Organ Dose Distribution and Estimated Cancer Risk to Paediatric Patients Undergoing Computed Tomography in a Nigerian Tertiary Hospital

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ABSTRACT

Aims: The aim of this research work is to estimate the organ dose distribution and the associated radiation induced cancer risk for some commonly performed Computerized Tomography (CT) examinations in a tertiary medical facility in South Nigeria.
Study Design: The study was designed to estimate the radiological implications of radiation dose that the paediatric patients were exposed to during routine CT examinations.
Place and Duration of Study: Department of Radiology, Obafemi Awolowo University Teaching Hospital Complex, (OAUTHC), Ile-Ife, Nigeria, between August 16, 2011 to August 15 2012.
Methodology: Well calibrated thermoluminescent dosimeters (LiF-100) were attached to the skin of paediatric patients such as skull, chest, abdomen, and pelvic in the path of the primary X-ray beam to determine radiation exposure during CT examination. The effective dose was calculated from the equivalent dose obtained from OAUTHC, and the cancer risk associated was estimated by multiply age-dependent lifetime cancer mortality risk (per unit dose) with estimated age-dependent doses produced by various CT examinations.
Results: Out of 258 paediatric patients scanned the equivalent dose measured for abdominal CT scan ranged from 23.49 - 55. 26 mSv; skull CT scan ranged from 10.07 – 69.94 mSv and chest CT scan ranged from 8.60 – 31.94 mSv. The peak tube voltage (kV_p) used range from 80 – 140 while the exposure current-time product (mA) range from 30 – 300. The abdominal CT scan had the highest cancer risk ranging from digestive 37.5% to lung cancer risk of 0.4%. The risks estimated in this work were higher than the ICRP recommended value. Reducing the millampere-second setting of the equipment for paediatric without significant loss of radiological information will reduce this risk.
Conclusion: In this study the estimated cancer risk to paediatric patients undergoing CT is high. This is in keeping with findings in a previous study thus emphasizing the need to standardize and optimize radiation dose in paediatric patients undergoing CT in Nigeria so as to keep cancer risk at the minimum.

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1. INTRODUCTION

Computerized Tomography (CT) is valuable across sectional imaging modality used for diagnostic purposes in various clinical scenarious in adults and children. According to Linet et. al. and Mettleret. al. CT delivers much higher radiation doses than the conventional diagnostic X-rays [1, 2]. Berrington et. al. reported that when paediatrics are exposed to radiation during medical exposure the likelihood of expressing a delay in radiogenic cancers is high, because paediatrics have high radiosensitivity of the actively growing tissue and high probability of longer life expectancy [3]. The exposure of paediatrics to ionizing radiation is one of the few established risk factors for childhood cancers. The DNA changes occur when human body is exposed to ionizing radiation, and may act as an initiator in carcinogenesis. The cells affected by larger doses of radiation cannot repair themselves but experienced cell death. The inadequate DNA-repair may result in mutations, which may change the reproduction and behaviour of cell growth. Damages to this molecule leading to cancer can be caused through the direct ionization by radiation or by its indirect action in the formation of free radicals in water in close proximity to the genome. The National Academy of Sciences' National Research Council comprehensively reviewed biological and epidemiological data related to health risks from exposure to ionizing radiation, published as the Biological Effects of Ionizing Radiation [4]. Many efforts to record patient dose have been initiated by many international groups such as FDA (Food and Drug Administration) [5], ACR (American College of Radiology [6], and IAEA (International Atomic Energy Agency [7]. Since radiation exposure from CT examinations are all associated with higher doses but none has been initiated in Nigeria, this work will stand as initiator. In the work of Twombly et. al. the possibility that CT may cause more cancers than it prevents has been raised with respect to full-body screening CT examinations conducted in asymptomatic persons [8]. In Nigeria, the research conducted by Ogbole et. al. shows that neither physicians nor patients are generally aware of the radiation associated with CT, its risk of carcinogenesis, or the importance of limiting exposure among younger patients [9]. If we know how much radiation dose medical imaging delivers then the potential for harm it may cause can be compared against the potential for benefit. It has been established that making both physicians and patients aware of this risk is important [10-12]. There is a potential increase in the lifetime risk of radiation- induced fatal cancer from paediatric CT [13]. Some research works have been done on CT in Nigeria [14-17], no work has been done to estimate the actual patient-specific radiation dose received by paediatric patients in clinical practice and the life time attributable risk of cancer this work will also be a starting point in Nigeria and this work addressed it.

