RADIATION DOSES TO PATIENTS DURING COMPUTED TOMOGRAPHIC (C.T.) EXAMINATIONS OF THE HEAD.

BY

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DEDICATION

This work is dedicated to my late Aunt, MRS. MARIAMU A. MSANGI who died during this period of my study.

DECLARATION

This dissertation is my own work and has **NOT** been presented for a Degree in any other University.

Signed ....

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This dissertation has been submitted for examination with my approval as University Supervisor.

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ABBREVIATIONS AND TERMINOLOGY

Absorbed dose	:	Amount of energy deposited per unit mass at a point in the human body exposed to radiation.
Artefact	:	Errors in the reconstructed image that are not present in the scanned object.
Exposure	:	A quantity expressing the amount of ionization caused in air by stray or gamma radiation.
Energy imparted	:	A measure of the total radiant energy deposited by ionizing radiation in a tissue volume in the patient during a radiological examination.
CAT	:	Computerized Axial Tomography
Equivalent dose	:	The summation of the products of absorbed doses, and radiation weighting factors.
D.F.	:	Degrees of Freedom
GRAY (Gy)	:	Unit of absorbed dose: 1Gy=1J/Kg=100 rads
HU	:	Hounsfield Unit
ICRP	:	International Commission on Radiation Protection.
ICRU	:	International Commission on Radiation units and Measurements.
Ionization	:	The removal of an orbital electron from an atom and production of ion pairs in electrical field.

KV :	Kilovolt, Kilovoltage (one thousand volts), a unit of electrical potential difference between electrodes of an x-ray tube, which determines the quality, that is the penetration power, and also the intensity of the x-ray beam.
LiF :	Lithium Fluoride, a thermoluminescent material used in dosimetry. Z-value = 8.2
mA :	Milliampere, (a thousandth of an ampere) a unit of an electric current, constituting x-ray tube current.
Deterministic effects:	These are radiation effects whose severity depends on the dose and thus a threshold may exist.
Radiation :	The emissions and diffusion of energy in the form of electromagnetic waves or of particles charged or uncharged electrically.
S.D. :	Standard Deviation
S.E.M. :	Standard Error of the Mean
Stray radiation :	Scattered radiation
TLD :	Thermoluminescence dosimetry
X-RAYS :	Invisible, highly penetrating electromagnetic radiations, similar in nature to visible light, but short in wave length, approximately 10^{-7} to 10^{-11}cm.

SUMMARY

Since the discovery of x-rays in 1895, and more recently the use of computerized Tomography (CT) there has been a growing interest in the assessment of the radiation energy absorbed by the patients during CT and other diagnostic x-ray procedures.

Consequently, there has been a development of radiation detectors for patient dose measurements. Among such devices is the (LiF) Lithium Fluoride, Thermoluminescent Dose Meter (TLD), which is placed on the skin surface of the patient being monitored. Some of the desirable properties of TLDs are high sensitivity and near energy -independence.

Tests have been conducted to assess the suitability of TLDs during CT procedures, with positive results.

Between September, 1993 and February 1994, a total of 75 patients who underwent CT-examinations of the head, at Kenyatta National Hospital were studied. While they were scanned their radiation doses were determined. The anatomical landmarks were chosen to correspond to the organs under dose assessment.

Thermoluminescent dosimeters (LiF) were placed on the site of interest before commencement of the CT procedure. After the procedure was completed, the TLDs were taken for readout using the TOLEDO 654-TLD Reader.

The organs monitored were the frontal bone, eyes (lens), parotid, submandibular and thyroid glands.

Other peripherally located organs were also surveyed, but only for a few patients, in order to establish how much stray radiation reached them. These organs were sternum, ovaries and testes.

Of the 75 patients, (25.3%) were referred for trauma while (74.7%) were non-trauma patients.

Adults represented 82.7% of the patients while only 17.3% were children.

Among patients attended, 64.0% were male and 36.0% were female.

The number of slices per CT-examination of the head ranged from 13 to 52. The mean doses to the thyroid among adult patients recorded to be 0.28mGy while the testes and ovaries among adults were 0.06mGy and 0.07mGy respectively.

The difference of the radiation doses among adult patients undergoing CT-examination of the head were statistically significant at $P<0.05$.

The current study shows that by scanning the head through the orbit, the mean absorbed dose to the eyes is 1.48mGy and 1.19mGy for scanning to avoid the orbits; four times less than those reported in the studies done elsewhere. Infact scanning to avoid the orbits was 5.58mGy. Scanning through the orbits in the same study was reported to be 43.44mGy higher than figures obtained in this study.

This study also reveals that post contrast mean doses recorded are higher than pre-contrast doses. It agrees with the figures reported in studies conducted under reference above.

An attempt to address the issue of gantry tilt versus absorbed doses has been made, as angling the gantry cranially can contribute to reduction in radiation dose to the lens of the orbit.

Among radiation detector devices, TLDs are highly recommended during CT-scanning of the head because of their overall sensitivity. They do not produce artifacts on radiographic image.

This study reveals that the absorbed doses to the eyes, frontal bone and parotid glands are higher than the rest organs around the Head.

During CT-scan of the Head, this series shows that organs around the head receive low mean absorbed dose when the gantry is angled cranially to avoid the eyes. Thus setting on angle the gantry cranially to avoid the orbits during Head Scanning can contribute to the reduction of the radiation dose.

Further studies of patient radiation dose during CT-examination not covered in this work are suggested.

A comparative study of patient radiation doses between different CT-models available in Kenya ought to be undertaken in future.

1. OBJECTIVES OF THE STUDY

Broad objectives:

To determine mean absorbed radiation dose to the patient during CT examination of the head.

Specific objectives:

a) To determine radiation absorbed doses to patients at the skin surface, during CT examinations of the head using the Phillips TOMOSCAN CX/Q, at Kenyatta National Hospital.

b) To study the influence of the scan parameters of slice thickness and number of slices on patient's dose.

c) To study the influence of gantry position on radiation doses recorded.

d) To study the influence of using contrast media on patient dose.

2. ETHICAL CONSIDERATIONS

The study population consisted of patients on whom CT examinations of the head had been requested. Referring clinicians were **NOT** aware of the study, hence their choice of referrals were not biased. In this study there were no ethical problems related to patient exposure to radiation, as the examinations would be done even without this study. Since the study was not a necessary part of the patients examination, the patient was requested to participate, the actual procedure was explained to the patient, and a written consent obtained (Appendix D). The results of this study were treated in confidence. Details of individuals radiation doses were not revealed.

As some types of dose meter tend to appear as artifacts on the patients images, with the potential for adversely affecting the diagnostic efficacy of the images, a pre-study investigation of this effect established that the dose meters used in this study did not influence patients' images.

The method of dose measurement was non-invasive, and did not cause the patient pain or any other inconvenience.

