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Comparison of Size specific dose estimates (SSDE) and $CTDI_{vol}$ values in patients undergoing CT examinations of abdomen and pelvis

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Abstract

Introduction: Computed Tomography Dose Index volume ($CTDI_{vol}$) is a measure of radiation output of the CT scanner and does not represent patient dose. It often underestimates the radiation dose being given to small children and smaller adults and overestimates the dose to larger patients. The use of Size Specific Dose Index (SSDE) helps convert $CTDI_{vol}$ into more patient size specific radiation dose and is a better measure of estimated patient dose than $CTDI_{vol}$.

Methods: This cross-sectional study was conducted in the Department of Radiology and Imaging of Tribhuvan University Teaching Hospital (TUTH), Maharajgunj, Nepal. CT scans were performed on the Siemens Somaton Definition AS+ 128 slice scanner. During 96 CT examinations of the abdomen and pelvis collected over a period of 4 months, effective diameters were calculated from the AP and Lateral diameters at the mid-liver region. These were used to determine the conversion factors which were then used to convert the $CTDI_{vol}$ values to SSDE. Obtained SSDE values were compared with the displayed $CTDI_{vol}$ values.

Results: The average $CTDI_{vol}$ was found to be 9.42 ± 3.26 mGy and the average SSDE was found to be 13.48 ± 3.53 mGy. Moderate positive correlation (r=+0.52, p<0.001) was found between $CTDI_{vol}$ and patient weight and low positive correlation (r=+0.17, p=0.08) was found between SSDE and patient weight. Similarly, moderate positive correlation (r=+0.5, p<0.001) was found between $CTDI_{vol}$ and patient BMI and low positive correlation (r=+0.14, p=0.15) was found between SSDE and patient BMI.

Conclusion: In comparison with SSDE, $CTDI_{vol}$ seemed to underestimate the patient dose estimate by 30.11%. $CTDI_{vol}$ values showed dependency with patient weight and BMI, this dependency was significantly reduced when those values were converted into SSDE (i.e. r=+0.52, p<0.001 ($CTDI_{vol}$ and Patient weight) vs. r=+0.17, p=0.08 (SSDE and Patient weight) and r=+0.5, p<0.001 ($CTDI_{vol}$ and BMI) vs. r=+0.14, p=0.15 (SSDE and BMI). Thus, providing more concrete evidence to the fact that SSDE values are a more reliable patient dose estimate since it addresses the patient's size.

Introduction

Ionizing radiation has been used in the field of medical imaging since the discovery of X-ray by Wilhelm Conrad Roentgen in 1895. It is inarguable that the ionizing radiation used in CT as well as other medical imaging procedures help save patients' lives. There is however, great concern about the potential risks related to radiation-induced cancer (1–3). In one study, investigators found an increase in the estimated cancer risk from CT radiation ranging from 0.4% (in 1996) to 1.5%–2.0% (in 2007) for all cancers in the United States (4) . Such data is not available in context of Nepal. Pediatric CT radiation has been associated with the development of malignancies in children, such as leukemia and brain cancer (5). Therefore, it is imperative for CT radiation exposure to be as low as reasonably achievable (the ALARA principle). The first step towards reducing radiation doses associated with CT examinations is to understand the dose descriptors used in CT.

The computed tomography dose index (CTDI) was originally designed as an index, not as a direct dosimetry method for patient dose assessment (6). The amount of radiation a CT scanner delivers during an examination (i.e. the radiation output) can be quantified by using the volume CT dose index ($CTDI_{vol}$), which allows measurement of the dose in an acrylic cylinder for a very specific set of conditions (7). Variations in CTDI with identical radiographic techniques (same kilovolt peak and milliampere second) result from differences in x-ray tube design, tube filtration, and beam-shaping (bow tie) filters (8). For any CT examination, the $CTDI_{vol}$ and the related Dose Length Product (DLP) are displayed for a reference phantom, the diameter of which (i.e. 16 cm or 32 cm) is selected by the scanner. The dose received by a patient from a CT scan is dependent on both patient size and scanner radiation output (9). $CTDI_{vol}$ can be used to compare the radiation output of different CT scanners and different scan protocols (10). However, because $CTDI_{vol}$ is a measurement only of scanner output, it does not include information about patient size and does not represent patient dose (11). Nevertheless, this value (along with dose-length product, [DLP]) is reported in the dose page of each patient CT study. With more patients interested in radiation dose delivered by CT and other medical imaging procedures, requests to get dose information are common, but unfortunately, the dose metrics that are readily available are often misunderstood (12).

