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Correlation of Volume Computed Tomography Dose Index and Dose Length Product with Acquisition Parameters in Abdomino-pelvic and Cranial Computed Tomography Imaging

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Introduction: The use of Computed Tomography (CT) in medical diagnosis showing more complex fractures and other pathological findings in 3D, delivers relatively higher radiation doses to patients when compared to conventional X-rays. In order to maintain good diagnosis while reducing patients' dose, it is necessary to assess the contributions of CT scan acquisition parameters (kV, mAs and scan length) to patient dose, and improve the selection of those parameters. This work aimed at investigating the relationship between the Volume CT Dose Index ($CTDI_{vol}$) and Dose

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Length Product (DLP) with scan acquisition parameters in other to establish the Correlation of $CTDI_{vol}$ and DLP with scan acquisition parameters in Abdomino-Pelvic and Cranial CT.

Methodology: A total of 61 existing patients' data with scan acquisition parameters were collected: Cranial CT (39) and Abdomino-pelvic CT (22). Pearson correlation analysis was used to establish the relationship between scan acquisition parameters and Total $CTDI_{vol}$ and Total DLP.

Results: The Total $CTDI_{vol}$ ranged from 135.6 to 215.5 mGy for cranial CT and 26.1 to 124.4 mGy for Abdomino-pelvic, while DLP ranged from 2631.0 to 6542.8 mGy.cm for cranial and 1147.5 to 5441.8 mGy.cm for Abdomino-pelvic.

The $CTDI_{vol}$ showed moderate positive correlation with kV (r = 0.625, P value < 0.01) for Cranial and strong positive correlation (r = 0.821, P value < 0.01) for Abdomino-pelvic CT, while DLP showed strong positive correlation (r = 0.767 and 0.839, P value < 0.01) for both Cranial and Abdomino-pelvic. The $CTDI_{vol}$ and DLP showed strong positive correlation with mAs (r = 0.843 and 0.839, P value < 0.01) for both cranial and abdomino-pelvic CT. $CTDI_{vol}$ and DLP showed a strong positive correlation with scan length (r= 0.712 and 0.881, P value < 0.001) for both Cranial and Abdomino-pelvic CT. Increase in kV, mAs and scan length may cause significant increase in $CTDI_{vol}$ and DLP in Cranial and Abdomino-pelvic CT.

Conclusion: The relationships between $CTDI_{vol}$ and DLP with scan acquisition parameters in adult patients have been investigated for both Cranial CT and Abdomino-pelvic CT. It was observed that scan acquisition parameters (kV, mAs and Scan length) had linear relationship with $CTDI_{vol}$ and DLP in both investigations.

Keywords: Computed tomography; correlation; Volume Computed Tomography Dose Index ($CTDI_{vol.}$); Dose Length Product (DLP); Abdomino-pelvic CT scans.

1. INTRODUCTION

Computed Tomography (CT) is an efficient diagnostic tool for the diagnosis and management of various clinical indications because of its ability to acquire high-quality 3-D diagnostic images. CT scans are particularly beneficial in the diagnosis of Cranial and Abdominal ailments because of its effectiveness in proper diagnosis. Therefore, it enables faster and accurate diagnosis without recourse surgical procedure. The amount of radiation dose associated with CT is 10 – 100 times greater than conventional X-ray which puts patients to higher risk of cancer induction [1].

Computed Tomography Dose Index (CTDI) and Dose Length Product (DLP) are considered as dose descriptors in CT. They are displayed at the end of each scanned protocol on the summary page of the scan monitor. The $CTDI_{vol}$ is a standardized measure of the radiation output of a CT scanner although not a direct measure of patient dose. It is the amount of radiation delivered to one slice of the body part being examined over a period of time in the helical CT scanner. The DLP is the total radiation energy delivered to all the slices of the body part being scanned during a particular protocol [2].

The CTDI and DLP depend on the following acquisition parameters; tube loading (mAs), kilovoltage (kV), body size and scan length. The radiation exposures to patients undergoing CT examinations are determined by two factors: equipment-related factors, which have to do with the design of the scanner with respect to dose efficiency, and application-related factors, which have to do with the selection of protocols and parameters by the radiographer [3].