2. MATERIALS AND METHODS

A set of three hundred and fifty (350) well calibrated Lithium fluoride (LiF) TLD-100 was used for the collection of data from 258 paediatric patients at OAUTHC. Each of the properly labelled annealed thermoluminescent dosimeters (TLDs) chip was enclosed in a black cellophane bag. Radiation doses to typical CT examinations such as chest, abdomen and skull/pelvic were measured with three (3) of this TLD chips the average reading was taken to be radiation dose for that examination. [15].

2.1 Computation of Effective Dose and Cancer Risk Estimates

An important aspect of this research work is to compute the effective dose from the equivalent dose obtained from OAUTHC Aborisade et. al. reported it [15], subsequently this work computed cancer risk associated with the procedures using the lifetime attributable cancer mortality risks per unit dose as function of age at a single acute exposure as estimated [13]. The resulting biological effects of different types of radiation having the same energy dose varies, additional biological weighting of the energy dose was necessary. This was done using the so-called equivalent dose. In ICRP paper [18] an equivalent dose for a certain organ or tissue is defined as

$$H_T = \sum_R W_R \, . \, D_{T,R} \qquad (1)$$

Where $D_{T,R}$ represents the dose applied to the organ T with respect to the type of radiation. W_R represents the radiation weighting factor, which

for X-ray is [18]. The varying radiosensitivity of different organs and tissues were taken into account, by introducing a tissue weighting factor, W_T, which gives effective dose *E* (as opposed to the equivalent dose H_T). The effective dose *E* which is the sum of the weighted equivalent doses in all the tissues and organs and it is given by

$$E = W_T . H_T = \sum_R W_T . W_R . D_{T,R} \quad (2)$$

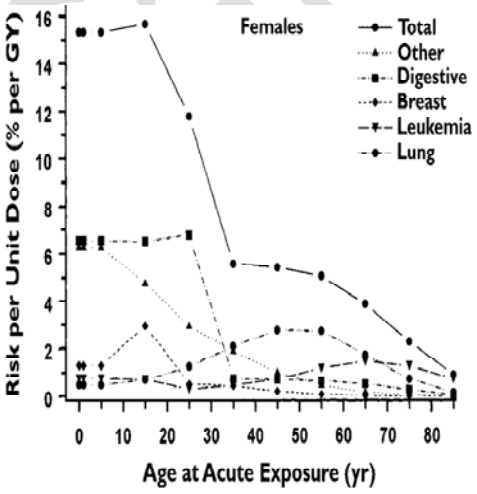
The induction of stochastic effects of carcinogenesis and genetic effect are major radiation risk to patients from CT examinations [18]. The effective dose is generally regarded as the best available dose descriptor for quantifying these stochastic risks in diagnostic radiology [19]. According to Huda (2002), for paediatric the effective dose cannot be used to estimate the risk because for a given amount of energy that is put in, the corresponding doses will be substantially higher than that of adult , this leads to substantially higher effective dose [20]. The main technique used in this work was to multiply age-dependent lifetime cancer mortality risk (per unit dose) by estimated age-dependent doses produced by various CT examinations [13]. The age dependence of the cancer mortality risk varies considerably from site as shown in Figure 1. Thus, for a highly inhomogeneous dose distribution produced by a CT examination, the age dependence of the overall cancer risk cannot be directly inferred from estimates of the total cancer mortality per unit effective dose. Instead, the age dependence of the risk for the various group sites are each separately calculated by applying appropriate site specific doses to the age and site-dependent risk, this site specific risks are then summed to yield the overall age-dependent lifetime cancer mortality risk [13].