3. INTRODUCTION

In conventional radiography, the shadows of all the structures through which the x-ray beam passes are recorded on a film in a two-dimensional image. This results in the superimposition of shadows representing various body structures, often obscuring anatomical areas of primary interest in the radiograph. In 1963, the most effective method of separating confusing shadows was found in the principle of body section radiography (conventional tomography) [1]. In this technique, objects at a chosen plane within the subject are projected into the film in good focus, while those above and below are blurred. This is usually achieved by a well coordinated movement of the x-ray tube and the x-ray film while the subject remains stationary. Although conventional tomography offered some advantages in obtaining clear images of some body parts, e.g. Lungs, temporo-mandibular joints, Internal ear and Kidneys (Nephrotomograms); it has been of limited value because it is associated with generally poor image contrast, and it has not been readily applicable to the generation of images in the transverse plane [1].

A revolutionary method of tomography called Computerized Tomography (CT) was introduced into clinical medicine by the British Physicist Godfrey Hounsfield in 1972 [2]. Many regard this invention as the greatest step forward in radiology since the discovery of x-ray by

Roentgen in 1895. It is resulted in 1979 in the Nobel Prize for medicine being awarded jointly to Dr. Hounsfield and Professor A.M. Cormack [2].

The CT method of imaging is based on the generation of a large number of x-ray attenuation data as x-rays are made to pass through a narrow transverse body section from different angular projections. These attenuation data and their corresponding geometrical co-ordinates are then processed by computer to produce a 'slice' image of the transverse section in the subject. The technique is characterized by high sensitivity to small differences in x-ray attenuation, resulting in images of very high contrast resolution [3].

The original CT scanner made use of a simple collimated x-ray source and scintillation detector scanning together in a linear manner across the patient. The gantry supporting the x-ray tube and detectors would then be rotated through 1^0, and the linear translational motion repeated to obtain data for a different projection. This rotate-translate sequence would be repeated until data for 180 angular projections were generated [3]. The main disadvantage of this first generation scanner was the slow scan time: - it required about 4 minutes to produce one image slice. In later generation scanners, modifications were introduced to employ fan-shaped x-ray beams and multiple detector systems. This evolution has eliminated the need for linear translational motion and hence enabled scanning times to be reduced to typically 2-4 seconds per scan in present-day scanners [3].

The most extensive application of Computerized Tomography (CT) has so far been in head examinations. The special attribute of high contrast resolution has enabled the visualization of minute differences in intra-cranial soft tissue structures to an extent completely unknown before the advent of CT.

Computerized Tomography (CT) has played a very big role in neuro-radiology and interventional radiology. Unpleasant and Invasive procedures such as carotid angiography, and air encephalography have become unnecessary and the need for angiography has been reduced significantly [4].

The introduction of a new technology such as CT calls for a wide evaluation of its radiological impact, including radiation does to staff and patients. It has long been established that exposure to ionizing radiation has the potential for inducing harmful biological effects. In low level exposure, the main concern is that of cancer induction in the various body organs. Radiation induced carcinogenesis is a stochastic process, in which the probability of inducing an effect is a variable function of the radiation dose [5].

In CT scanning of the head, the important organs to be considered include the lens of the eyes and the thyroid glands. In extensive examinations, the eye lens may be susceptible to cataract induction, a deterministic type effect of radiation which is believed to have threshold dose [6]. The lens of the eyes may respond to damage from radiation by the formation of cataract with a characteristic appearance in the posterior pole of the lens. It is therefore important that users of CT systems should be aware of the dose delivered by CT procedures in general and the dose ranges associated with the type of system they use. The doses they deliver with their units should be assessed by means of a technique and protocol that allows comparison with data collected for identical and different systems.

In modern CT-systems, the gantry rotates around the patient and exposes an extremely narrow field which reduces scattered radiation. At a constant voltage of 120Kv, the absorbed dose is a function of mAs product and the number of projections in each scan. Therefore there is a need to use the shortest time possible so that the maximum skin dose is minimized.

In Kenya, CT scanners have been used since 1986. However, no studies have previously been undertaken to establish the levels of patient dose delivered. The purpose of this investigation is to determine the radiation doses to patients from CT scans of the head. Several factors affect the radiation dose received during CT scanning of the head, including the model of CT scanner and the examination technique. In this investigation, the variation of patient dose with the CT protocol employed will be studied. Apart from providing additional data on patient doses, the findings of this study are expected to lead to some recommendations on radiation protection measures.

4. RATIONALE

The needs for undertaking this study are as follows:-

a) It is important to establish and indeed to know the absorbed doses delivered to organs within and distal to the head, so that the evaluation of radiation hazards and the justification of CT-procedures of the head can be made.

b) Computerized Tomography (CT) in Kenyatta National Hospital is a new technology of imaging; therefore, there is a need to acquire knowledge of radiation doses from CT-procedures.

c) It is necessary to stimulate awareness among clinicians, radiologists and radiographers on the magnitudes of the absorbed doses delivered to patients during CT examination of the head, so that radiation protection measures can be effected.

d) There have been no previous studies done in Kenya of patient doses from CT-procedures of the head; hence, there is a need to establish a baseline.

5. LITERATURE REVIEW

Many methods of CT dosimetry have been made available for the measurement of ionizing radiation. The use of thermoluminescent materials such as LiF, photographic film, and ionization chambers have been thoroughly investigated [7]. A radiation dosemeter for accurate measurement of patient dose in CT scanning should have a reasonably constant energy response for beam qualities in the range of 4-12 mmAL HvL.

In 1932, Swedish scientists began to use routinely for patient dose measurements small ionization chambers, the so called condenser chambers, which were entirely separated from the reading instrument [8]. Ionization chambers can be used as dosimeters in assessing patient dose in computed tomography.

The disadvantages of ionization chambers in CT include the practical problem of placing the chamber exactly within the scanning x-ray beam during the measurement. The exposure pattern perpendicular to the scan plane is usually not uniform. In case of multiple scans dose distribution is not very uniform, leading to the possibility of obtaining incorrect dose value for a multiple slice study. Therefore because of the practical limitations, using ionization chambers for direct measurement of radiation dose in CT is complex. Bassano et al [9] suggested the use of 10cm cylindrical chamber as a dosimeter in CT. This has not yet found wide use in CT examination of the head.

Photographic film can be used as a dosemeter in (CT), especially in assessing the x-ray tube leakage, gonad and organ exposure due to scattered radiations. The response of photographic film is highly energy dependent in the range of diagnostic x-ray qualities with a variation of up to a factor of 40 in the range 100 Kev to 40 Kev [10]. It may not be possible to calibrate the film response to be accurate for all beams encountered in CT scanning even though one can probably derive a mean calibration factor for a single CT scanner.

The precision of photographic sensitometry is another complication. Despite these problems, film dosimetry provides a method of obtaining much dose information with minimal readout efforts and better spatial resolution. Shope et.al. showed that the film dosimetry results in CT obtained using calibration curves, agreed with TLD results to within 25% for most CT systems tested [11].

