level.

3.18 iDose^4 (SNR improvement algorithm)

Fourth-generation hybrid iterative reconstruction algorithm introduced by Philips, this CT scan parameter can be turned off or on. This new technique provides a genius solution for SNR improvement in which iterative processing is performed in both the image domains and projection. The first filtering performed for projection data, where it performs correction for the noisiest CT measurements. Through an iterative diffusion process, the noisy data is canceled without edge disturbances. The second filtering of the iDose^4 deals with a subtraction of the CT image noise while saving the edges associated with anatomy and pathology. Following this, an operator chooses among seven levels of idose[4] the seventh level allows for more dose reduction and a more clear CT image (27) iDose[4] provides a significant increase in the image quality with a lower radiation dose to patients. The older reconstruction techniques were reducing artifacts, but idose[4] prevents it completely as shown in figure 16, and provides better spatial resolution (28).

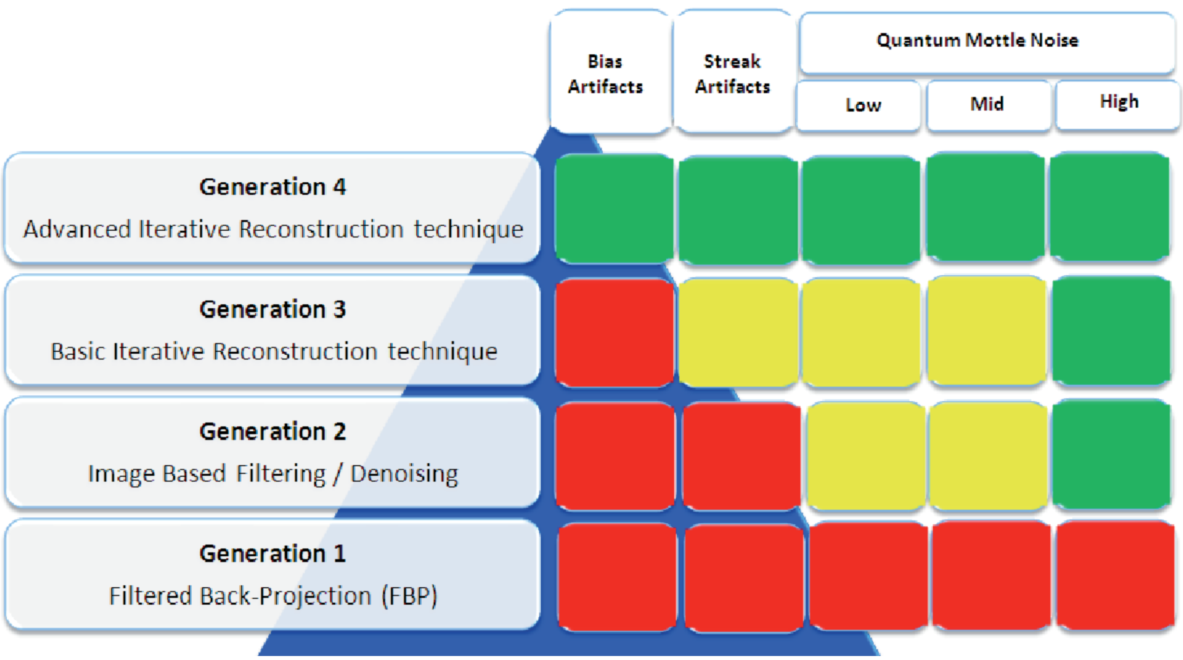

Figure 16: Comparison between the different generations of the reconstruction algorithm (red: poor, yellow: mediocre, green: better) (28).

3.18.1 Idose[4] and Dose Reduction

Idose[4] allows for radiation dose reduction up to 80% in some CT examinations, while saving the quality and the diagnostic appearance of the images, and allows acquiring better images from a lower radiation dose as shown in figure 17 (28).

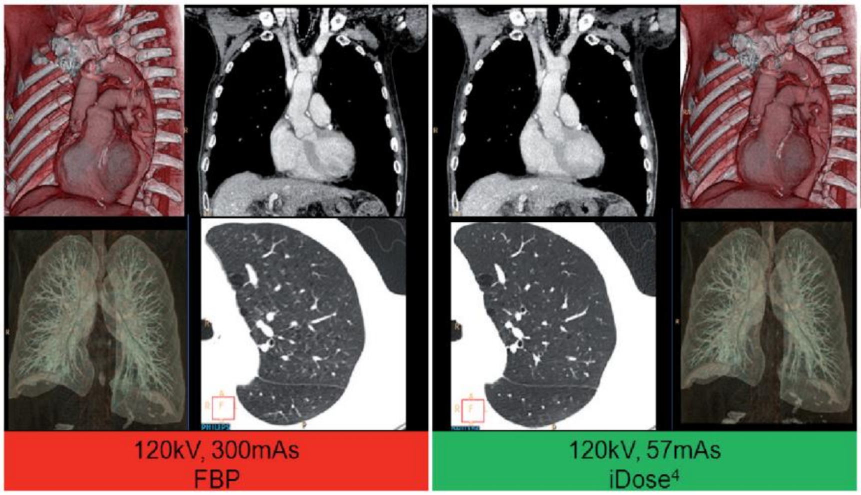

Figure 17: comparison between filter back projection and iDose^4, here we can notice that iDose^4 provides better images using ultra low dose protocol (28).

3.18.2 IDose^4 and spatial resolution

IDose^4 can improve spatial resolution and contrast resolution of all CT examinations, without disturbance in signal to noise ratio as shown in figure 18. Phantom study shows that iDose^4 can improve spatial resolution by up to 68% (28).

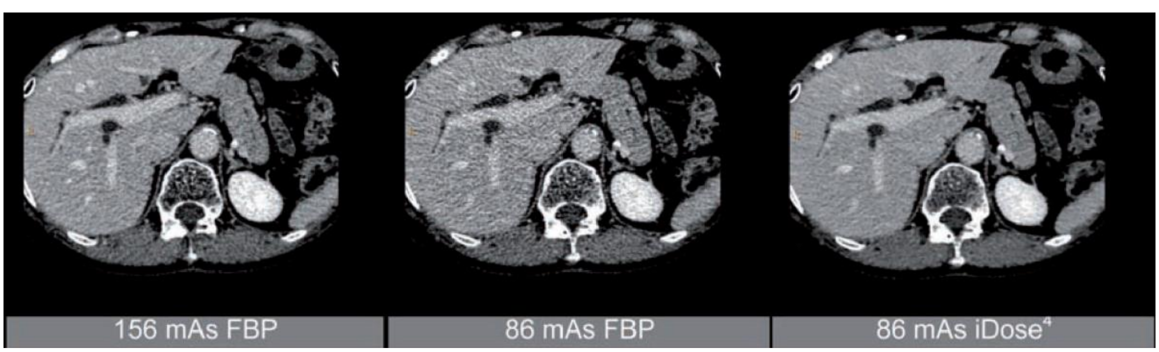

Figure 18: iDose^4 provides better images with a lower radiation dose (28).