The values of the dose measured from OAUTHC by various organs were used to estimate the cancer risk. The specific groupings of potential types of cancer for which evaluated radiation-induced risks are available are leukemia, breast (for female) cancer, lung cancer digestive system cancer and other cancer using the estimate lifetime attributable cancer mortality risks per unit dose as function of age at a single acute exposure as estimated by the National Academic of Science BEIR V [21]. In this work other cancer means cancer of brain, thyroid, bladder, kidney, adrenal gland, spleen, thymus, skin, bone testes (for men) and uterus (for female) and ovaries (for women), while digestive cancer means cancer of colon, stomach, liver, pancreas, esophagus, and small intestine. For leukemia, lung, and breast cancer in female dose to the bone marrow, lung and female breast were respectively used. For digestive cancer, a weighted average of the doses to the relevant organs was used, the weighting consisting of the relevant radiation-carcinogenic sensitivities of these organs. Thus, the dose to the digestive organs was computed as

$$D_{digestive} = \frac{\sum_T w_T . D_T}{\sum_T w_T} \quad (3)$$

Where the summation is over the tissues (T) of the colon, stomach, liver, pancreas, esophagus,

Graph A



Graph B

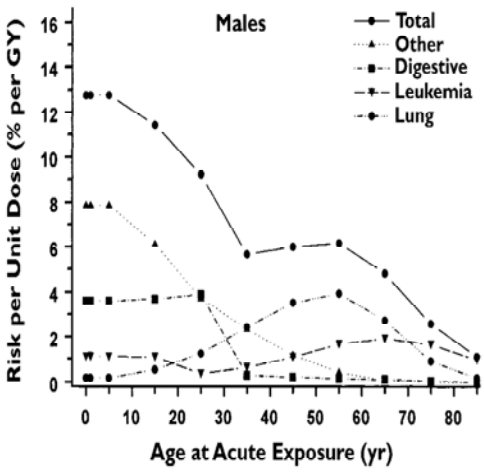


Fig. 1. Breakdown by Cancer Type. A and B, Graphs show breakdown by cancer type of risk per unit dose for females (A) and males (B) of lifetime attributable cancer mortality risks as a function of age at a single acute exposure as estimated by the National Academy of Sciences BEIR V (Biological Effects of Ionizing Radiations) committee. [22]

and small intestine, w_T are the weighting factors representing the evaluated relative radiation-carcinogenic sensitivities of the different tissues and were taken from 1990 International Commission of Radiological Protection recommendations [13]. Similarly, the dose of other cancer was computed as

$$D_{other} = \frac{\sum_T w_T . D_T}{\sum_T w_T} \quad (4)$$

Where the summation is over the tissues (T). Other cancer means cancer are brain, thyroid, bladder, kidney, adrenal gland, spleen, thymus, skin, bone testes (for men) and uterus (for female) and ovaries (for women).

3. RESULTS AND DISCUSSION

In one calendar year a total of two hundred and fifty eight (258) paediatric patients were scanned at OAUTCH for this research work. The rate at which paediartics were scanned at the hospital was low because of the high dose involved in CT examination; therefore most of them were examined with Magnetic Resonance Imaging (MRI).

Out of the 258 who had CT examinations 143 (55.43%) are male while 115 (44.57%) are female. Out of the 258 paediatrics 127 of them had CT examination of the skull, 61 abdomen while 70 had chest CT. Contrast media was used on 182 of the patients while no contrast was used on 76 of the patients because of the nature of the examination involved.

The values of the equivalent dose measured with the calibrated dosimeter chips for abdominal CT scan ranged from 23.49 - 55. 26 mSv; skill CT scan ranged from 10.07 – 69.94 mSv and chest CT scan ranged from 8.60 – 31.94 mSv. The peak tube voltage (kV_p) used range from 80 – 140 while the exposure current-time product (mA) range from 30 – 300.

Samples of the effective doses calculated using equation (2) from the equivalent dose obtained at OAUTHC are presented in Tables 1-3.

3.1 Estimated Risk of Cancer from CT Examination

Equation 2 was used to calculate the effective dose for the following organs active bone marrow, breast, colon, liver, lung, ovary, prostate, stomach, thyroid, uterus and urinary bladder. The result is presented in Tables 1-3.