The TLDs are superior to the photographic film and ionization chamber described earlier on. The advantages of LiF include: - the dosimeters can be re-used after dose erasure. The response of LiF at diagnostic energies is linear with dose over a wide range. The sensitivity is high, the LiF is small in size and does not produce artifacts on the diagnostic image. Automation is well developed in

TLD as compared to photographic dosimetry. In addition, TLDs are relatively less expensive in the long term due to their re-usability.

The use of ^{60}Co as the source of TLD calibration is common to ensure consistency from center to center [12]. Comparisons between TLD and ionization dosimetry during patient dose measurements have shown good agreement. In one study, the ratio of the calculated absorbed dose from TLD and the measured dose from ionization chamber measurement was found to lie between 0.97 and 1.03 [13].

Quantities used to evaluate patient radiation dose include: skin dose, effective dose, and energy imparted (14), among others.

In conventional radiological studies, the patient skin facing the x-ray tube receives a higher dose of radiation as opposed to the skin at the exit side. In CT, the skin receives the highest dose of radiation; with no difference between the entrance and exit side as the source of radiation rotates about the patient. A number of studies have been performed that measured the skin dose in various situations (15). Values ranged from as low as a few tenths of a gray (Gy) to a high value of 0.50 Gy or more [15]. The difference depended on the type of instrument used, whether there were single or multiple continuous slices obtained, whether contrast media were used and high resolution accuracy modes were employed, during CT-scan of the head.

In experimental studies, values of the dose distribution resulting from typical CT examinations from different types of CT scanners have been reported by several authors using standard dosimetry techniques [14]. In some studies, the mean circumfrential skin dose for all scanners used were reported to be 0.015Gy [16], in a series of eight consecutive scans. Some authors reported skin dose varying from 0.019 to 0.058 Gy per single scan [17], during CT examination of the head.

The effective dose is another quantity used to evaluate patient radiation dose in CT. The effective dose recommended by ICRP is calculated using the resultant organ or tissue doses [18]. In practice however, it is tedious and time consuming to calculate the absorbed dose or organ surface dose using the ICRP criteria.

The energy imparted or integral dose is more important than skin dose, because it reflects the total amount of radiation energy absorbed by the body, and takes into account the area exposed. Since the total volume of tissue irradiated is frequently smaller with CT than with conventional radiography, the integral dose is correspondingly lower [19]. The energy imparted has many disadvantages which include:- measurement of exposure area-product; a need to have transparent ionization chamber, and conversion factors. The determination of integral dose, is, in practice, a tedious procedure.

The amount of radiation a patient receives during a CT examination is a function of many parameters used in the design of the scanning equipment. The dose can vary considerably from scanner to scanner and from image to image, depending on what is required by the investigator.

Variants affecting patient dose in CT of the brain include:- scan time, interscan delay, total number of scans in sequence, table increment between scans, tube output, detector efficiency, the details of the gantry position and slice thickness.

Factors leading to elevated radiation dose include among others the use of older scanners with poorly optimized geometry, tubes and electronics. Dose also increases for high resolution scans with long scan time, high mAS (product of tube current with exposure time) settings, or geometrical modifications such as moving the tubes closer to the patient as is done in third generation scanners. Thin slices may also elevate the dose because of the need to increase tube output to suppress noise. Therefore overlapping and contiguous slices cause an increase in the radiation dose of 20% to 40% [20]. It has also been reported that solid state detector array absorb almost 100% of all radiation reaching them, as compared to a lower percentage of 60% to 80% for gas (xenon) detectors [20]. Thus, solid-state CT systems can help reduce patient dose.

Several studies on CT scanners have shown that table increment distance can be at variance with the actual distance moved by the table by as much as 3mm or more [21]. For these scanners, patient dose values calculated from single profile data are likely to disagree significantly with the dose actually received.

Stray radiation from within the patient and from x-ray tube are other problems which need attention. Many studies have been performed to acquire information about scattered radiation dosage and the role of laying a lead apron on a patient, and radiation dosages around CT-scanner [22]. This study revealed that laying a lead apron below and above the patient can reduce amount of radiation reaching peripheral organs during CT scan of the head.

Studies have shown that angling the gantry cranially to avoid the orbit, can result in a considerable reduction in radiation dose to the lens. In so doing, the CT users can prevent cataract formation. In one study on CT- of the head, the mean radiation dose measured with TLD was 5.58 mGy for scanning to avoid the orbit and 43.44 mGy for scanning through the orbit [5]. The mean maximum dose recorded was 57.44 mGy for scanning to avoid the orbit [5]. The threshold dose for the lens cataracts was reported to be 0.5 to 2.05 Gy [23]. During CT investigation of internal auditory meati, Tweed et al, recorded a dose to the lens of 78.1 mGy [24].

The following recommendations have been made previously as a result of previous studies on CT dosimetry:

1) Regular patient dosimetry and periodic checking of CT-scanners.

2) Where possible, an alternative non-ionizing imaging modalities such as magnetic Resonance Image (MRI), especially for posterior cranial fossa lesion and cranial ultrasound for neonates should be considered.

3) Repeat of CT-examination of the head should be carefully evaluated.

6. MATERIALS AND METHODS:

The study comprises of 75 patients, both adults and children who met the criteria for inclusion. Patients referred by clinicians to x-ray department for CT-examination of the head between September, 1993 to January 1994 were included. The study was conducted at Kenyatta National Hospital X-ray Department which consist of regular X-ray facilities, two high quality ultrasonography units, and one Phillips CT-Scanner. The study was prospective, set out to determine radiation doses to patients undergoing CT-examination of the head. Kenyatta National Hospital is a referral and a teaching Hospital.

CT- EQUIPMENT

TOMOSCAN CX/Q is a third generation scanner manufactured in September 1991. It employs a fan-beam with rotating detectors and pulsed X-ray radiation. Image reconstruction and storage in the TOMOSCAN CX/Q take place in a 256 x 256 matrix. On the other hand the image is displayed in a 320 x 320 or 512 x 512 image matrix [27]. The number of measuring channels in the asymmetric fan amounts to 576.

TECHNICAL SELECTABLE DATA (27)

MEASURING SYSTEM

Scan field	:	15-42 cm, diameter, selectable 1.6 to 42
slice thickness	:	3 slice thickness selectable: 2, 5 and 10mm
Gantry tilt angle	:	+/ - 20
Detector	:	*High pressure Xe gas detector*

X-RAY SYSTEM

X-ray generator	:	High frequency generator with computer controlled regulation and parameter selection.
Scan system	:	Rotate/rotate + offset detector
Floppy disk	:	12 to 20 slices
Constant voltage	:	120Kv
Field of View (Fov)	:	150, 210, 250, 360 or 420 selectable
Milliampere second	:	300-1200 mAs

SCAN DATA

Measuring times	:	2.8 sec., 4.5 sec., 6.0 sec. depending on the programme.

IMAGE REFORMATION AND DISPLAY

Image reformation time: 12 sec. for standard scans.