To overcome the drawbacks of CTDI, a method to estimate patient dose that accounts for patient size was introduced in the American Association of Physicists in Medicine (AAPM) Report 204 in collaboration with the International Commission on Radiation Units and Measurements and the Image Gently campaign of the Alliance for Radiation Safety in Pediatric Imaging (9). Data for absorbed dose in the center of the scan region were normalized to $CTDI_{vol}$, combined among the four research groups, and fit to an exponential relationship as a function of size. Use of the tabulated size-dependent conversion factors (f-size), combined with a measurement of patient size, allows conversion from $CTDI_{vol}$ to the size-specific dose estimate (SSDE). Patient dimensions such as anteroposterior (AP) lateral (LAT) width can be determined from the CT radiograph before the scan or from cross-sectional CT images after scan acquisition. Once the patient size is determined the effective diameter can be calculated as the square root of the product of the anteroposterior and lateral diameters then according to the effective diameter, f_{size} can be found from the appropriate table in the AAPM Report 204. SSDE of a patient can then be calculated as the product of $CTDI_{vol}$ and respective $f_{size.}$

$$\text{Effective diameter} = \sqrt{(AP \times LAT)}$$

$$SSDE = CTDI_{vol} \times f_{size}$$

The AAPM report 204 has defined SSDE as “A patient dose estimate which takes into consideration corrections based on the size of the patient, using linear dimensions measured on the patient or the patient images.” In all cases SSDE should correspond to tissue doses not air kerma or other quantities. Hence the f_{size} values (air kerma to tissue dose correction values) should explicitly be a part of the SSDE metric. SSDE as given by the AAPM report 204 significantly reduced the discrepancy in radiation dose estimates of $CTDI_{vol}$ in the clinical study and allowed dose estimate comparisons between scanners to be more meaningful. Thus, radiation dose estimates can be made accurate when using the SSDE instead of $CTDI_{vol}$ metric for reporting and comparing patient dose indices (12). Size specific dose estimation on the basis of radiation exposure metrics such as volumetric CT dose index is a great step forward in the ability to monitor and control the radiation dose associated with CT imaging (13). The use of SSDE helps convert $CTDI_{vol}$ into more patient size specific radiation dose. For SSDE calculation, transverse CT images should be used to estimate patient size rather than the localizer, since localizer radiographs generally overestimate patient size due to magnification. Measurement of patient size can be obtained from the mid-slice location on the transverse CT image series **(**14). The application of SSDE conversion factors provides patient dose estimates with improved accuracy and precision by accounting for differences in body habitus and $CTDI_{vol}$ calibration phantom diameter. Mitigating these discrepancies prior to delivering CT radiation dose information to the patient is a prime reason to apply SSDE methods as a first step in a larger, future effort to achieve more accurate radiation dose and risk estimates for the patient (12).

Supanich M and Peck D (15) in 2012 tried to validate the use of a SSDE, as proposed by AAPM TG Report 204, as an indicator of absorbed organ doses. They concluded that Size-Specific Dose Estimate offered a patient-specific, estimate of absorbed organ doses for clinical CT studies of the Abdomen and Pelvis in the absence of access to Monte Carlo simulation software. Absorbed organ doses are very close to SSDE in CT exams of the abdomen and pelvis (15). Researchers from the Henry Ford Health System in Detroit found a linear relationship between SSDE and mean absorbed organ doses, measuring a slope of 1.05 and a Pearson correlation coefficient of 0.97. They concluded that SSDE is a reliable indicator of organ doses in the abdomen and pelvis when the organ of interest is fully covered in the exam and offered a rapid, straightforward method to estimate organ doses without the need for Monte Carlo simulations. Similarly, Moore B, Brady SL , Mirro A and Kaufman RA (16) in 2014 tried to investigate the correlation of SSDE with absorbed organ dose. The correlation factors in both the chest (1.1; range 0.7– 1.4) and abdominopelvic region (0.9; range 0.7–1.3) were, on average, near unity for organs fully covered by the scan volume. They concluded that for organs fully covered within the scan volume, the average correlation of SSDE and organ absolute dose was found to be better than ± 10%. In addition, for organs not fully covered in the scan volume, they tried to provide a complete list of organ dose correlation factors.