In this work the values of the lifetime cancer mortality risk attributable to radiation from paediatric CT examinations is inexplicably much larger than the data obtained by Brenner et al.(2002): abdominal CT Scan 37,5% vs. 0,18%,

Table 1. The effective dose for various organ/tissue for patients who undergone chest CT scan at OAUTHC

	Bone marrow	Brest	Colon	Liver	Lung	Ovary	Prostate	Stomach	Thyroid	Uterus	Bladder	Reminder
17 hours male	1.032	NA	1.032	0.344	1.032	NA	0.0785	1.032	0.043	NA	0.026	3.98
45 days male	0.141	NA	1.583	0.528	1.583	NA	0.066	1.583	0.046	NA	0.022	7.64
11 years male	3.833	NA	0.028	0.09	0.028	NA	0.028	0.028	1.278	NA	0.0092	26.7

Table 2. The effective dose for various organ/tissue for patients who undergone abdominal CT scan at OAUTHC

Age (years)	Bone marrow	Brest	Colon	Liver	Lung	Ovary	Prostate	Stomach	Thyroid	Uterus	Bladder	Reminder
11 years	0.0862	4.478	4.478	1.493	14.478	2.706	NA	4.478	0.0287	4.059	1.353	9.678
4 years male	0.0485	NA	3.396	1.132	3.396	NA	3.396	3.396	0.0162	NA	1.132	12.388
8 years male	0.0279	NA	6.631	2.2103	6.631	NA	6.631	6.631	0.093	NA	2.110	24.276

Table 3. The effective dose for various organ/tissue for patients who undergone skull CT scan at OAUTHC

	Bone marrow	Brest	Colon	Liver	Lung	Ovary	Prostate	Stomach	Thyroid	Uterus	Bladder	Reminder
4 months male	2.607	NA	0.095	0.012	0.095	NA	0.085	0.035	0.869	NA	0.012	17.966
15 years female	8.393	0.1084	0.1084	0.036	0.1084	0.0094	NA	0.1084	2.798	0.014	0.0047	58.25
2 years male	3.529	NA	0.114	0.0084	0.114	NA	0.0251	0.0251	1.1765	NA	0.0084	24.42
9 years female	7.577	0.106	0.106	0.035	0.106	0.07	NA	0.106	2.526	0.011	0.0036	52.56

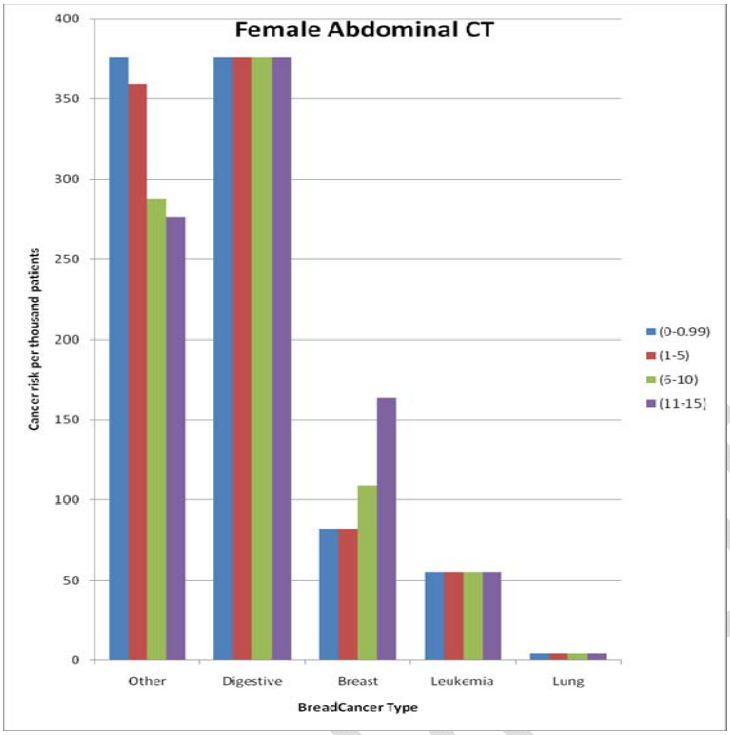


Fig. 2. The estimated cancer risk per thousand patients from patients who had abdominal CT scan