Computed Tomography (CT) value scale:

window level - 2,000 to 4,000 HU

window width 1 to 6,000 HU

(Household Unit)

THE PATIENT SAMPLE:

The sample size was limited to 75 patients. Patients in this study were referred to X-ray department for CT-scans of the head. Patients were either in or out-patients. The selection of patients was done randomly.

INCLUSION CRITERIA:

1. Only patients referred for CT-examination of the head were studied.

2. Patient's age between 2 - 60 years.

METHODOLOGY:

A preliminary test was performed to establish whether or not LiF dosimeters to be used in this study would interfere with patients' images. A water phantom was constructed using a transparent paper, well sealed, so that as far as possible air bubbles were excluded within it. The phantom measured 13 cm in diameter and 7cm in height. The Phillips CT-water phantom was also tested. The LiF - TLDs, a total of seven, were placed in a circle at intervals of 2.5cm. The gantry was centered to the phantom then the control panel was set as per brain protocol i.e. 120KVp, 90mA scan time of 4.5 seconds and 10 mm slice thickness.

If there ware no ring artifacts seen on the screen, it was concluded that LiF - TLDs placed on patient's surface during CT-scan of the head would not interfere with the diagnostic image.

Because of intrabatch variations in the response between individual TLD, a group of LiF dosimeters were exposed equally to x-radiation and their thermoluminescent signals were measured. The test was necessary for the comparison of the radiation doses recorded on different patients, keeping the sensitivity of LiF dosimeters the same.

PROCEDURE - TECHNIQUE FOR HEAD EXAMINATION:

Routine cuts were taken starting at the base of the skull through the posterior fossa and sella level at 5mm intervals and then 10mm intervals through the remainder of the brain. The gantry was tilted -7^0 to -20^0 (Negative gantry tilt) or $+8^0$ to $+20^0$ (positive gantry tilt), depending on the position of the head (Appendix B_1 and B_2).

Intravenous contrast medium, either 60% Sodium meglumine diatrizoate or meglumine iodamide 300 was routinely administered in patients suspected to have tumors, vascular malformation, inflammation, and other related pathology. It was not administered to patients with trauma and in some cases of recent suspected infarction. Children and restless patients were sedated using Diazapan 0.5mg per Kg. Possibilities for coronal and sagittal reconstruction was available. Permanent records of the images were obtained on single emulsion x-ray films. Some of the images were stored on floppy disks.

The TLD-ribbons were placed on the patient's region of interest before the commencement of the CT-procedure (patients regions are detailed below).

For the eyes (lens), TLD-ribbons were placed at the inner canthus of the eyes for each CT-examination of the head.

For the parotid glands, two TLD-ribbons, one on either side of the face, were placed between the mastoid and angle of mandible.

For submandibular glands; two TLD-ribbons, one on either side of the gland, were placed midway between the angle of mandible and gnathion.

For the thyroid glands, two dosimeters were placed, one on each lobe anteriorly.

For the assessment of radiation doses to the sternal area, about six TLD-ribbons were placed at intervals of 2.5cm, along the anterior surface of the sternum.

For the ovary, two dosimeters were placed on left iliac fossa and another on the right iliac fossa approximately 2.5cm medial and 3.75cm below the anterior iliac spine.

For the testis a TLD-ribbon was placed on the scrotum.

The LiF-TLD was attached on patient's skin surface with cellotape. The dosimeters remained in place until the CT-procedure was over. Dosimeters were removed from the patient after the CT-examination, ready for read-out. A diagram of dose measurement sites is provided below (Page 56).

Some unexposed TLD-ribbons in the same batch were kept aside to serve as controls. Exposed TLD-ribbons were read out on the Toledo 654 TLD-Reader together with control dosimeters (Appendix G). Using the results of dose calculated from a ^{60}CO calibration, the absorbed dose was obtained by dividing the calibrated dose by an average correction factor of 1.3. The sensitivity of the LiF TLD-100 ribbons had been determined to range from 1.1 to 1.4 greater than for ^{60}CO [9].

Data collection forms designed for this study were used to record patient particulars (age, sex, whether in or outpatient) and CT-parameters (slice thickness, number of slices and scan time) used. Eventually, readout and calculated doses were also recorded (Appendix E).

DATA ANALYSIS:

Data was collected from Kenyatta National Hospital X-ray Department. The data was then coded and entered into a computer using dBase software. Data cleaning was carried out to check for completeness of data entry and ensure that data had been entered correctly without mistakes.

The actual analysis was carried out using the Statistical Package for Social Sciences (SPSS) software, to measure the distribution and the relationships between different variables using T-test method.

The results were presented in table forms (Tables I to V), photographs and simple drawings.

7. RESULTS:

Of all patients involved in this study, 75 met the criteria for inclusion. The patients were grouped into children between 1 - 13 years of age and Adult patients between 13+ - 60 years. The adult patients were (82.7%) and children represented 17.3%. In the adult age groups, the proportion of male patients was greater than female patients, the male to female ratio being 1.8:1. The majority of the patients referred, were from the neurological outpatient clinic 30 (40.0%), Surgical outpatient clinic 21 (28.0%), medical outpatient clinic 18 (24.0%) and paediatric outpatient clinic 6 (8.0%). The number of in-patients compared to out-patients were almost equal.

The indications for CT- of the head were grouped into trauma and non-trauma. Non-trauma included headache, convulsions, weakness upper/lower limbs, loss of vision/hearing, vomiting and dizziness. The number of patients who were referred for trauma were 19 (25.3%) and non-trauma cases 56 (74.7%), three times more than were for trauma.

The results obtained in this study are presented in table form, and later on discussed.

Table I shows the mean absorbed doses, standard deviations and standard errors of the means to patients as delivered by Tomoscan

CX/Q. There was considerable variation in most of the parameters for various variables: for example, absorbed doses to the eyes, parotid, submandibular, thyroid glands and sternum were characterised by large standard deviations. To be able to stabilize the variance, a transformation was required before an analysis could be made. The data presented in the tables was calculated after application of a logarithmic transformation to the measured doses. The mean doses were higher at the center of the head and diminished distally.

Table II presents the mean absorbed doses at the various measurement sites according to the gantry position. All organs listed recorded low mean absorbed doses when the gantry was tilted to avoid the orbits. The eyes and parotid glands received higher doses than the thyroid glands. A possible explanation for these variations in doses could be due to the facts that the eyes, frontal bone and parotid glands are nearer to the primary beam than the thyroid and submandibular glands which are located distally. These differences in mean doses for the two different scan planes were significant at $P < 0.05$.