4 Chapter IV
Methodology

4.1 Materials and Methods

Philips ingenuity CT scanner 64 slices were used in the study. The study used 22 mGy CTDIvol, which did not provide diagnostic Brain CT, the image was noisy to such a degree that radiation dose increased to reduce the noise. The next Brain CT which was performed with 25 CTDIvol has also shown unacceptable results, then with 30 CTDIvol, the results were near the acceptable Brain CT but still needing slight improvements. After that, the researchers edited the protocol to 33.8 CTDIvol, which gave diagnostic images, two images were used for each patient, the source image, and the image after the application of the Brain post-processing algorithm. To determine the quality of the images, four radiologists participated to determine the diagnostic appearance, and six medical imaging technological experts participated to determine the quality criteria match test.

4.2 The problem of signal reduction

Signal reduction leads to an increase in image noise, this problem is solved by applying iDose^4 at level 5, slice thickness increased to 5mm. The reduction in Dose was in mAs, because Kvp reduction causes more signal reduction than mAs reduction and the used acquisition type is spiral because it needs less radiation than axial (17).

4.3 Applying Brain Post Processing algorithm

In this study, the strong level of contrast enhancement is used to provide more contrast resolution, and it is used in the original setting from the manufacturer. Sometimes, the soft and medium levels do not produce a significant difference in the image. In this study, the researchers will measure the diagnostic appearance of this algorithm, and how it affects the quality criteria.

4.4 Study population

The study population includes all patients to be adults with ages ranging from 18 to 80 years, who were requested to perform sinuses CT with the use of a low dose protocol.

4.5 Study sample

The study suggested a sample size of 35 adult patients. It was requested that they do a sinuses CT with the use of a low dose protocol.

4.6 Inclusion and exclusion criteria

All adult patients were asked to perform a sinuses CT, except pregnant patients, claustrophobic patients, and patients who refused to agree to the patient consent form.

4.7 Study instruments

CT Philips ingenuity 64 slice, uses the fourth-generation hybrid iterative reconstruction algorithm. A new low dose protocol will be introduced to the CT scanner, described in Table 2 in comparison with the standard protocol. Other computer software's has been used; Microsoft Excel, SPSS, and radiant DICOM viewer.

Table 2: hospital protocol, and our suggested protocol.

Protocol	Current axial protocol	Low dose protocol
Kvp	120	140
mAs	380	180
Thickness	2.5	5mm
Increment	10	2.5mm
Pitch		.297
Filter	Brain standard	Brain standard
Center	40	40
Width	80	80
Acquisition type	Axial	Helical
Dose modulation	yes	no
Rotation time	.75	.4s

4.8 Patient file

Data about the Patient's age and, DLP, $CTDI_{vol}$, Brain CT, Four radiologist reports were extracted from the patient files for each participant in the study, as well as the date of the study.

4.9 Ethical approval

- The study proposal was submitted to Al-Quds University - Faculty of Graduate studies review board to obtain approval and permission to conduct the study. The approval was achieved in 5/1/2019
- The patient who was shared in the study accepted sharing his medical information.

4.10 Statistical test

Simple descriptive statistical tools like percentages and means were used to compare the data. The statistical t-test (29) was done between a low dose protocol, and a standard protocol to ensure that the protocol provides the diagnostic appearance and that the images match the quality criteria for brain CT.

4.11 Quality criteria for brain CT

In this study, six expert medical imaging technologists participated to determine if the resulted image matches the quality criteria of the reference study. Here, the researchers used this scale (1: weak, 2: moderate, 3: perfect). Then, they calculated the percentage of examinations for which the criteria were fulfilled from all medical imaging technologists' assessment. Here, the researchers compared two images, one with a brain post-processing algorithm, and the other without it.

4.12 Measuring Criteria for Image Quality

Three tests were used to compare two samples: the low dose protocol sample, and standard protocol sample.

- Four radiologists participated to determine if the resulted images are diagnostic and to compare between the processed CT images using a brain algorithm, and the source image. Here, the used numerical criterion is (1: diagnostic, 2: not diagnostic). After that, the researchers calculated the percentage of examinations for which the criteria were fulfilled. The diagnostic appearance of the standard protocol, which has a 100% fulfilled diagnostic appearance for the four radiologists who participated in the study, which was used as a reference in the statistical test.
- Six expert medical imaging technologists participated to determine if the source brain CT matches the quality criteria for brain CT by the numerical criterion (1: weak, 2: moderate, 3: perfect). Then, the researchers calculated the percentage of examinations for which the numerical value of the diagnostic appearance was

fulfilled. The study published by (Calzado et al.2000) was used as a reference for the quality criteria in statistical tests.

- A statistical test between CTDIvol, DLP (dose length product) for the standard protocols and the introduced protocol by the study was also used.

5 Chapter V
Results And Discussion

5.1 Results for diagnostic appearance

The first result for low dose CT was not acceptable for diagnosis. As described in Table 3. However, the 30mGy $CTDI_{vol}$ was near the acceptable brain CT. Then, the $CTDI_{vol}$ has been raised to 33.8 mGy, which provides a diagnostic image, so the study continues with the sample size of 35 patients. Figure 19 shows the first result for the low dose protocols, the less the radiation dose the noisier the image as shown in the left-hand side image, the image is noisy more than the right-hand side image, due to lesser radiation dose.

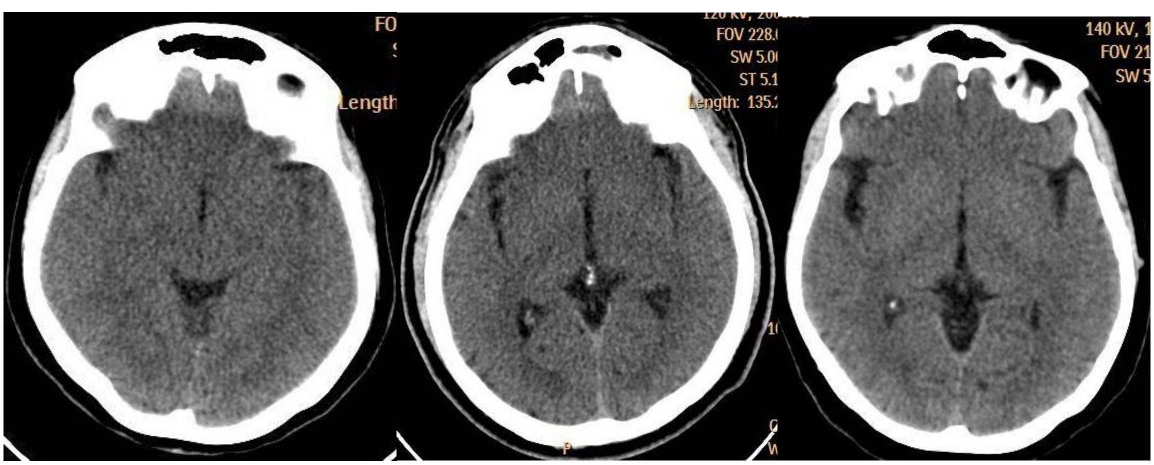

Figure 19: The left-hand side brain CT with 22 mGy CTDIvol, the middle image 25 mGy CTDIvol, and the right-hand side image 30 mGy CTDIvol.