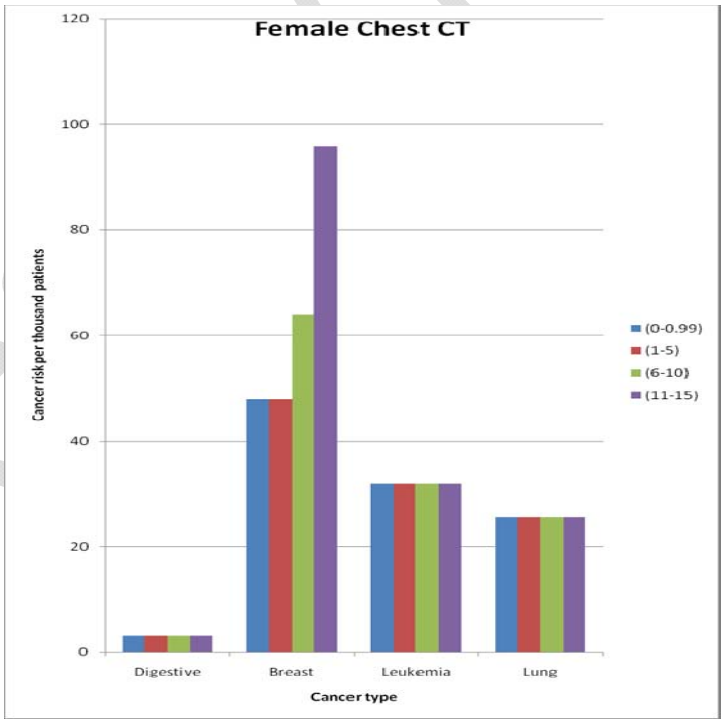


Fig. 3. The estimated cancer risk per thousand patients from paediatric patients who had chest CT scans

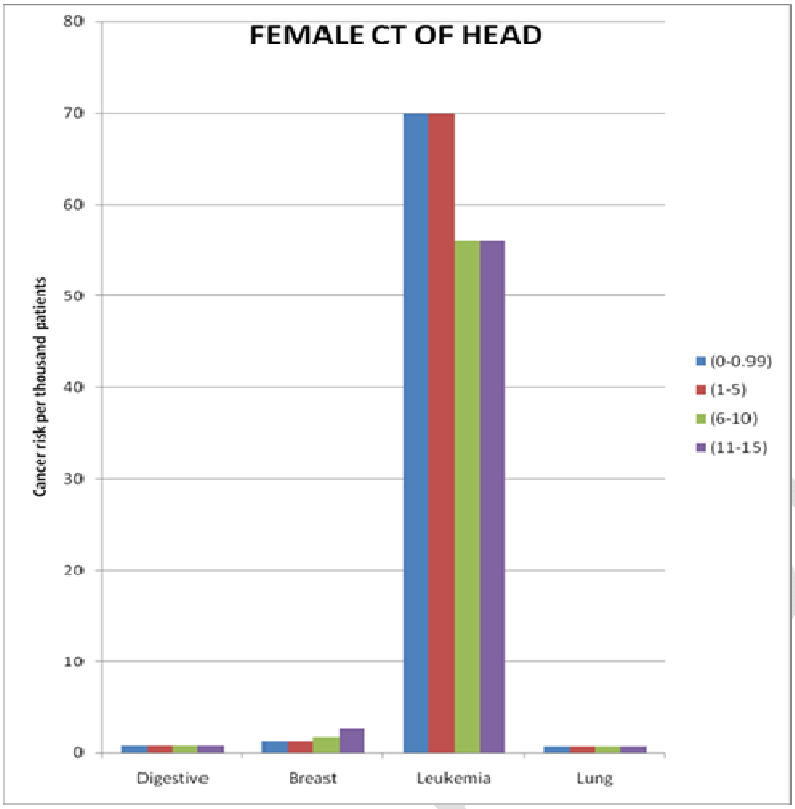


Fig. 4. The estimated cancer risk from paediatric patients who had Skull CT Scans

208 times higher; head CT 7% vs 0.067%, 104 times as shown in Figs. 2 and 4.

Form CT examinations considered in this work—abdominal and head—the dominant predicted induced malignancies are, respectively, of the digestive organs and of leukaemia (the brain) Fig. 5. Female are more radiosensitive than male as shown in Fig. 5. Several studies have suggested that a technique with significant reduction in exposure (milliampere-seconds) could be adopted for paediatric CT examinations without significant loss of required radiological information according to (Robinson et al. 1986) [23-26] reduction in the dose will lead to corresponding reduction in risk.

3.2 Comparison of Risk in the Body

Figs. 2 to 4 show the estimated lifetime cancer mortality risk attributable to a single CT examination performed on paediatric at different ages. Results are shown for three of the most common routine CT examinations, CT of chest, CT of the head and CT of the abdomen.