Table III shows the influence of pre and post contrast techniques on mean absorbed doses. The organs monitored are listed. The eyes, frontal bone and parotid glands recorded generally higher mean absorbed doses than the rest of organs. Except for the ovaries, the enhanced scans revealed higher mean doses compared to

TABLE I: MEAN RADIATION DOSES (S.D. AND S.E.M.) TO PATIENTS DURING CT-EXAMINATIONS

Organs scanned	Mean Dose (mGy)	(S.D.)	(S.E.M)
FRONTAL BONE	1.66	0.20	0.05
EYE	1.32	0.43	0.05
PAROTID	0.89	0.40	0.05
SUBMANDIBULAR	0.41	0.26	0.03
THYROID	0.28	0.17	0.03
STERNUM	0.17	0.08	0.02
TESTIS	0.06	0.03	0.02
OVARY	0.07	0.02	0.01

SD - Standard Deviation
SEM - Standard Error of the Mean

TABLE II: MEAN RADIATION DOSES AT CT-HEAD BY GANTRY POSITION

ORGANS SCANNED	-VE GANTRY TILT		GANTRY AT 0^0 +VE TILT	
	Mean Dose (mGy)	(S.D.)	Mean Dose (mGy)	(S.D.)
THYROID	0.27	0.16	0.29	0.19
SUBMANDIBULAR	0.39	0.21	0.43	0.31
EYE	1.19	0.50	1.48	0.25
PAROTID	0.89	0.41	0.90	0.40
STERNUM	0.16	0.09	0.21	0.06
FRONTAL BONE	1.66	0.22	1.69	0.07
OVARY	0.05	0.01	0.09	0.02

TABLE III: MEAN DOSES AT CT-HEAD BY WITH/WITHOUT CONTRAST

ORGANS SCANNED	NON-ENHANCED Mean Dose (mGy)	(S.D.)	ENHANCED Mean Dose (mGy)	(S.D.)
THYROID	0.23	0.17	0.32	0.17
SUBMANDIBULAR	0.35	0.19	0.46	0.29
EYE	1.28	0.34	1.36	0.50
PAROTID	0.84	0.37	0.94	0.43
FRONTAL	1.59	0.20	1.76	0.17
OVARY	0.08	0.02	0.05	0.01

TABLE IV: PATIENTS MEAN RADIATION DOSES AT CT-HEAD ACCORDING TO NUMBER OF SLICES

ORGANS SCANNED	NO. OF SLICES ≤20 Mean Dose (mGy)	(S.D.)	NO.OF SLICES ≥ Mean Dose (mGy)	(S.D.)
THYROID	0.20	0.09	0.34	0.20
FRONTAL	1.59	0.19	1.77	0.18
SUBMANDIBULAR	0.32	0.13	0.49	0.31
EYE	1.31	0.37	1.33	0.49
PAROTID	0.80	0.32	0.97	0.45
STERNUM	0.17	0.06	0.17	0.11
OVARY	0.08	0.02	0.05	0.01

TABLE V: PATIENTS MEAN RADIATION DOSES AT CT-HEAD BY SLICE THICKNESS

ORGANS SCANNED	SLICE THICKNESS 5mm		SLICE THICKNESS 10mm	
	Mean Dose (mGy)	(S.D.)	Mean Dose (mGy)	(S.D.)
THYROID	0.56	0.28	0.25	0.13
SUBMANDIBULAR	0.66	0.31	0.38	0.24
EYE	1.46	0.20	1.31	0.45
PAROTID	1.18	0.41	0.86	0.39
STERNUM	---	---	0.18	0.08
OVARY	---	---	0.07	0.02

8. DISCUSSION:

As many as 40% of the patients referred for CT of the head were from the neurological outpatient clinic. The majority of these were adults. The small number in paediatric clinic as revealed in this study, may be due to the small sample size, or inability of meeting the cost of the examination. Infants were preferentially referred for ultrasonography. There was a male preponderance. The female patients attended were 24%.

The number of patients studied in the series were 75, five times more than the figure reported in the study done elsewhere [5]. It was noted that, in the majority of cases, determination of absorbed doses during CT-scan of the head, a human phantom was used [11,20]. This played an important role as doses vary, depending on the methodology employed.

Indications for CT-examination of the head was divided into trauma and non-trauma. Non-trauma included headache, impaired vision, vomiting, dizziness, confusions, weakness upper/lower limbs and impaired speech/hearing. The indications for CT of the head should carefully be assessed for its justification.

In analyzing the indications for CT examination, it was seen that majority of patients refereed for CT-of the head were non-trauma (74.7%). The second group of patients were referred following trauma or head injury (25.3%).

The study by Strehlau [25] reported non-trauma as the commonest indication for CT of the head. The total cases referred for trauma were only 22, while those due to non-trauma were 135. In her study, headache was (53.0%), followed by weakness upper/lower limbs. These findings were well correlated with the current study.

It can be deduced that, the most frequent indication for CT-scan of the head was due to non-trauma, followed by trauma.

It has been found that the availability of other imaging modalities such as MR1 and ultrasound (for neonates) would be of a great help in eliminating ionizing radiation procedures such as CT.

Jewel [29] compared MR1 and CT and concluded that MR1 is more sensitive diagnostic study and is optimal neuroradiological screening procedure. In addition, it is better for soft tissue contrast resolution, MR1 does not expose the patient to any form of ionizing radiation nor does it require the use of intravenous contrast material. The MR1 would eliminate unnecessary radiation doses to some patients from CT-scanner.

The number of slices by mean absorbed doses were grouped into ≤ 20 and >20. In this series when the number of slices were ≤ 20, the frontal bone recorded higher mean doses than the rest of organs

(Table IV). The mean doses were higher around the mid-sections of the head, and diminished distally. The organs peripherally located received relatively lower mean doses. These included thyroid, sternum and ovary, which received radiation doses through scattered radiation.

As expected in the majority of cases, the mean doses were higher when the number of slices were >20.

The frontal bone and eyes recorded even higher mean doses, when compared to the number of slices ≤ 20. The parotid glands received higher mean absorbed dose when compared to submandibular glands, the variation is due to anatomical location, the bone structure involved and the number of slices chosen. The mean dose recorded by thyroid and submandibular glands were higher with the statistical significance at $P < 0.05$. The difference in the mean doses between the two groups of number of slices is better explained by the location of the organ (whether proximal or distal), This study also revealed that the more the number of slices during CT of the head, the higher the mean doses were recorded. This correlated well with previous published reports [20].

In one study by Conway et al [6] reported, the number of slices ranged from 8 to 40 for the routine head procedures, This report differs from the current study where the choice of number of sections ranged from 13 to 52. There were two cases of hydrocephalus which revealed the number of slices to be 49 and 52, higher than the rest of the cases. The explanation for this was possible due to enormous size of the head due to hydrocephalus which in turn needed more sections. However, the previous report [5] on slice sections which reported use of 12 sections of 10mm section thickness or 15 sections of 8mm section thickness employed a procedure similar to that in the current study.

An attempt was made to restrict the number of slices and slice thickness which are both operator selectable parameters on the majority of CT-systems, including Tomoscan CX/Q which was used in the current study.

The selected slice thickness in this study, employing Tomoscan CX/Q third generation of 1991 were 5mm and 10mm cuts. This correlated well with Conway et al [6] who reported a 10mm section thickness in most cases, although for the siemens DR system, it was 8mm.