Table 3: first low dose sample result

Patient no	**DLP**	**$CTDI_{vol}$**	**result**
Patient 1	485.1	22	Not diagnostic
Patient 2	497.4	25	Not diagnostic
Patient 3	596.1	30	Not diagnostic

The first result after ending patient radiography was, not fully diagnostic and still needed more improvement. Here, the protocol edited to provide 33.8 $CTDI_{vol}$ which provides a diagnostic radiograph, as shown in figure 20. Here, the reader should notice that the increase in $CTDI_{vol}$ was in accordance with the amount of noise in the image as determined by the researcher. Then, patient imaging continued for the 35 patients, the reconstruction for each radiograph included saving a new radiograph after applying a post-processing algorithm to use later in the comparative study. The result for diagnostic appearance which was determined by the four radiologists is described in table 4.

Figure 20: brain CT with 33.8 CTDI, provide diagnostic appearance.

Table 4: 33.8 $CTDI_{vol}$ protocol results for a diagnostic appearance from four radiologists, here 1 mean diagnostic, 2 mean not diagnostic.

PATIENT	Radiologist 1	Radiologist 2	Radiologist 3	Radiologist 4
1	**1**	**1**	**1**	**1**
2	**1**	**1**	**1**	**1**
3	**1**	**1**	**1**	**1**
4	**1**	**1**	**1**	**1**
5	**1**	**1**	**1**	**1**
6	**1**	**1**	**1**	**1**
7	**1**	**1**	**1**	**1**
8	**1**	**1**	**1**	**1**
9	**1**	**1**	**1**	**1**
10	**1**	**1**	**1**	**1**
11	**1**	**1**	**1**	**1**
12	**1**	**1**	**1**	**1**
13	**1**	**1**	**1**	**1**
14	**1**	**1**	**1**	**1**
15	**1**	**1**	**1**	**1**
16	**1**	**1**	**1**	**1**
17	**1**	**1**	**1**	**1**
18	**1**	**1**	**1**	**1**
19	**1**	**1**	**1**	**1**
20	**1**	**1**	**1**	**1**
21	**1**	**1**	**1**	**1**
22	**1**	**1**	**1**	**1**
23	**1**	**1**	**1**	**1**
24	**1**	**1**	**1**	**2**
25	**1**	**1**	**1**	**1**
26	**1**	**1**	**1**	**1**
27	**1**	**1**	**1**	**1**
28	**1**	**1**	**1**	**1**
29	**1**	**1**	**1**	**1**
30	**1**	**1**	**1**	**1**
31	**1**	**1**	**1**	**1**
32	**1**	**1**	**1**	**1**
33	**1**	**1**	**1**	**1**
34	**1**	**1**	**1**	**1**
35	**1**	**1**	**1**	**1**

5.2 Results for the diagnostic appearance after applying Brain processing algorithm

The study performed a comparison between two radiographs for the same patient, one with a post-processing algorithm and the other radiograph without it, Table 5 shows the result for the diagnostic appearance after applying brain post-processing algorithm.

Table 5: results from four radiologists for the diagnostic appearance after applying a brain post-processing algorithm, here, 1 means diagnostic, 2 means not diagnostic.

PATIENT No	Radiologist 1	Radiologist 2	Radiologist 3	Radiologist 4
1	**1**	**2**	**2**	**2**
2	**1**	**2**	**2**	**2**
3	**1**	**2**	**2**	**2**
4	**1**	**2**	**2**	**2**
5	**1**	**2**	**2**	**1**
6	**1**	**2**	**2**	**2**
7	**1**	**2**	**2**	**2**
8	**1**	**2**	**2**	**1**
9	**1**	**2**	**2**	**2**
10	**1**	**2**	**2**	**2**
11	**1**	**2**	**2**	**2**
12	**1**	**2**	**2**	**2**
13	**1**	**2**	**2**	**2**
14	**1**	**2**	**2**	**2**
15	**1**	**2**	**2**	**2**
16	**1**	**2**	**2**	**2**
17	**1**	**2**	**2**	**2**
18	**1**	**2**	**2**	**2**
19	**1**	**2**	**2**	**1**
20	**1**	**2**	**2**	**2**
21	**1**	**2**	**2**	**1**
22	**1**	**2**	**2**	**1**
23	**1**	**2**	**2**	**2**
24	**1**	**2**	**2**	**2**
25	**1**	**2**	**2**	**2**
26	**1**	**2**	**2**	**2**
27	**1**	**2**	**2**	**2**
28	**1**	**2**	**2**	**2**
29	**1**	**2**	**2**	**2**

Continue from Table 5

30	**1**	**2**	**2**	**2**
31	**1**	**2**	**2**	**2**
32	**1**	**2**	**2**	**2**
33	**1**	**2**	**2**	**2**
34	**1**	**2**	**2**	**2**
35	**1**	**2**	**2**	**2**

5.3 Diagnostic appearance

Assessments for diagnostic appearance are represented in Figure 27. Its clear low dose protocol provides diagnostic images, but after applying a brain post-processing algorithm the images become mostly not diagnostic, in the Y-axis which represents the mean for assessments from four radiologists, number 1 is the main diagnostic, and number 2 main not diagnostic. The Statistical t-test ($P<5\%$), shows that the low dose Brain CT provides a diagnostic appearance for the radiologists who have a share in the study, after applying the algorithm, there are disturbances in the diagnostic appearance in the processed Brain CT. Here, we should know that the question for radiologists is whether or not they can use the radiograph after applying the algorithm without the source radiograph.