Studies emphasizing on CT parameters and radiation dose have been performed in the past [4-7]. However, a systematic analysis of the relationship between CT dose descriptors (CTDI and DLP) of Abdomino-pelvic and Cranial CT with varied parameters (kV, mAs, weight and scan length) has not been sufficiently investigated. In order to investigate how variations in acquisition parameters affects patients' dose, the relationship between the acquisition parameters and $CTDI_{vol}$ and DLP needs to be evaluated [8].The rapid evolution of CT technology and its application in patients' diagnosis, requires detailed understanding and critical investigation.

This study focuses on how scan input parameters influence patient dose during CT investigations, using Cranial and Abdomino-pelvic CT procedures. The findings will be useful in moderating the acquisition parameters (kV, mAs, weight and scan lenght) in relation to the scanner output.

2. THEORETICAL BACKGROUND

Two related measures of CT radiation dose are available on CT consoles: the Volume Computed Tomography Dose Index ($CTDI_{vol}$) and the Dose Length Product DLP. Both functions have reasonable proxies for absorbed dose but do not represent the actual patient dose.

Computed Tomography Dose Index (CTDI) represents the radiation dose of a single CT slice and is determined using acrylic phantoms. These acrylic phantoms are cylinders of a standard length and are generally in diameters of 16 cm and 32cm. The original incarnation of the CTDI was based on an axial CT scanner. Several variations of the CTDI have been defined. The $CTDI_{100}$ is the dose contribution from a 100 mm range, centered on the index slice. The weighted CTDI ($CTDI_w$) is the weighted sum of two-thirds peripheral dose and one third central dose in a 100 mm range in acrylic phantoms [9].

The Volume Computed Tomography Dose Index ($CTDI_{vol}$) represents the scanner output. It is defined as $CTDI_w$ divided by the beam pitch factor (equation 1). It is the most commonly used index for modern Multiple Detector Computed Tomography (MDCT) equipment.

The $CTDI_{vol}$ can be calculated as:

$$\mathrm{CDDI_{vol}} = \frac{\mathrm{NT}}{\mathrm{I}}(\mathrm{CTDI_w}) \quad (1)$$

Where: $CTDI_w$ is the weighted or average CTDI given across the field of view, N is the number of simultaneous axial scans per x-ray source rotation, T is the thickness of one axial scan (mm) and I is the table increment per axial scan (mm).

In helical CT, the ratio of I to NT is the pitch. Therefore, in helical mode,

$$\mathrm{CTDI_{vol}} = \frac{1}{\mathrm{Pitch}} * \mathrm{CTDI_w} \quad (2)$$

$CTDI_{vol}$ represents the dose for a specific scan protocol which takes into account gaps and overlaps between the radiation dose profile from consecutive rotations of the x-ray source. Therefore, $CTDI_w$ represents the average radiation dose over the x and y direction, whereas $CTDI_{vol}$ represents the average radiation dose over the x, y and z directions [9].

Dose Length Product (DLP) is the measure of ionizing radiation exposure during the entire acquisition of images [10].

DLP (mGy.cm) = $CTDI_{vol}$ x irradiated length (slice thickness x number of slices) in centimeters (3)

$CTDI_w$ and $CTDI_{vol}$ are independent of scan length for determining the total energy absorbed whereas DLP is proportional to scan length.

The CT machine input parameters are kilovoltage peak (kV) and milliampere-second (mAs).

Kilovoltage peak (kV) is the peak voltage applied to the x-ray tube. It determines the highest energy of the x-ray photon. It is responsible for the acceleration of electrons from the cathode to the anode.

In Computed Tomography, reducing kV can be an effective means of reducing the radiation dose imparted during an examination. As a rule of thumb, the radiation dose changes with the square of kV, thus a reduction in kV from 120 to 100 reduces radiation dose by 33% while a further reduction to 80kV can reduce dose by 65%. Nevertheless, unlike reductions in mAs, which have a linear and relatively predictable effect on image noise and contrast-to-noise ratios, decreases in kV can result to non-linear, exponential increases in image noise [11].