The current study showed that with 5mm slice thickness, majority of the organs around the head received higher mean absorbed dose as compared to a 10mm cut in the same series. The selection of 5mm slice thickness or less is preferred when dealing with very fine anatomical structures such as pituitary fossae. Such selections should be done very carefully to avoid unnecessary radiation dose to the patient.

Conway et al [6] found that the majority of the dose values to the eyes ranged from 34 to 55 mGy. The average doses were taken at the midpoint onto the central axis of a standard dosimetry phantom of the head. A study by Nishizwa et. al. [14] reported range from 22mGy. The central axis at the midpoint of the head during CT-scanning in this study was approximately recorded as an average value ranged from 0.41 to 1.66 mGy, less than in the previous literature. The current study also revealed that the mean dose for the eyes and parotid glands were 1.43 and 0.89 mGy respectively. The possible reasons for difference in doses include:- type, model of CT-scanner, protocol selection and calibration method.

Nishizwa et. al. [14] reported mean dose of 0.003mGy for the ovaries and 0.002 mGy for the testes, much less than the figures encountered in the present study, which recorded the mean doses of 0.07 mGy for the ovaries and 0.06 mGy for the testes. The same study [18] also reported the mean dose of 0.548 mGy for the thyroid. The eyes received the mean value of 22.40mGy much less than reported figures in an earlier study [5]. The variations in doses were explained by technique for given model of CT-scanner, differences in image quality desired for the diagnostic task. These necessitated differences in protocol selection or from differences in system performance, calibration and the use of lead aprons below and above the thyroid and gonad areas.

The gantry position is one of the factors which affected the dose to the organs around the head, during CT scanning of the brain. Two groups of gantry position were identified as negative gantry tilt and positive gantry at 0°. An attempt to address the issue of the variation of the gantry positions versus the mean absorbed doses to organs within the cranium was made. The gantry tilts ranged from -2^0 to -20° (Appendix B). When the gantry tilts were negative, the primary beam was directed cranially from the orbitomeatal line to avoid the eyes. Gantry angulation to avoid the eyes was not done routinely. It was only done to compensate for the head angulation, especially when it was difficult to position the head so that the orbitomeatal line was 90° to the table top.

YEOMAN et. al. (5) reported that with Reid base line, the orbit cannot be avoided. The same is true for the majority of patients in whom the orbito-meatal line is used. Therefore, the eyes can be avoided and the mean radiation dose significantly reduced only if a different scan plane is used that is designed especially to avoid the eyes through cranial beam angulation above the orbito-meatal line. In their survey [5], an average of 32% (58 of the total sample 184 centres) routinely angle the gantry away from the eyes in all patients. North America hospitals average was 41% (24 of 58), with only 22% (12 of 54) of hospitals in the United Kingdom, and 21% (4 of 19) of hospitals in Australia routinely avoid the lens. A further 4% of the total of 184 hospitals (7) avoid the eyes only in children. There is no correlation between findings in the current study and those reported elsewhere. In Kenyatta National Hospital, no attempt was made to protect the eyes in either children or adult patients during CT-scan of the head on routine basis.

Consideration given to lens radiation doses versus gantry position was variable. As expected, the mean absorbed dose to the eyes were higher when the scan plane was directed through the orbits. In the majority of the cases, the mean doses were low when the primary bean was angled cranially to avoid the eyes.

In the current study, the mean dose for the eyes measured with the TLD (75 patients) was much less for scanning to avoid the eyes and higher for scanning through the eyes. The mean dose for scanning through the orbits was slightly higher for frontal bone than for scanning to avoid the eyes.

The mean doses were low in my study, than those reported in literature above. The variations possibly were due to differences in technique selection, model of CT-scanner, methods of determining radiation dose, and calibration. It has been noted that first scanner delivered fairly high-mean radiation doses.

Thyroid and submandibular glands received more or less the same mean doses for scanning to avoid the eyes. In the same series, parotid gland recorded higher mean absorbed dose than thyroid gland while submandibular gland recorded higher mean dose than thyroid for scanning through the orbit. Parotid gland in the same protocol received higher mean dose than the previous figures for scanning to avoid the eyes.

Non-enhanced scans showed low mean absorbed doses to the thyroid, submandibular, parotid glands and the eyes. Enhanced scans revealed higher mean doses to all organs listed in Table III when compared to non-enhanced scans, the reason for the variation in dose is due to the larger number of gantry rotations (exposures) in the case of enhanced scans.

The thyroid glands showed slightly higher mean dose in enhanced scans as compared to non-enhanced scans.

The eyes and parotid gland received higher mean doses as compared to the rest organs around the head, possibly due to their anatomical location.

The submandibular gland for enhanced scans received higher mean doses compared to non-enhanced scans in the same series. Observed variations in dose was explained by the fact that the eyes and parotid glands were closer to the primary beam while the thyroid and submandibular glands were located further or distally. When enhanced scan technique is employed, the head in this case is double exposed.

It is very important to consider the justification for non-enhanced or enhanced scans. It would be unethical to do scans of the head using enhanced technique on routine basis. In this study, it was observed that all cases referred for trauma/head injury and infarcts were scanned using non-enhanced technique. Non-trauma cases were done with pre and post contrast scans.

Yeoman et. al. [5] reported that the delivery of 1,000mGy of radiation as a single dose may be cataractogenic. They also suggested that the capability exists to deliver doses from 536 to 2,855 mGy (i.e. single dose cataractogenic levels) if the operator employs maximum Kilovolt peak, a very long scanning time up to maximum milliampere seconds, and overlapping sections for non-enhanced and contrast-enhanced axial scans plus contrast enhanced coronal scans for the ocular orbit. The largest dose was seen in scanning in the dynamic mode (2,855 mGy). There is no evidence that such examinations are being performed. Radiologists and radiographer should however be aware that CT-scanning can potentially result in administration of cataractogenic radiation doses.

RADIATION PROTECTION MEASURES:

Radiation doses from CT-scanner contribute to potential hazard to human kind. The operator should take the following measures to reduce the radiation dose to patients:-

1) The operator of CT-scanner must be well trained.
2) The indication for CT-examination of the head must be justified.
3) An alternative diagnostic procedures should be considered. For example, MRI modality where it is available should be the ideal radiological investigation for the posterior cranial lesion and cranial ultrasound for neonates. These modalities are the best where applicable because they are non-invasive, and deliver no radiation dose to the patient.
4) The repeat of CT-scanning should be carefully assessed.
5) Selection of the head protocol during CT-scanning should be done to fit the expected diagnosis.
6) Correct selection of scan parameters (i.e. slice thickness and number of slices).
7) Angling the gantry cranially during CT-scanning of the head.