More recently, another AAPM working group, published AAPM Report 220 (17), which described how to best measure patient size. Previously SSDE was calculated by only using the geometric measurement of the patient. However, x-ray attenuation is the fundamental physical parameter affecting the absorption of x-rays and is thus more relevant than geometric patient size in determining the radiation dose absorbed by the patient. AAPM Task Group 220 was tasked to develop a robust and scientifically sound metric for automatically estimating patient size in CT that would account for patient attenuation and allow routine determination of SSDE for all patients. They introduced the concept of Water equivalent diameter i.e. Dw. In the thorax, use of effective diameter instead of Dw lead to an overestimation of patient attenuation and an underestimation of SSDE. In the abdomen, the errors were much smaller, in the range of a few percent. Thus, the Report (17) suggests that even though use of Dw is recommended, when only geometric data are available to the user, it is still reasonable to calculate SSDE based on any of the geometric input parameters shown in Report 204 (9).

The objective of our study was to compare $CTDI_{vol}$ and SSDE values in patients undergoing CT scans of the abdomen and pelvis. We aimed to determine the relationship of $CTDI_{vol}$ with the weight and BMI of the patient. We also sought to determine the relationship of SSDE with the weight and BMI of the patient. The variation of $CTDI_{vol}$ and SSDE in the different BMI classes were also studied.

Methods

Participants

This quantitative, cross-sectional study was performed in adults referred for CT examinations of the abdomen and pelvis for various clinical indications to the Department of Radiology and Imaging of Tribhuvan University Teaching Hospital, Maharajgunj, Nepal. Data were collected from mid-July to mid-October. Convenience sampling was employed and a total of 96 examinations were included. Adult patients, both males and females (above 18 years) were included in the study.

CT scanner and scan parameters

Data were obtained from the 128 slice MDCT Siemens Somaton Definition AS+ CT scanner. The CARE DOSE 4D and CARE KV parameters were kept ON for all the required examinations. The parameters are summarized in Table 1. The scan coverage was from the dome of diaphragm to the symphysis pubis. Scans were obtained at arrested expiration.

Table 1. CT Acquisition parameters used during the examination.

Parameter	Value
Detector Rows	64
Scan mode	Helical
Convolution kernel	Standard
Reconstructed slice thickness	5mm
Automatic mA control	CARE Dose 4D
Automatic kV control	CARE KV

Data collection

$CTDI_{vol}$ was calculated by the scanner by using the average tube current throughout the entire scan and was recorded for each patient. For each patient, AP (Antero-posterior) and LAT (Lateral) dimensions at the mid-liver region i.e. at the level of the portal vein were measured from axial CT images by using digital calipers on the scanner console (Figure 1). These values were used to calculate the effective diameter. The AAPM Report 204 provides tables based on effective diameter that were used to find the f_{size} that, when multiplied by $CTDI_{vol}$, yielded corresponding SSDE values (9). (Table 2)

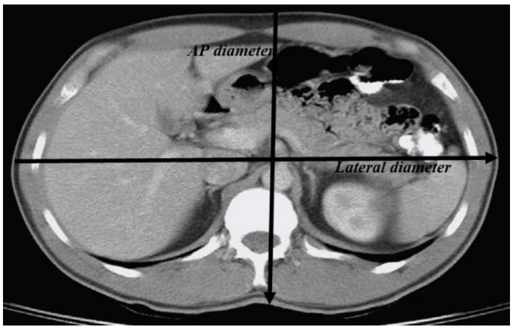

Figure 1. Axial CT image showing mid-liver region where AP and Lateral diameters were measured.

Table 2. Conversion factors based on the use of the 32 cm PMMA phantom for $CTDI_{vol}$ calculation. The conversion factors are a function of effective diameter. Note: Data are from the AAPM Report No. 204 (9).