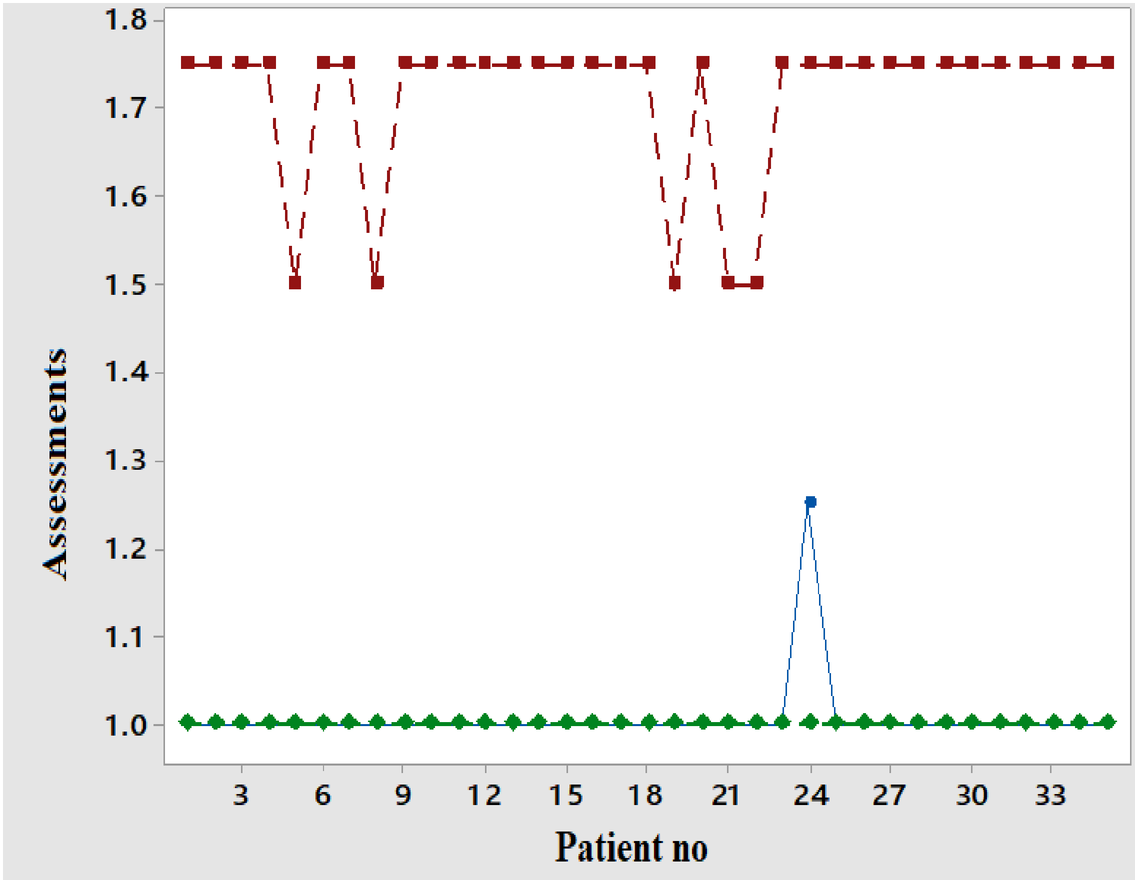

Figure 21: the result for diagnostic appearance compared with the standard protocol (green line), the blue line superimposed with the green line represents the low dose protocol without an algorithm, both are closed to number 1 which mean that the radiograph is diagnostic, just one radiograph in a low dose protocol, its average from four radiologist of 1.3, and this doesn't produce a significant difference at (P<5%) each point in the figure represents the average for diagnostic appearance from four radiologists, number 1 means that the diagnostic and the closed line attached to it means that the radiograph provides diagnostic appearance, number 2 means that the radiograph, not the diagnostic appears with the red line near the number 2, so the radiograph is mostly not diagnostic, for the radiologists who share this study.

5.4 Results for Quality criteria for brain CT

In this study, six expert medical imaging technologists participated to determine if the resulting image matches the quality criteria scale. Here, the researchers used this scale (1: weak, 2: moderate, 3: perfect), Table 6 shows the result for quality criteria, and as shown, low dose protocol provides images a match quality criteria for brain CT.

Table 6: displays expert radiographers assessment results for low dose brain CT Criteria, the first row represents the results from a low dose protocol, the second row represents the results after applying the brain post-processing algorithm, which has a greater value than the low dose protocol, the third row represents Ibrahim et al. 2016 study which has better results than the reference study, and the fourth row represents the reference study.

Protocol	criteria 1	criteria 2	criteria 3	criteria 4	criteria 5	Mean
Without algorithm	84%	91%	99%	88%	92%	91%
With algorithm	96%	93%	98%	93%	96%	95%
(Ibrahim et al. 2016)	80%	68%	96%	78%	89%	82%
(Calzado et al.2000) The reference study	30%	20%	100%	90%	90%	66%

5.5 Statistical test for quality criteria Brain CT

The results from the quality criteria assessment. Here, the researchers used this scale (1: weak, 2: moderate, 3: perfect). Then, they calculated the percentage of examinations for which criteria were fulfilled from all the medical imaging technologists' assessments. Here, the researchers compared two images, one with a brain post-processing algorithm (the red line), and the other without the application of this algorithm (the blue line). As shown in figure 21, the brain post-processing algorithm has a better match for quality criteria, determined by the reference study.

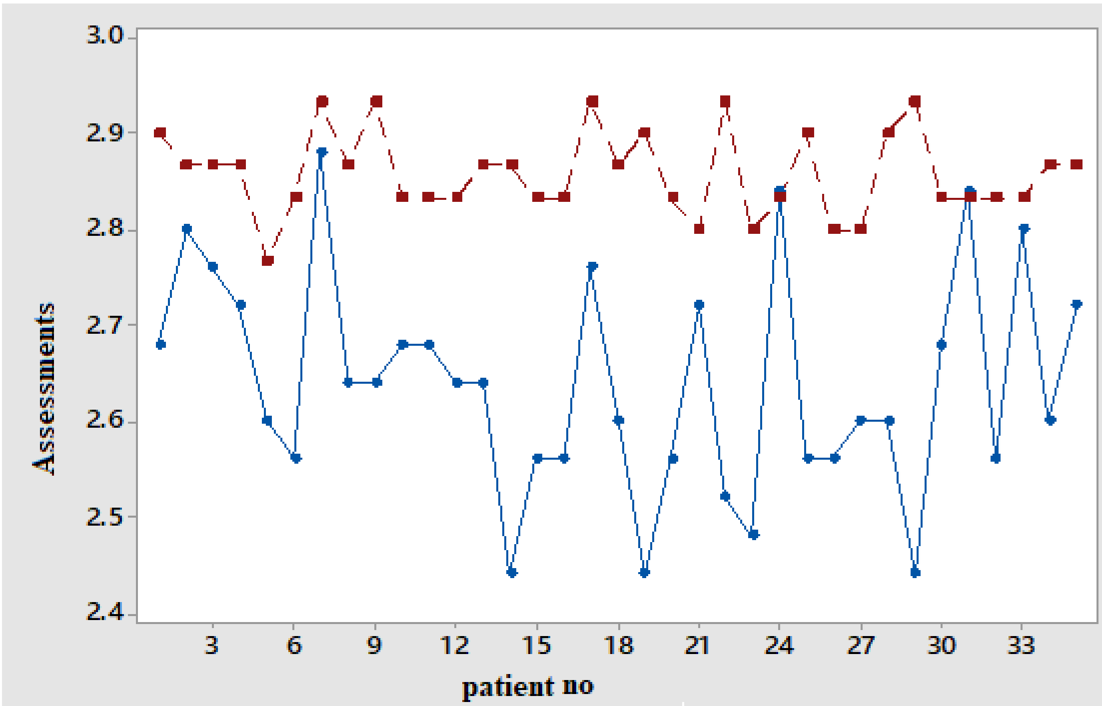

Figure 22: The average of the quality criteria with the algorithm presented with the red curve, and without the algorithm presented with the blue curve.

The last figure shows the result for the average of the five criteria. Now, the study will talk about each one exclusively.

5.5.1 Statistical test for sharp reproduction between white and grey matter

Assessments for sharp reproduction between white and grey matter is represented in Figure 22. Its clear brain post-processing algorithm provides better differentiation between white matter, and gray matter. The Statistical t-test (P<5%), shows that low dose Brain CT matches the quality criteria and provides a sharp reproduction of the border between white and grey matter in Brain CT, and after applying the brain post-processing algorithm there is a better match for the criteria.