Along these measures, reduction of potential radiation hazards from CT-scanner can be achieved by the use of lead aprons below and above, covering organs which are not under investigation. This study revealed that organs such as thyroid, sternum, ovaries and testes do receive radiation dose through stray radiations during CT-scanning of the head. There should be efforts made to protect these organs in routine basis at Kenyatta National Hospital of which they have been lacking. Data from the study by McCulloghuh et al [13] reported that ovaries doses for 20 second scans of the head and upper thorax are less than 1mGy/scan. Even though the internal lead plate reduces the dose considerably, the studies with the lead aprons indicate that X-ray tube leakage and scatter from the wedges in this machine contribute more dose than the internal scatter. If one is worried about micro-rad doses to the ovaries, then lead aprons above and below are called for. It was also reported in the same study that a dose of about 1mGy/scan at 1 meter for a routine clinical technique can be reduced to less than 200 UR/scan if a 0.25mm lead equivalent apron was employed.

The limitations of the present study included:

1) Data were collected from Kenyatta National Hospital only, using Philips Machine TOMOSCAN CR/Q. It would have been better if data were collected from more than one hospital with different types of CT-machines, or on more than one similar unit.
2) Two charges for CT-examination of the head were raised in between when this study was done, such that some of the patients could not meet the cost (limited sample size).
3) Computerized Tomography (CT) machine at Kenyatta National Hospital was not functional for some months, due to shortage of X-ray films which were not available.
4) TOLEDO-654-READER broke down, while this study was being carried out.
5) Due to the above limitations, patients sample size was limited to 75.

9. CONCLUSIONS AND RECOMMENDATIONS

Computerized Tomography (CT) of the head has a major role in the diagnosis of patients requiring neurological evaluation. Computed Tomography of the head contributes to high radiation doses to the lens.

1) The overall sensitivity of TLDs as radiation detector during CT-scanning of the head is high and there is no artifacts noted on radiographic image. It is therefore concluded that with the aid of careful selection and calibration of TLDs as radiation detector, it is possible to measure absorbed doses to patients, during CT-examination of the head.

2) The absorbed doses to the eyes, frontal bone and parotid glands from CT-scanning of the head in this study were higher than the rest of the organs around the head. It is recommended that during CT-scanning of the head, an attempt should be made to angle the gantry cranially, to avoid the orbits. Angling the gantry routinely ensures reduction in radiation doses to the lens.

3) As was to be expected, there is a relationship between the gantry position, enhanced scans, slice thickness, number of slices and absorbed doses. Careful selection of slice parameters and radiographic factors would assist in reducing radiation doses. The more the slice numbers and/or the smaller

the slice thickness, the higher the mean radiation doses.

4) It is recommended that where possible, lead aprons above and below the area being scanned should be used to cover organs which are not under investigation. During CT-examination of the head, the gonads area should be covered by lead aprons. Using lead aprons below and above led to reduction in radiation doses to ovaries and testes.

5) The Phillips TOMOSCAN CX/Q not only requires proper operation, but periodic preventive maintenance and user routine checks. A log book should be kept up-to-date, for recording all preventive maintenance, routine checking and patient dosimetry.

6) Further studies of patient radiation dose during CT-examinations not covered in this work is suggested.

7) Comparison study of patient radiation doses between Phillips TOMOSCAN CX/Q and other CT models available in Kenya such as the SIEMENS/SOMATOM should be undertaken in future.

8) Further studies on justifications/indications for the CT procedures of the head should be conducted.

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APPENDIX A

...diation detecting devices*

Detector	Types of radiation measured	Typical full-scale readings	Use	Minimum energy measured	Advantages	Possible disadvantages
Scintillation counter	Beta, X, gamma	0.02 to 20 mRh^{-1}	Survey	20 keV for X-rays Variable for betas	High sensitivity Rapid response	Fragile Relatively expensive
Geiger-Muller counter	Beta, X, gamma	0.2 to 20 mRh^{-1} or 800 to 80,000 counts min^{-1}	Survey	20 keV for X-rays 150 keV for betas	Rapid response	Strong energy dependence Possible paralysis of response at high count rates or exposure rates Sensitive to microwave fields May be affected by ultra-violet light
Ionization chamber	Beta, X, gamma	3 mRh^{-1} to 500 Rh^{-1}	Survey	20 keV for X-rays Variable for betas	Low energy dependence	Relatively low sensitivity May be slow to respond
Pocket ionization	X, gamma	200 mR to 200 R	Survey and monitoring	50 keV	Relatively inexpensive Gives estimate of intergrated dose Small size	Subject to accidental discharge
Film	Beta, X, gamma	10 mR and up	Survey and monitoring	20 keV for X-rays 200 keV for betas	Inexpensive Gives estimate of intergrated dose Provides permanent record	False readings produced by heat, certain vapours and pressure Great variations with film type and batch Strong energy dependence for low-energy X-rays
TLD	Beta, X, gamma	10 mR to 10^5 R(LiF)	Survey and monitoring	1 MeV for betas 10 keV for X-rays	Low energy dependence High sensitivity Low cost	Evaluation temperature dependence

*Source: National Council for Radiation Protection (NCRP) 48, Radiation Protection for Medical and Allied Health Personnel

APPENDIX B

TOMOSCAN CX/Q Reference guide

Gantry angulation limits

B_1

Negative gantry tilt	
table height (millimetres)	max. angle
0 to 9	-7°
10 to 19	-10°
20 to 29	-12°
30 to 39	-15°
40 to 49	-18°
50 to 250	-20°

B_2

Positive gantry tilt	
table height (millimetres)	max. angle
0 to 9	+8°
10 to 19	+10°
20 to 29	+12°
30 to 39	+14°
40 to 49	+16°
50 to 59	+18°
60 to 250	+20°

APPENDIX C

TOMOSCAN CX/Q Reference guide

Protocol suggestions

Key protocols

	Brain	Post fos	Thorax	Abdom	Spine
head / body	H	H	B	B	B
matrix*	320	320	512	512	512
FOV	210	210	360	360	420
scan time	4.5	6.0	2.8	4.5	6.0
slice th.	10	5	10	10	5
filter	0	0	3	2	2
kV	120	120	120	120	120
mA	90	90	150	110	110
T index	10	5	-10	-10	-5
scan count	12	10	30	30	25
U level	40	50	-700	30	40
U width	85	150	800	400	400
L level	40	250	20	30	175
L width	150	1200	350	200	1000
scano	LAT	LAT	PA	PA	LAT
length	250	250	350	450	250
slice th.	2	2	2	2	2
filter	0	0	3	3	4
kV	120	120	120	120	120
mA	50	50	90	70	110
direction	out	out	in	in	in
U level	200	200	375	175	200
U width	400	400	400	350	400
L level	100	100	200	150	200
L width	250	250	400	250	400

APPENDIX D

DEPARTMENT OF RADIOLOGY - KNH

RADIATION DOSES TO PATIENTS DURING CT OF THE HEAD AT KNH

CONSENT FORM

DATE ..../..../....

(1) I .... of ....
agree to undergo CT Scan examination.

(2) I agree to have my child undergoing CT Scan examination of which nature and effects have been fully explained and understood by me, and that the outcome of this study will be treated in confidence .

Patient's signature

Witnesses's signature
(Investigator)

....