Tube Loading (mAs) is a measure of radiation produced over a period of time in seconds via an x-ray tube. An increase in current (mA) results in a higher production of electrons in the x-ray tube. This will therefore increase the quantity of radiation produced. Increase in mAs improves image quality and decreases image noise. The relationship between the tube loading and patient dose is essentially linear. Increase in mAs results in a comparable increase in patient dose [12].

3. MATERIALS AND METHODS

A retrospective study involving collection of various exposure parameters of Cranial and Abdomino - pelvic CT scan post investigation with a Toshiba Aquilion 64 slice CT machine at the Radiology Department, University College Hospital, Ibadan. The study population comprised of patients with medical request for cranial or abdomino-pelvic CT that report for the investigation within the period of the study at the

CT unit of the Radiology Department, UCH, Ibadan. The assessment involved adult Patients with medical request, who were scanned for cranial or Abdominal – pelvic CT, and exclude; children, unconscious patients, very ill patients, CT patients with high risk of contrast media administration and patients with other CT examination request.

The sample size was calculated considering the population of all patients whose CT (cranial and abdomino-pelvic) procedures were within the interval of April – June, 2019. The sample size was determined using Taro Yamane formula [13,14]. The formula is stated in equation 4.

$$n = N(1 + Ne^2) \quad (4)$$

Where N signifies the minimum sample size, e is the significant level (0.05%), resulted to 73 sample size.

$$n = 73(1 + 73\ (0.05)^2) = 61.7 \quad (5)$$

Exposure parameters such as kV, mAs, Scan length, and Slice thickness were obtained from the CT scanner. The resultant dose descriptors: Volume Computed Tomography Dose Index CTDI $_{vol}$ and Dose Length Product (DLP) were obtained from the CT machine patients' data base. Total mAs and total scan time including patient's demographic data: age, sex and weight were also recorded. A total of 61 patients' data that underwent CT examination were retrospectively studied. Thirty-nine (39) patients underwent cranial examination and twenty-two (22) patients underwent Abdomino-pelvis examination. In the cranial category, there were 21 male and 18 female patients and in the Abdomino- pelvic category there were 8 male and 14 female patients. The mean age of patients for cranial examination was 52$\pm$12 years while that of Abdomino-pelvic examination was 57$\pm$3 years.

The data collected was analyzed descriptively (mean, range and standard deviation) using Statistical Package for Social Science (SPSS-27). Each of the scan parameters (kv, mAs, weight, scan length) were correlated with the dose descriptors ($CTDI_{vol}$ and DLP) using Pearson Product – Moment Correlation.

The exposure parameters; kV, mAs, slice thickness, for both procedures are presented in Table 1.The acquisition detector configuration is also stated in the table, which is the product of the number of detector rows (N) and the slice thickness (T). Pitch is the ratio of the table movement per rotation and detector configuration.

In this study the pitch was 21 for cranial and 53 for abdomino- pelvis CT examinations.

4. RESULTS AND DISCUSSION

A comparison between kV, mAs, Scan length, weight and the dose descriptors $CTDI_{vol}$ and DLP was done. Correlation was performed using Pearson's Correlation to establish the degree of linear relationship between two variables which is the Scan input parameters with the $CTDI_{vol}$ and DLP.

The relationships between weight and Total $CTDI_{vol}$ with weight and DLP are represented with a scatter plot shown in Fig. 1a and 1b respectively. There was a very weak correlation between weight and Total $CTDI_{vol}$ (r = .117, n = 39, p = > .05). Similarly, there was no significant correlation between weight and DLP (r = .285, n = 39, p = > .05).

Table 1. Exposure parameters for Cranial CT and Abdomino-pelvis CT examinations

Exposure Parameters	Cranial CT	Abdomino-pelvis CT
Range of Tube Loading (mAs)	200– 250	263-381
Range of Tube Voltage (kV)	100-120	100-120
Acquisition Detector Configuration	32 x 0.5mm	32 x 1.0mm
Slice Thickness	0.5mm	1 mm
Rotation Time	0.4s	0.4s
Pitch	21	53
Range of Patients' weight (kg)	42.9-98.8	46.7-93.1
Range of Patients' Age (yrs)	18–89	18–77
Scan Length	19-26	36.0 -46.5
Total mAs	8475-15300	3395-15285
Total $CTDI_{vol}$	135.6-215.5	26.1-124.4
Total DLP	2631.0 - 6542.8	1147.5 - 5441.8

The relationships between kV and Total $CTDI_{vol}$ with kV and DLP are shown in Fig. 2a and 2b. There was a significant correlation between the variables. There was a moderate positive correlation between kV and Total $CTDI_{vol}$ (r = .625, n = 39, p < .01), which indicated a linear relationship, while the relationship between kV and DLP showed a strong positive correlation (r= .767, n=39, p < .01).