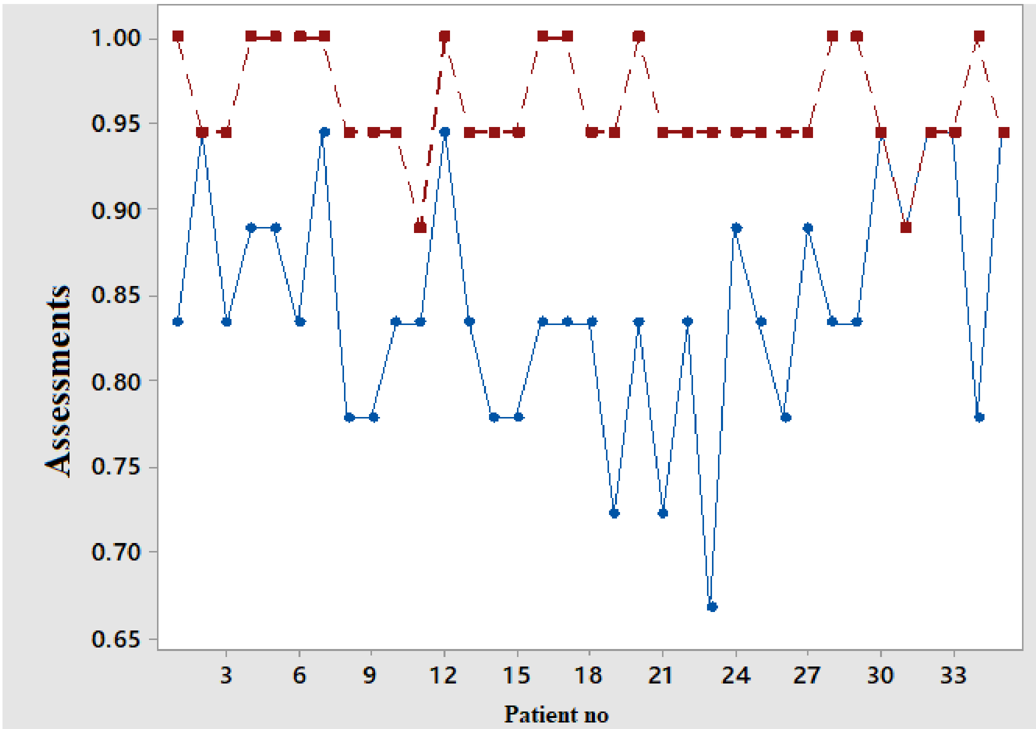

Figure 23: the results for average criteria 1, from the 6 expert medical imaging technologist, the average for the source Brain CT (blue line) ranges from 67% to 95%, and after applying the post-processing algorithm (red line) we get a better result ranging from 90% to 100%.

5.5.2 Statistical test for sharp reproduction of the basal ganglia

Assessments for the sharp basal ganglia are represented in Figure 23, and its clear brain post-processing algorithm provides a better appearance for basal ganglia. The Statistical t-test (P<5%), shows that the low dose Brain CT matches the quality criteria and provides a sharp reproduction of the basal ganglia, and after applying the brain post-processing algorithm the results were better examined for basal ganglia due to the enhanced contrast resolution.

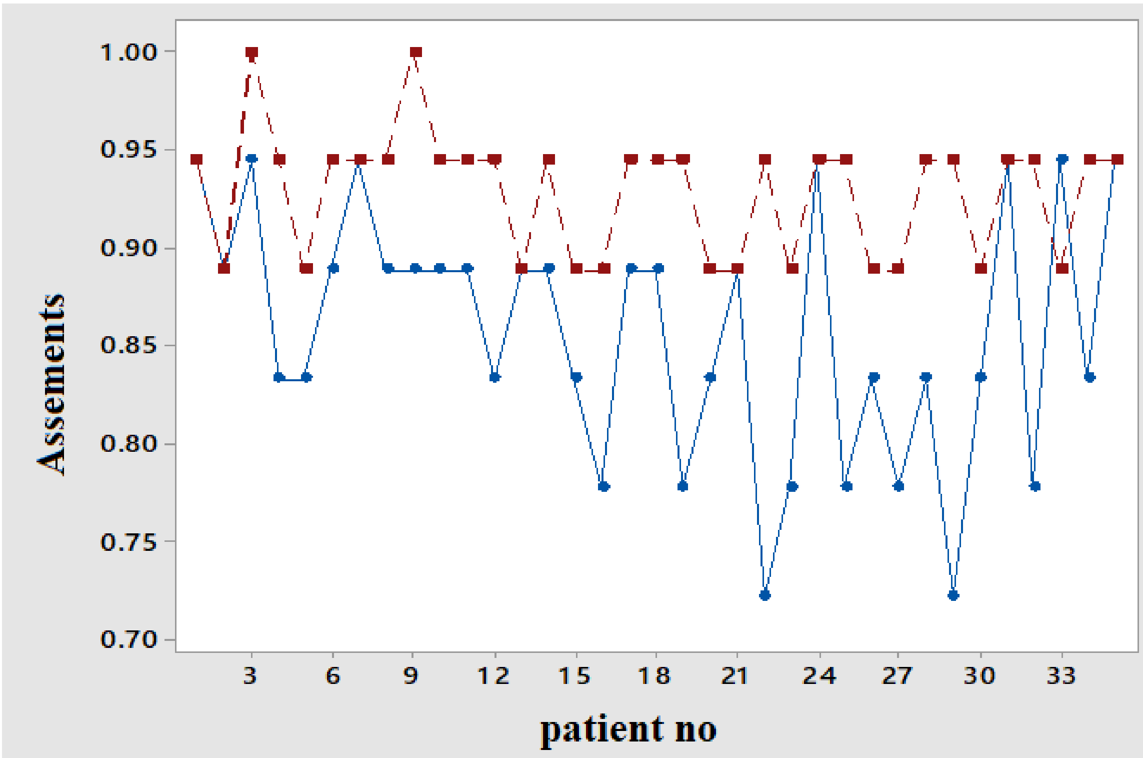

Figure 24: the average results from six expert medical imaging technologist, the (blue line) represents the results for basal ganglia without applying an algorithm, with the average result for each radiograph coming between 73% and 95%, the (red line) represents the results after applying an algorithm, with the average result falling between 90% and 100%.

5.5.3 Statistical test for sharp reproduction of the ventricular system

Assessments for the sharp reproduction of the ventricular system are represented in Figure 24. The Statistical t-test (P<5%), shows that the low dose Brain CT matches the quality criteria and provides a sharp reproduction of the ventricular system, the results after applying a post-processing algorithm show no significant difference between source radiograph and the post-processing algorithm.