Effective Diameter (cm)	Conversion factor (f_{size})
8	2.76
9	2.66
10	2.57
11	2.47
12	2.38
13	2.30
14	2.22
15	2.14
16	2.06
17	1.98
18	1.91
19	1.84
20	1.78
21	1.71
22	1.65
23	1.59
24	1.53
25	1.48
26	1.43
27	1.37
28	1.32
29	1.28
30	1.23
31	1.19
32	1.14
33	1.10
34	1.06
35	1.02
36	0.99
37	0.95
38	0.92
39	0.88
40	0.85
41	0.82
42	0.79
43	0.76
44	0.74
45	0.71

Data analysis

Descriptive statistics such as mean, standard deviation and range were calculated for $CTDI_{vol}$, SSDE, patient weight, patient BMI and patient age. Spearman correlation coefficients were obtained to determine the relationship of patient size with SSDE as well as $CTDI_{vol}$. All statistical analyses were performed with SPSS and Microsoft Excel.

Ethical considerations

Ethical approval was obtained from the Institutional Review Committee of Institute of Medicine and the Institutional Review Board of Tribhuvan University Teaching Hospital. An informed consent form was signed by all the participants before participating in the study.

Population statistics

A total of 96 patients were selected for this study. Among them 55 patients were female and 41 were male. The mean age of the patients was 43 ± 16 years. The mean weight was found to be 60.14 ± 12.68 kg and the mean BMI was 23.95 ± 4.21 kg/m^2(Table 3). The effective diameter ranged from 18 to 36 cm which corresponded to f_{size} values of 1.91 and 0.99 respectively.

Table 3. Descriptive statistics of population.

Patient Parameters	Maximum	Minimum	Mean	SD
Age (years)	83	20	42.76	15.99
Weight (kg)	99	35	60.14	12.68
BMI (kg/m^2)	37.2	15.6	23.95	4.21
Effective diameter (cm)	36	18	25.36	3.52
f_{size}	1.91	0.99	1.47	0.18

SSDE and $CTDI_{vol}$

The average SSDE was found to be 13.48 ± 3.53 mGy and the average $CTDI_{vol}$ was found to be 9.42 ± 3.26 mGy (Table 4). Thus, average $CTDI_{vol}$ reported was 30.11% lower than the average SSDE values.

Table 4. Comparison of SSDE and $CTDI_{vol}$ values.

Parameters	Maximum	Minimum	Mean	SD
$CTDI_{vol}$ (mGy)	20.27	3.94	9.42	3.26
SSDE (mGy)	24	7.01	13.48	3.53

$CTDI_{vol}$ and patient size

Data were tested for normality using the Shapiro-Wilk's test ($p<0.05$) which showed that the data were not normally distributed. Non-parametric correlation coefficient (Spearman's correlation coefficient) between $CTDI_{vol}$ and patient weight was found to be 0.527 i.e. moderate degree of correlation existed between $CTDI_{vol}$ and patient weight that was statistically significant ($p<0.001$). Spearman correlation coefficient between $CTDI_{vol}$ and patient BMI was found to be 0.5 i.e. moderate degree of correlation existed between $CTDI_{vol}$ and patient BMI that was statistically significant ($p<0.001$) (Table 5 and Figure 2).

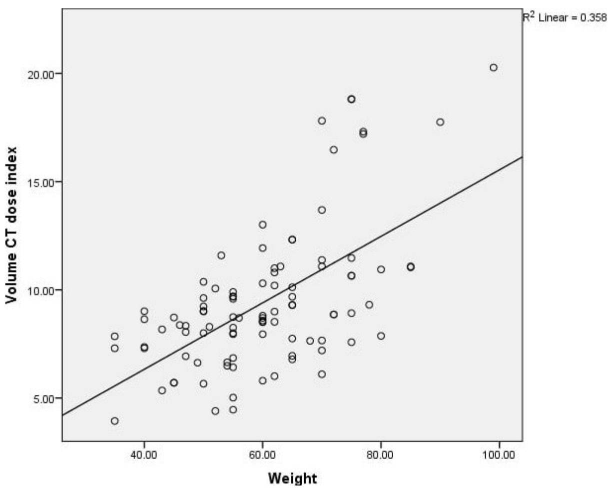

Figure 2. Scatter plot with line of fit showing relation between $CTDI_{vol}$ and patient weight

Table 5. Relation between $CTDI_{vol}$ and patient size.