Breakdowns of the estimated lifetime cancer mortality by sex and by site are shown in Fig. 5. For head CT examinations, the estimated "other cancer" mortality category is dominated by brain cancer. For abdominal CT examinations, the risks are dominated by digestive organ cancer, primarily stomach, liver, and colon cancer. Overall, the estimated risks for abdominal CT examinations are significantly greater than those for chest and head examinations, primarily because of the larger combined lifetime mortality risks (per unit dose) for exposure of the digestive organs relative to exposure of the brain and thyroid.

Estimated lifetime cancer mortality risks from abdominal CT examinations are somewhat

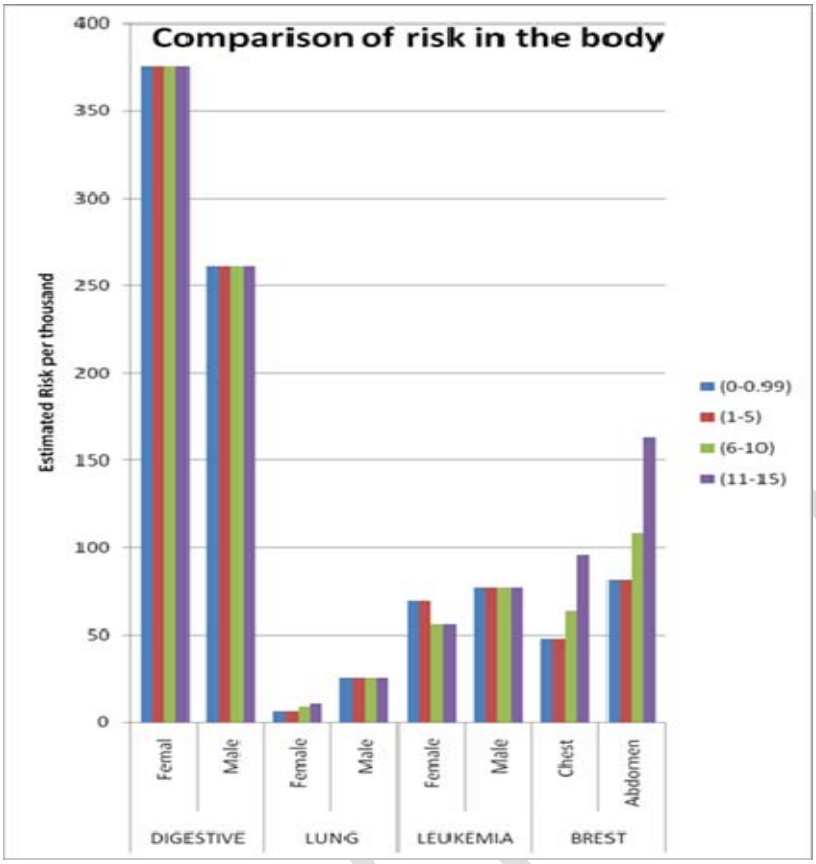


Fig. 5. The comparison between male and female estimated cancer risk from paediatric patients who had CT scans at OAUTHC

greater for women than for men, an effect that is caused by the significantly greater estimated risks per unit dose for digestive organ cancer in women (Fig. 1). The sex effect for head examinations is smaller because estimated brain tumour risks do not vary greatly with sex.

Estimated lifetime cancer mortality risks breast cancer type is uniform from a newborn baby to 5 year old but increases with age from 6 year old to 15 year because the female starts developing breast from these ages.

4. CONCLUSION

The risks estimated in this work are higher than the ICRP recommended value and values. The dose and the risks obtained in this work are age and sex dependent. This is due to exposure parameters which are not optimized for different paediatric age groups. We recommend further training of all personal involved in paediatric imaging in the use of age specific CT protocols. As suggested by previous researchers, there is also need for procurement of CT scanners with paediatric protocols for CT imaging. The result of this work has shown that there is an urgent need for standardization of procedures and establish refence levels for the various diagnostic procedures in the country.

CONSENT DISCLAIMER

As per international standard or university standard, patient's written consent has been collected and preserved by the author(s).

ETHICAL APPROVAL

The authors got the Ethics and Research Committee approval from the hospital with Registration number IBR/IEC/0004553

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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