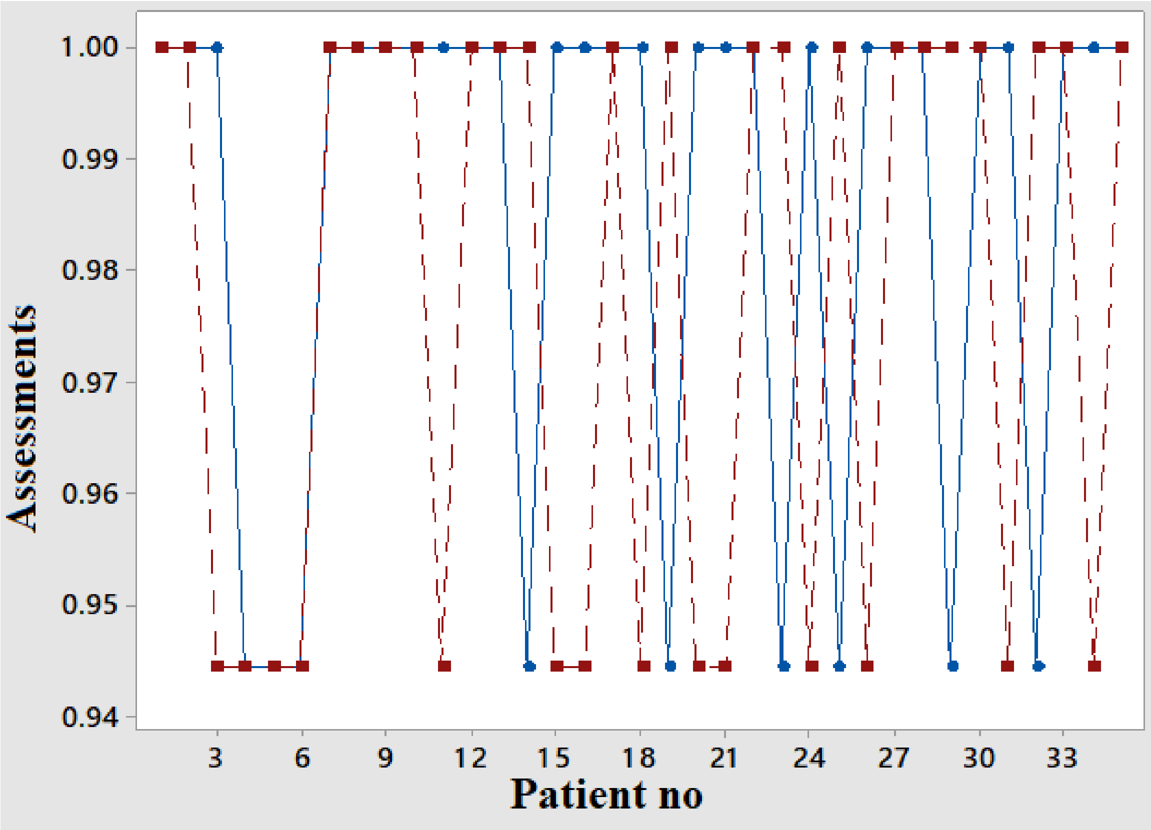

Figure 25: the result for criteria 3, visualize a sharp reproduction of the ventricular system, (blue line) a source radiograph without an algorithm, (red line) after applying the algorithm, both have the same average coming in between 94% and 100%, thus, brain post-processing algorithm doesn't produce a significant difference in criteria 3.

5.5.4 Statistical test for sharp reproduction of the cerebrospinal fluid space around the mesencephalon

Assessments for a sharp reproduction of the cerebrospinal fluid space around the mesencephalon is represented in Figure 25. The Statistical t-test (P<5%) shows that low dose Brain CT matches the quality criteria and provides a sharp reproduction of cerebrospinal fluid space around the mesencephalon, showing that low dose Brain CT matches with criteria 4, and after applying the algorithm we achieve a better result.

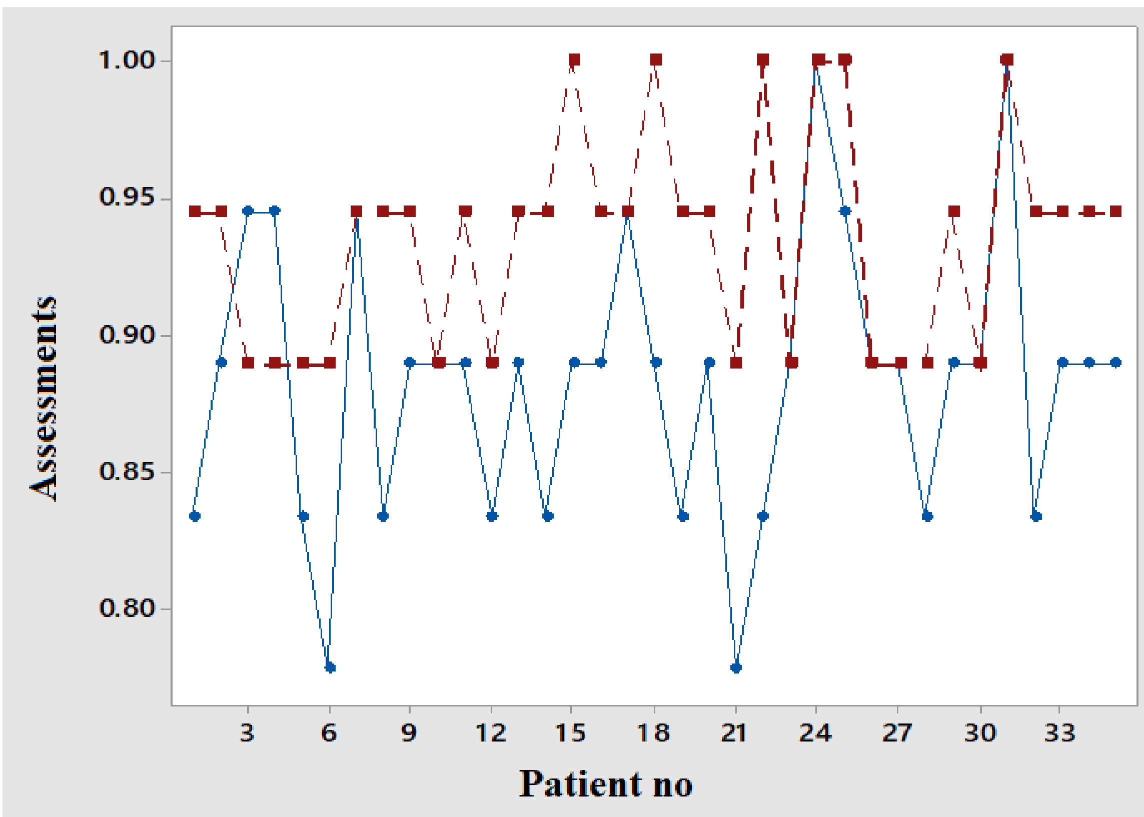

Figure 26: the result for criteria 4, a sharp reproduction of the cerebrospinal fluid space around the mesencephalon, the (blue line) represents a low dose without an algorithm,

with the average result for each point falling between 75% and 95%, and after applying the algorithm the average result falls between 89% and 100%.

5.5.5 Statistical test for sharp reproduction of the cerebrospinal fluid space over the brain

Assessments for a sharp reproduction of the cerebrospinal fluid space over the brain are represented in Figure 26. The Statistical t-test (P>5%), shows that the low dose Brain CT matches the quality criteria and provides a sharp reproduction of cerebrospinal fluid space over the brain, showing that the result from the low dose Brain CT matches with criteria 5, and after applying the algorithm the result become better.