Parameters	Spearman correlation coefficient (r)	p-value
$CTDI_{vol}$ and Patient weight	0.52	0.00
$CTDI_{vol}$ and Patient BMI	0.5	0.00

SSDE and Patient size

Non parametric correlation coefficient (Spearman's correlation coefficient) between SSDE and patient weight was found to be 0.175 i.e. low degree of correlation existed between SSDE and patient weight that was statistically insignificant (p=0.08). Spearman's correlation coefficient between SSDE and patient BMI was found to be 0.14 i.e. low degree of correlation existed between SSDE and patient BMI that was statistically insignificant (p=0.15) (Table 6 and Figure 3).

Table 6. Relation between SSDE and patient size.

Parameters	Spearman correlation coefficient (r)	p-value
SSDE and Patient Weight	0.17	0.08
SSDE and BMI	0.14	0.15

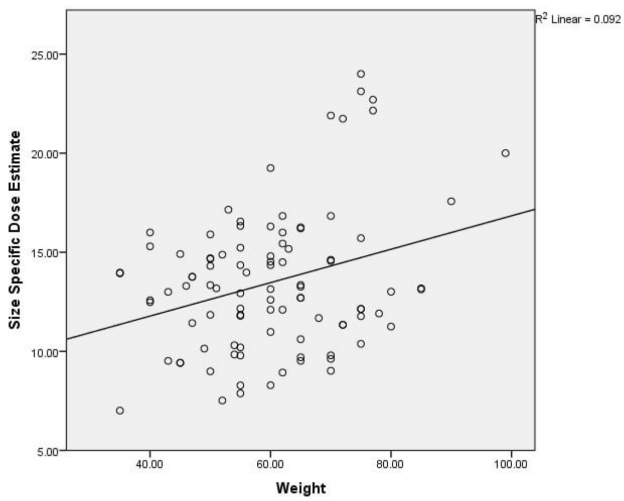

Figure 3. Scatter plot with line of fit showing relation between SSDE and patient weight

$CTDI_{vol}$ and BMI groups

The patients were divided into 4 BMI groups (Underweight <18.5, Normal 18.5-24.9, Overweight 25-29.9 and Obese ≥ 30). Independent samples Kruskal Wallis test showed significant difference in $CTDI_{vol}$ values across the 4 BMI groups (p<0.05).

SSDE and BMI groups

Independent samples Kruskal-Wallis Test showed that SSDE values were not significantly different across the 4 BMI groups (p>0.05).

Discussion

We found that the average $CTDI_{vol}$ values were 30.11% lower than the average SSDE values. Considering a 1:1 relationship between SSDE and absorbed dose (15,16) we can assume that $CTDI_{vol}$ underestimates the radiation dose by approximately 30%. Looking at individual data we found that $CTDI_{vol}$ values underestimated the radiation dose being given in all cases; except 2 cases when the effective diameters were greater than 35 cm. This was due to the decrease in f_{size} values below 1 with the increase in effective diameter beyond 35 cm.

We found a moderate positive correlation between patient weight and $CTDI_{vol}$ (r=+0.52) and a low positive correlation between patient weight and SSDE (r=+0.17). Similarly, a moderate positive correlation was found between $CTDI_{vol}$ and patient BMI (r=+0.5) and a low positive correlation that was statistically insignificant was found between SSDE and patient BMI (r=+0.14). Thus, if $CTDI_{vol}$ was used as a surrogate for patient dose (rather than as a measure of scanner output), larger patients could appear to receive higher doses than smaller patients. However, $CTDI_{vol}$ alone does not measure patient dose; patient size must be taken into account. After patient sizes were considered and $CTDI_{vol}$ values were converted to estimates of patient dose (SSDE), the correlation between patient dose and patient size (weight and BMI) was significantly reduced. $CTDI_{vol}$ values are indicated on the patient's report, and it often ends up over or under-estimating the dose estimate to the patient, depending on the size of the patient. If SSDE values are displayed instead of $CTDI_{vol}$ values, they will provide a more accurate dose estimate to patients as well as physicians. The independent samples Kruskal-Wallis test showed that $CTDI_{vol}$ values varied significantly in the 4 BMI groups (Underweight, Normal, Overweight and Obese). However, SSDE values did not differ significantly across the 4 BMI groups. Thus, reinforcing the fact that conversion of $CTDI_{vol}$ into SSDE reduces its dependency on patient size.