APPENDIX E

RADIATION DOSES TO PATIENTS DURING COMPUTED TOMOGRAPHIC EXAMINATIONS OF THE HEAD AT KNH

DATA COLLECTION FORM

1. Name of the patient: .... Wds ....
2. Address .... Clinic No. .... Surgical ...
   Neuro ..... Med ..... Paed .....
3. Age ..... Sex: M ..... F .....
4. CT examination requested: Head (Brain) .....
5. First done ..... Repeat .....
6. INDICATION FOR CT SCAN: TRAUMA .... NON-TRAUMA .....
7. CT parameters: Detector .... Filter .... KvP ....
   Scan time .....Secs MA .....
8. Slice thickness ....mm Number of slices .....
9. Scan angle ..... Baseline .....
10. Scan method: head first .... Feet first ....
    Scan without contrast material ... Pre and post contrast ....
    TLDs SITE OF APPLICATION: ..... Corresponding organ ....
    After readout dose ......
11. Radiation dose in Absorbed dose ....mGy
    Record reading of all TLDs: Organ dose

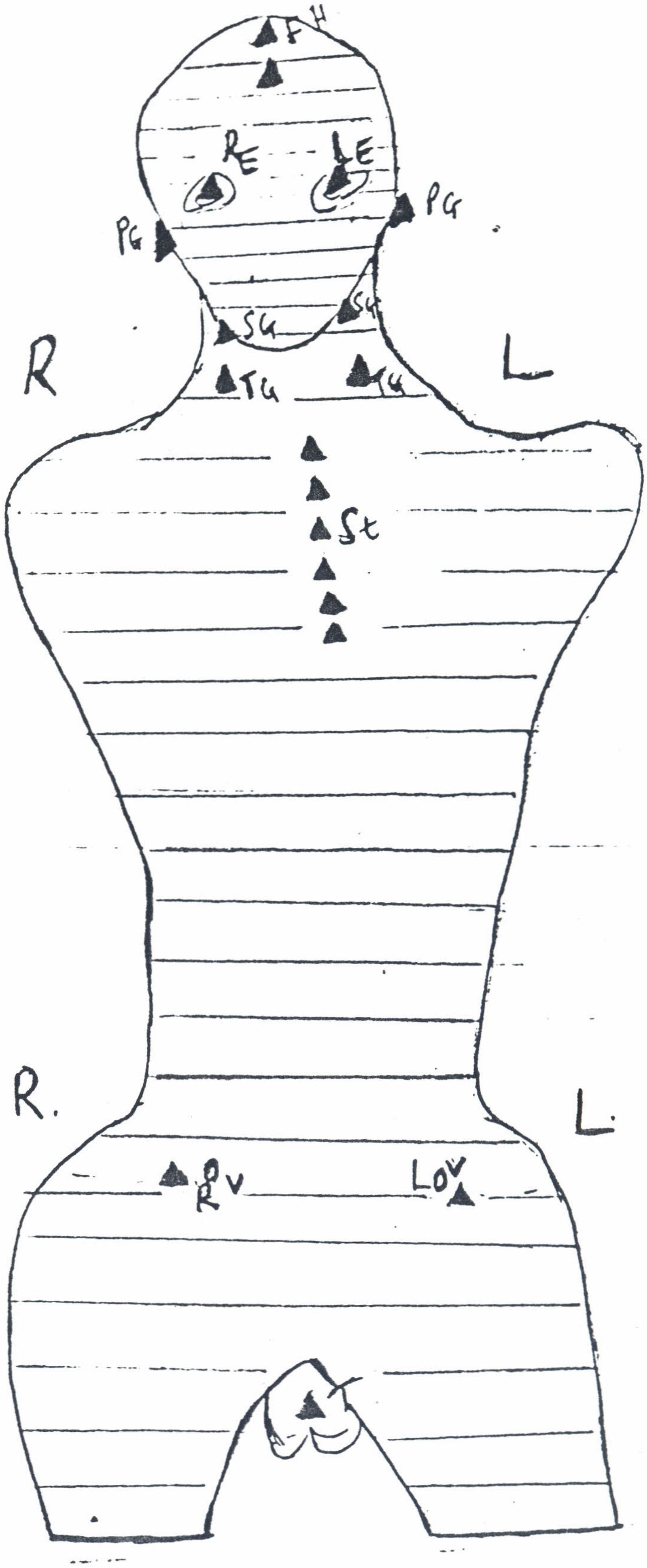
Organ	dose
1) Frontal bone	....
2) Eye	....
3) Parotid	....
4) Sub-mandibular	....
5) Thyroid	....
6) Sternum	....
7) Testes	....
8) Ovary	....

Investigator:

Resident Doctor:

Supervisor:

F:- DIAGRAM OF DOSE MEASUREMENT



Key :-

FH = Forehead

▲ = Dosemeter-TLD-Li

RE = Right Eye

LE = Left Eye

PG = Parotid gland

SG = Submandibular glan

TG = Thyroid gland

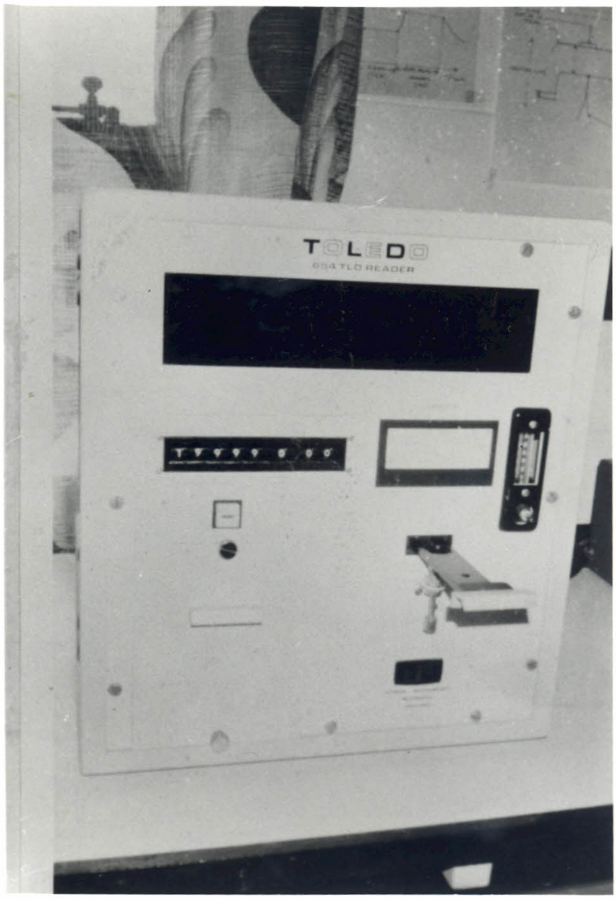
St = sternum

Rov = Right overy

Lov = Left overy

T = Testes

G:- <u>THE TOLEDO - 654 - READER</u>



H:- I - GANTRY AT 0°

H-2:- <u>NEGATIVE GANTRY TILT</u>

H-3:- CONTROL PANEL