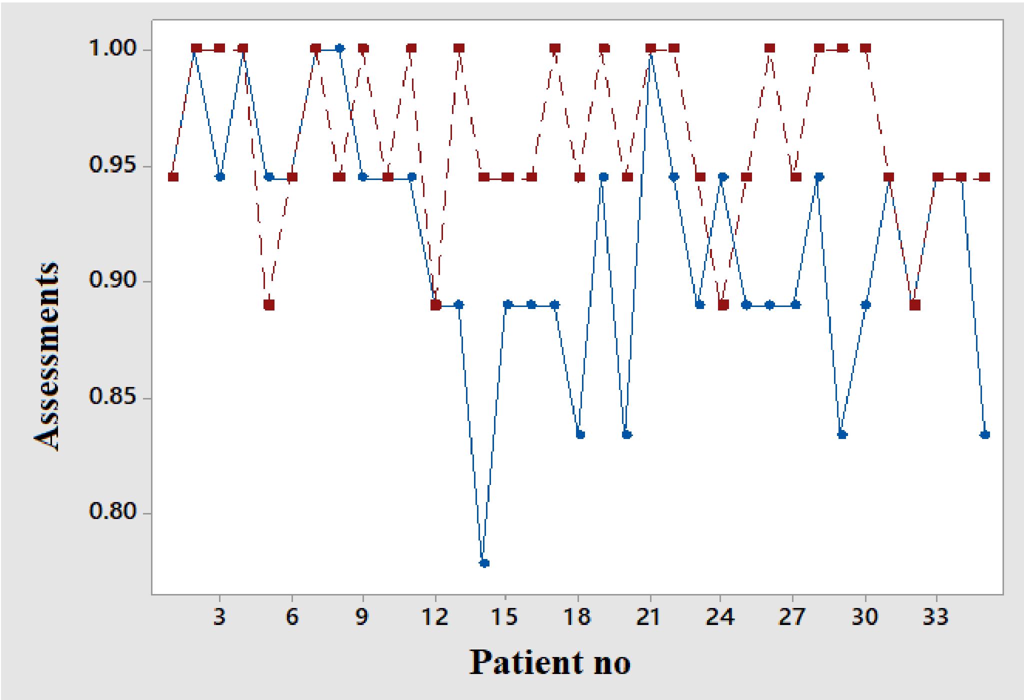

Figure 27: the average result for criteria 5, a sharp reproduction of the cerebrospinal fluid space over the brain, the (blue line) represents the average result from the source radiograph with a fall between 77% and 100%, the (red line) represents the result after applying the algorithm falling between 89%and 100%.

5.6 $CTDI_{vol}$ and DLP

Here the study will compare $CTDI_{vol}$, and DLP for the standard and low dose protocol, the results for both protocols are shown in table 7. The comparison will be done to determine how much the low dose protocol reduces the absorbed dose by the patient. Here, the study can't measure the reduction with certainty because a special phantom is needed, but the $CTDI_{vol}$ and DLP provide an index for reduction, it doesn't provide an accurate value for the absorbed dose but it's of an important value for comparison between the different scanner's and protocols, so we can measure the percentage of reduction, not the amount of reduction.

Table 7: $CTDI_{vol}$ and DLP for standard and low dose protocol.

PATIENT	LOW DLP	LOW $CTDI_{vol}$	STANDARD DLP	STANDARD $CTDI_{vol}$
1	757.1	33.8	1076	63.3
2	773.1	33.8	968	60.5
3	759.6	33.8	1231	72.4
4	827.2	33.8	1010	59.4
5	765	33.8	1194	74.6
6	774.2	33.8	1021	63.8
7	706.9	33.8	1001	45.6
8	740	33.8	1035	60.9
9	698.8	33.8	1201	66.7
10	724.5	33.8	963.2	60.2
11	681	33.8	1081	63.6
12	782	33.8	840	52.5
13	749	33.8	1191	62.7
14	689	33.8	963.2	60.2
15	720	33.8	1093	64.3
16	764.6	33.8	993.6	62.1
17	757.7	33.8	1450	76.3
18	832.5	33.8	1257	69.3
19	696.8	33.8	1188	68.7
20	774.4	33.8	1186	65.9

Continue from Table 7

21	709	33.8	1258	66.2
22	720.8	33.8	996.2	58.6
23	732.4	33.8	1403	66.8
24	754.7	33.8	1372	68.6
25	757	33.8	939.2	58.7
26	764	33.8	1237	77.3
27	825	33.8	972.8	60.8
28	968	33.8	1152	64
29	764.9	33.8	1303	72.4
30	783	33.8	937.6	58.6
31	734.2	33.8	1046	65.3
32	773	33.8	1076	59.8
33	731	33.8	1081	63.6
34	727	33.8	1046	63.6
35	698	33.8	1323	73.4

5.1 Statistical test for $CTDI_{vol}$ and DLP

Results for $CTDI_{vol}$ from the standard protocol, and a low dose protocol represented in Figure 28. Figure 29 represents DLP for the two protocols. Its clear low dose protocol uses a less amount of radiation than the standard protocol. The Statistical t-test ($P<5\%$), shows that low dose Brain CT provides a less radiation dose than the standard protocol and a fixed $CTDI_{vol}$ at level 33.8 mGy, enough for diagnosis.

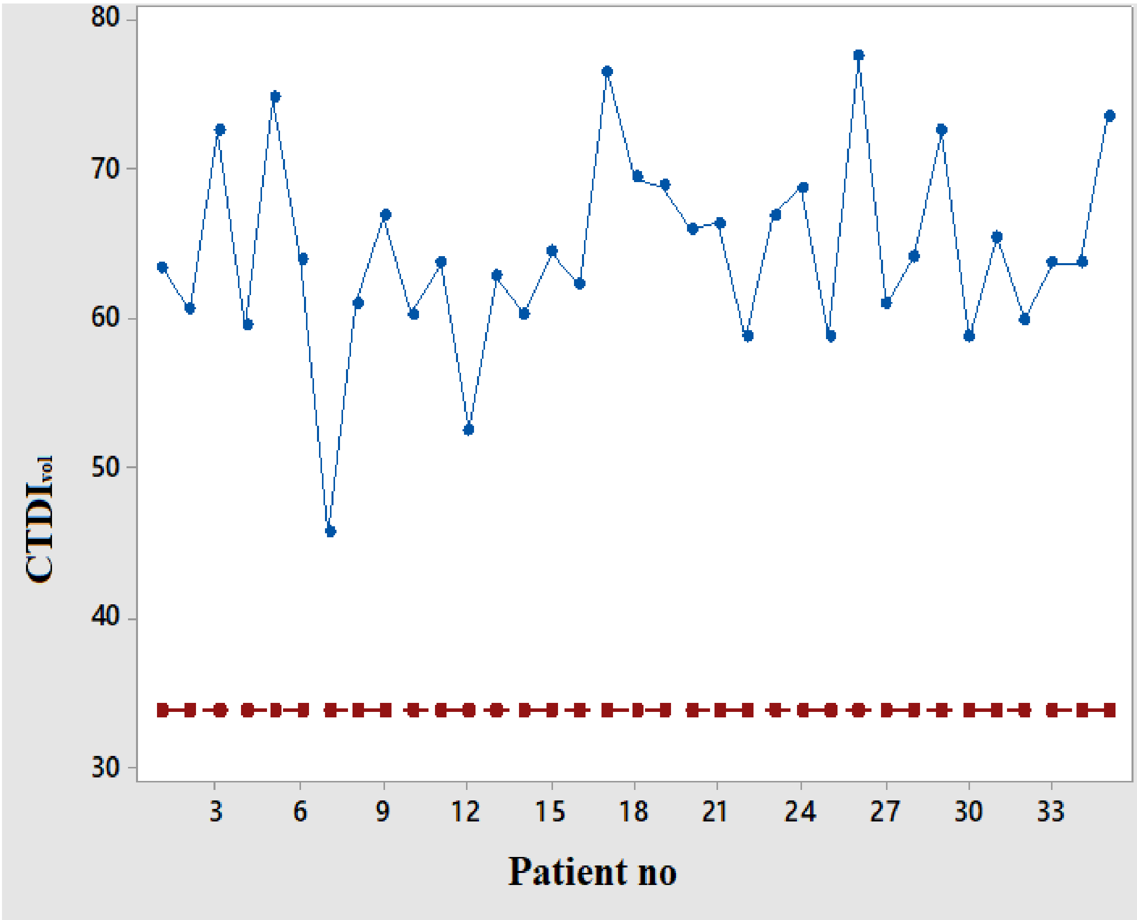

Figure 28: the result for $CTDI_{vol}$, the red line is a low dose protocol fixed at 33.8 mGy, the blue line is the result for the standard protocol, it’s fixed at 65 mGy but due to the use of dose modulation it became unfixed, and increased with some patients and decreased with others.