The relationships between mAs and Total $CTDI_{vol}$ with mAs and DLP are shown in Fig. 3a and 3b. There was a significant correlation between the variables, with an r-value of 0.555 and .843 for $CTDI_{vol}$ and DLP respectively. Fig. 3a shows a moderate positive correlation between mAs and Total $CTDI_{vol}$, (r = .555, n = 39, p<.01), which indicated a linear relationship. Fig. 3b shows a strong positive correlation between mAs and DLP (r= .843, n=39, p < .01).

The Weight and Total $CTDI_{vol}$ was correlated for Abdomino-Pelvic Scan and there was a strong positive correlation between the two variables significantly (r = .701, n = 22, p<.01), which indicated a linear relationship. This is shown in Fig. 4a.The relationship between weight and DLP also had a strong positive correlation, significantly (r = .817, n=22, p < .01). Fig. 4b shows a scatter plot correlating weight and DLP.

The relationships between kV and Total $CTDI_{vol}$ with kV and DLP are shown in Fig. 5a and 5b. The kV and Total $CTDI_{vol}$ was correlated and a strong positive correlation was observed between the two variables, significantly (r = .821, n = 22, p<.01. The kV and DLP also had a strong positive correlation, significantly (r = .839, n=22, p < .01).

The relationships between mAs and Total $CTDI_{vol}$ with mAs and DLP are shown in Fig. 6a and 6b. There was a significant correlation between the variables, with an r-value of .837 and .839 for $CTDI_{vol}$ and DLP respectively, which indicated a linear relationship.