The result of this study in relation to dependence of SSDE with patient size (r=+0.17) somewhat differed from that conducted by Christner et al. in 2012 which showed complete independence of SSDE with patient size (18). This may be due to the use of a different AEC system as well as a smaller population sample in our study.

In this study combination of AP and Lat diameters were used to calculate the effective diameter which in turn was used for calculation of SSDE. This method was utilized in accordance to the study by Brady SL, Kaufman RA (19). They compared the five methodologies the American Association of Physicists in Medicine Report 204 used to calculate size-specific dose estimates (SSDEs) for pediatric computed tomography (CT) i.e. using AP diameter only, using lateral diameter only, using sum of AP and lateral diameters, using the age-related approach and using the effective diameter. They found that SSDEs derived from individual measurements varied 2%-12%. The combination of measurements (sum or effective diameter) varied 0.9%-2%. In either case, these results demonstrated that the combination, when available, of AP and lateral measurements, as a summation or effective diameter calculation, were more useful than either measurement applied individually, and that the age approach to determining effective diameter and ultimately calculating SSDE was most effective for preadolescent patients (up to 13 years) but was less accurate for teenage and young adult patients. Generally, for all patients, the most effective method for determining SSDE was the direct measurement of patient dimensions with electronic calipers from the CT radiograph.

In this study only the SSDE values were calculated. Further studies to convert these SSDE values into effective dose may be carried out in accordance to the previous study by Brady SL, Mirro AE, Moore BM, Kaufman RA (20) in 2015. They tried to calculate effective dose in CT using size-specific dose estimates and to correct the current method using dose-length product (DLP). They concluded that the current use of DLP to calculate effective dose was shown to be deficient because of the outdated means by which the k-coefficients were derived.

Looking back, The Alliance for Radiation Safety in Pediatric Imaging/Image Gently in 2008 held a summit and asked vendors and stakeholders to help create a better dose index. In 2011, the AAPM task group published an AAPM Report 204 (9) that included conversion factors to translate $CTDI_{vol}$ to SSDE in accordance with patient size. The more recent AAPM Report 220 gave a method to calculate SSDE more accurately by taking into account the patient's x-ray attenuation (17). Though the use of Dw was recommended by the Task group, in the absence of proper means of calculating Dw, only the effective diameter was used for SSDE calculation in this study.

The effective diameter as well as the water equivalent diameter varies along the z-axis of the patient. However, using the mean $CTDI_{vol}$ from the whole scan range and Dw from the image at the center of the scan range provided an easily obtained estimate of SSDE for the whole scan range that agreed well with values from an image-by image approach, with a root mean square difference less than 1.4 mGy (9%) (21). In the present study the effective diameter was calculated at approximately the center of the scan range i.e. the mid liver region. SSDE is likely to not only improve risk prediction of CT exposure but also to encourage the establishment of DRLs based on SSDE and development of imaging protocols with lower exposure, while maintaining the quality of the diagnosis(22).

The limitations of this study were that only a single scanner from one manufacturer, and hence, only one AEC system, was evaluated. Neither risk nor organ doses were determined in this work. SSDE values were calculated using the effective diameter and not the water equivalent diameter which would have been ideal. Another limitation was that only adults were included in the study. Pediatric population were excluded since the scanner in use made use of the 32cm PMMA phantom for the $CTDI_{vol}$ measurement of pediatric abdomen whereas the AAPM report has strictly mentioned the need for a 16 cm PMMA phantom if SSDE were to be calculated using the f_{size} factors provided in the report (9).

Conclusion

$CTDI_{vol}$ underestimated the patient dose estimation by 30.11%. $CTDI_{vol}$ values showed moderate positive correlation with patient weight (r=+0.52, p<0.001). It also showed moderate positive correlation with BMI (r=+0.5, p<0.001). SSDE values showed low positive correlation with weight (0.17, p=0.08) and low positive correlation with BMI (r=+0.14, p=0.15). CTDI values are influenced by the patient's weight and BMI, and hence tend to over/under estimate dose to the patient. Thus, SSDE values are a more reliable patient dose estimate since it addresses the patient's size.

Statements and Declarations

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Competing Interests

The authors declare that there are no conflicts of interest.

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Prior presentation

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