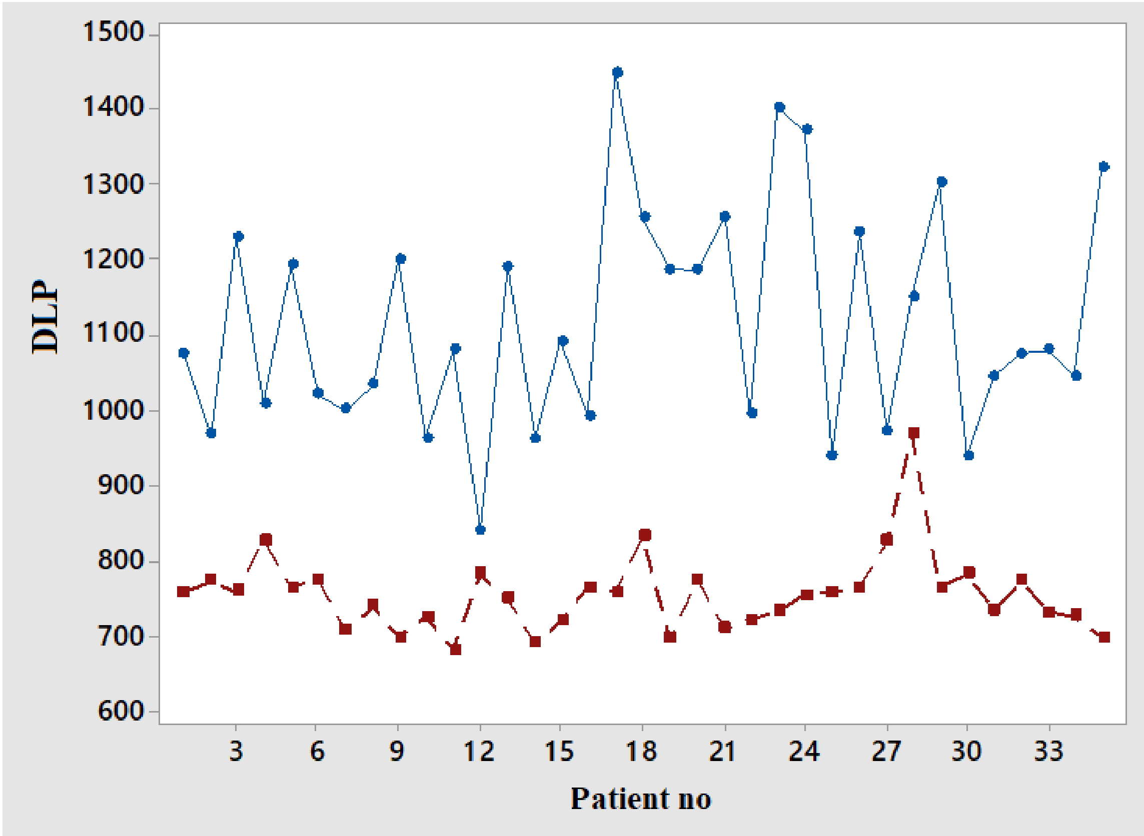

Figure 29: the result for DLP, the red line is the result for low dose protocol and the blue line is the result for the standard protocol. DLP equals $CTDI_{vol}$ time scans length, and due to differences in the body habits between patients, thus, cannot be fixed.

5.2 Brief results for Diagnostic appearance

In this study four radiologists participated to determine if the resulted radiograph provided any diagnostic appearance. The brief results from their assessment are concluded in Table 8 for the standard protocol images, and Table 9 for images after applying the Brain post-processing algorithm.

Table 8: the final results for the radiologist tests with a diagnostic appearance without applying an algorithm.

radiologist	diagnostic	not diagnostic
1	35	0
2	35	0
3	34	1
4	35	0

Table 9: final results for the radiologist tests with a diagnostic appearance after applying an algorithm.

radiologist	diagnostic	not diagnostic
1	35	0
2	0	35
3	5	30
4	0	35

5.3 Brief results for $CTDI_{vol}$ and DLP

The study includes a statistical test for $CTDI_{vol}$ and a DLP for the last 35 patients who had a brain CT radiograph using the standard protocol and the patients who had a low dose brain CT, the brief results are concluded in Table 10.

Table 10: final results for CTDI and DLP for the current protocol and the low dose protocol.

CT protocol	Mean CTDI	Mean DLP
current hospital protocol	64.3	1116.7
Low dose protocol	33.8	754.7
reduction percentage	47%	32%

5.4 Brief Discussion

5.5 Quality criteria for brain CT

The observed result for quality criteria without applying the algorithm shows that it is a match for the reference study and the study done by (Ibrahim et al.,2016). After a statistical independent t-test ($p<5\%$) the resulting radiograph without applying the post-processing algorithm matches the quality criteria for brain CT.

After applying the algorithm we have a better match of quality criteria and it is clear that the algorithm improves contrast resolution. Here, after the independent t-test ($p > 5\%$), the resulting radiograph matches the criteria.

5.5.1 Diagnostic appearance

The result from the independent statistical t-test ($p > 5\%$) with the high dose group which has a 100% diagnostic appearance ensures that the low dose brain CT without applying algorithm provides diagnostic appearance, but after applying the algorithm we lose diagnostic appearance, and the radiologist cannot use it alone without the source radiograph.

5.5.2 CTDI and DLP

CTDI has been reduced by 47%, and DLP has been reduced by 32%. Also, the radiograph is diagnostic and matches the quality criteria for brain CT, here, we accept the low dose protocol.

5.6 Study limitation

Low dose protocol provides poor quality for sagittal, and coronal view (when applying brain window) as shown in figure 30. In this regard, the diagnostic appearance is better in the axial view.

Figure 30: a coronal view on the left-hand side and a sagittal view on the right-hand side, both appearing with less quality than the axial view.

5.7 Conclusion

Low dose Brain CT provides a diagnostic appearance and a match quality criteria for brain CT, after applying a post-processing algorithm we have a sharp match for quality criteria, yet it doesn’t provide a full diagnostic appearance, thus we can use it to help us in the diagnosis but we cannot depend on it without the source radiograph.

5.8 Future perspective

Low dose Brain CT conducted by 33.8 mGy CTDIvol and a 47% dose reduction provides the diagnostic appearance and matches quality criteria for brain CT. After the application of the post-processing algorithm, the researchers had a better match for quality criteria, but it doesn't provide a full diagnostic appearance. Therefore, it cannot help the researchers in the diagnosis, and cannot be depended on without the source image.

Image processing and reconstruction can improve image quality, SNR, and reduce patient dose, a lot of working and development of the processing and reconstruction of the algorithm leads to greater improvement in image quality and dose reduction.

Brain post-processing algorithm enhances contrast resolution and provides better anatomical appearance, yet disturbs diagnostic appearance. Here, our research question, how can we enhance image contrast without any disturbance in diagnostic appearance?

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