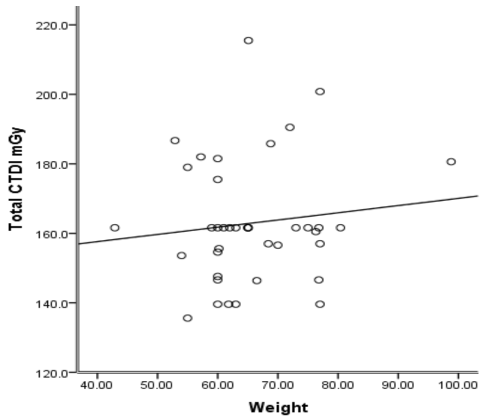

Fig. 1a. Scatter plot of weight and $CTDI_{vol}$ in Cranial CT

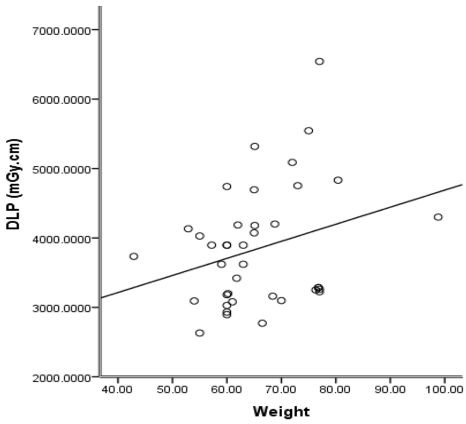

Fig. 1b. Scatter plot of weight total and DLP in Cranial CT

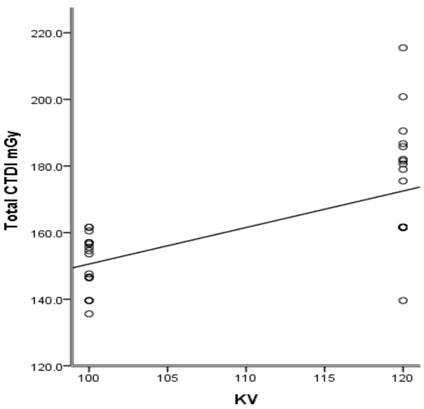

Fig. 2a. Scatter plot of kV and total $CTDI_{vol}$ in Cranial CT

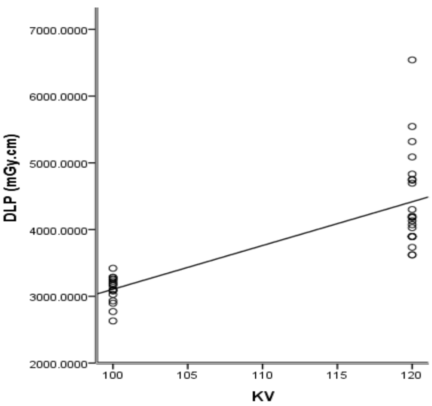

Fig. 2b. Scatter Plot of kV and DLP in Cranial CT

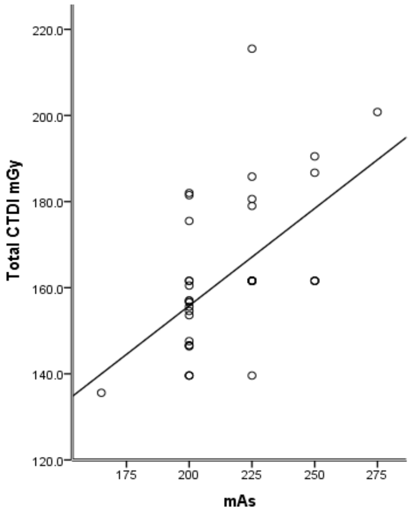

Fig. 3a. Scatter plot of mAs and total CTDI in Cranial CT

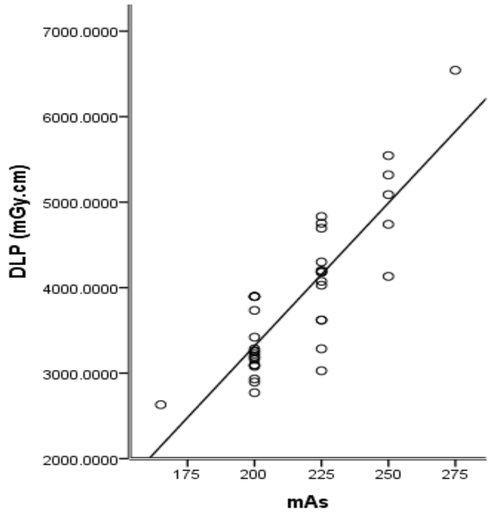

Fig. 3b. Scatter plot of mAs and DLP in Cranial CT

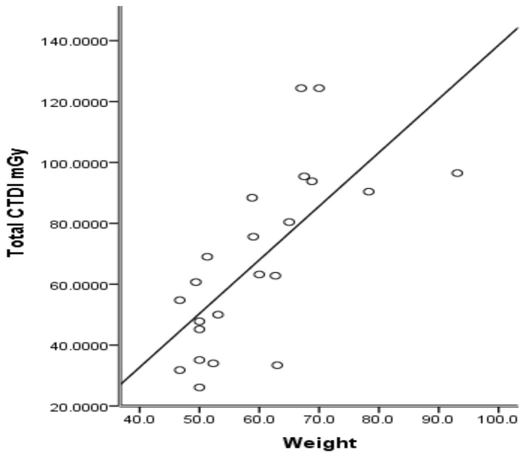

Fig. 4a. Scatter plot of weight and total $CTDI_{vol}$ in Abdomino-Pelvic CT

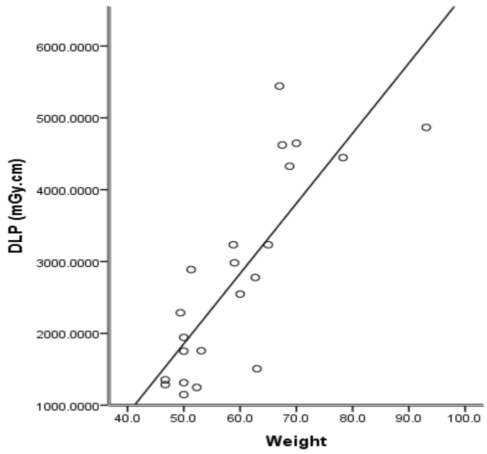

Fig. 4b. Scatter plot of weight and DLP in Abdomino-Pelvic CT

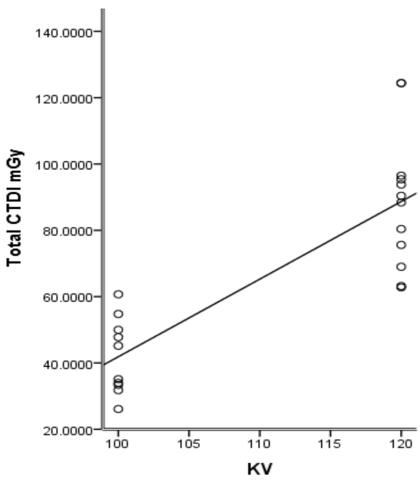

Fig. 5a. Scatter Plot of kV and Total $CTDI_{vol}$ in Abdomino- pelvic CT

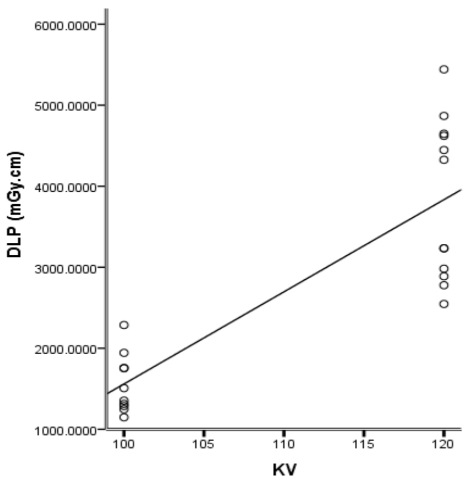

Fig. 5b. Scatter Plot of kV and DLP in Abdomino-pelvic CT

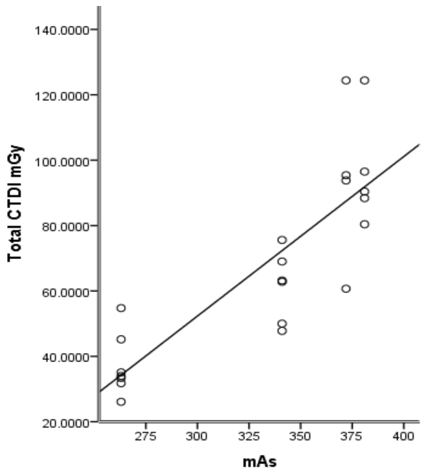

Fig. 6a. Scatter plot of mAs and Total $CTDI_{vol}$ in Abdomino- pelvic CT examination

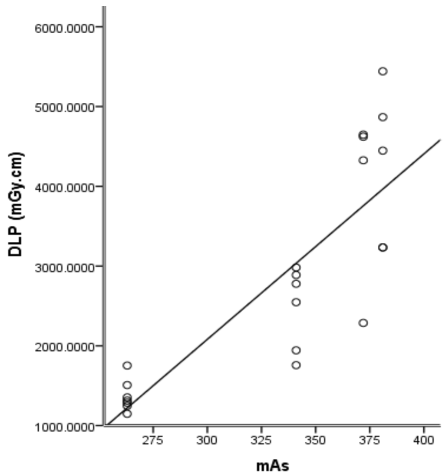

Fig. 6b. Scatter plot of mAs and DLP in Abdomino- pelvic CT examination

5. CONCLUSION

The results and findings obtained from this study are in line with the findings in the literatures. The dose metrics ($CTDI_{vol}$ and DLP) for both Cranial and Abdomino-Pelvic CT scans had linear relationships with kV, mAs and scan length. Increase in these parameters however increases the dose metrics and patient dose. In order to reduce patient dose, the scan acquisition parameters (kV, mAs and scan length) need to be reduced. This finding confirms the need to optimize the CT scan acquisition parameters, which will be useful for CT scan radiographers, as part of dose reduction techniques. It is expected that a reduction of the scan input parameters will influence the image quality. Therefore, the effect of reduction of these parameters on image quality should be investigated in future studies.

CONSENT

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

ETHICAL APPROVAL

Ethical approval was granted by the University College Hospital, Ibadan, before commencing the research work.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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