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Original Research

Body weight estimation based on the anterior abdominal subcutaneous fat thickness and autopsy weight measured using post-mortem computed tomographic scans in Malaysian

Tawfiq Yousef Tawfiq Zyoud[1], Saiful Nizam Abdul Rashid[2], Subapriya Suppiah[1,], Rozi Mahmud[1], Umar Ahmad[3], Abubakar Kabeer[4], Suzana Ab Hamid[1], Mohamad Syafeeq Faeez Bin Md Noh[1], Ezamin Abdul Rahim[1,*]

ABSTRACT

Background: Estimation of body weight is an important approach in forensic investigation and its science that uses post-mortem computed tomography (PMCT) to gain insight into the cause of death and identification of human disaster victims. **Objective**: The present study determines the regression formula for cadaveric body weight estimation based on the length of the spine, anterior abdominal subcutaneous fat thickness (ASCFT), and autopsy weight (AW) of Malaysian corpse bodies. **Methods**: Retrospectively, 107 corpses were analyzed to assess the correlation between the autopsy weight (AW) and anterior subcutaneous fat thickness (ASCFT) measured on both sides at the level of the umbilicus and to determine body weight by multiple regression analysis techniques to derive regression equations for cadaveric body weight estimation. **Results**: The findings of this study confirm that PMCT is an accurate method for estimating the body weight of the body, and there is a strong positive correlation between autopsy weight (AW) and ASCFT (mean) ($r = 0.565$, $p = 0.001$). Moreover, there is no significant difference in right ASCFT [$F(3, 103) = 1.464$, $p = 0.942$] and left ASCFT [$F(3, 103) = 1.273$, $p = 0.926$] among ethnic groups in Malaysia. Multiple regression analysis showed a significant linear relationship using TL, SL, TCL, and ASCFT with AW, and a formula for body weight was derived. **Conclusions**: Body weight estimation can be determined by the use of PMCT and is important, especially when carrying out forensic corpse investigations, to roughly estimate the body weight of the study population aged between 22 and 68 years old cadavers.

Key words: Cadaver, computed tomography, autopsy, bodyweight estimation

[1]*Department of Imaging, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia*

[2]*Ramsay Sime Darby Parkcity Medical Centre, 52200 Kuala Lumpur, Malaysia*

[3]*Department of Anatomy, Faculty of Basic Medical Sciences, Bauchi State University, PMB 65 Gadau, Nigeria*

[4]*Department of Human Anatomy, College of Medical Sciences, Federal University Lafia, P.M.B 146 Akunza, Lafia, Nasarawa State, Nigeria*

Correspondence

Ezamin Abdul Rahim, Department of Imaging, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia

Email: drezahar@gmail.com

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INTRODUCTION

Body weight estimation is nowadays being sed in forensic science to explore information related to the dead body, cause of death, and other relevant details that may aid proper investigation, especially in detecting what transpired during a crime scene[1]. An individual's body weight determined is very crucial in autopsy examination[2] and has been widely applied in forensic investigation, especially in this era of frequent mass disasters[3,4]. Anthropologic assessment of the skeletal body may help in the body identification process as it has been tested and proven[5,6]. Fat in the abdominal region is divided into visceral fat and subcutaneous fat[7], which is the focus of the present study. Literature indicates that abdominal fat could be used to measure and effectively determine an individual's weight using magnetic resonance imaging (MRI) or computed tomography (CT)[8–10]. Several studies indicate a relationship between the anterior abdominal subcutaneous fat thickness (ASCFT) with body mass index (BMI) and body weight estimation[11–13]. However, little is done to determine the body weight of an individual using anterior abdominal subcutaneous fat thickness (ASCFT), and there is no study that estimated the body weight of a cadaver using the abdominal subcutaneous fat and the autopsy weight. Thus, anterior abdominal subcutaneous fat thickness (ASCFT) has been found to be the key predictor in estimating cadaveric body weight.

Over the years, post-mortem computed tomography (PMCT) and postmortem magnetic resonance imaging (PMMRI) have been used in clinical and forensic laboratories to investigate, visualize disease, and cause of death[14], especially as they serve as a virtual guide for autopsy[15]. In an emergency clinical situation, obtaining a patient's height and weight can be difficult. There are situations when the patient's weight is unknown or when the patient's condition is too weak for conventional weight assessment using scales. Thus, their weight needs to be estimated for fluid infusion, drug dosage, and administration of contrast me-

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dia [16]. Moreover, according to our literature search, there is very limited study in this area of research that uses anterior abdominal subcutaneous fat thickness (ASCFT) and autopsies weight in estimating the body weight particularly in the cadaver sample of the Malaysian population. Hence, we hypothesized that the CT technique may accurately predict the cadaveric body weight based on ASCFT and autopsy weight as obtained from CT output. Therefore, the study aims to estimate the cadaveric body weight based on anterior abdominal subcutaneous fat thickness (ASCFT) and autopsy weight (AW) of the Malaysian corpse bodies. To achieve the study aim, we collected PMCT scan images retrospectively and measured the cadaveric body weight using autopsy length (AL), anterior subcutaneous fat thickness (ASCFT), and autopsy weight (AW), which were used in predicting the body weight by multilinear regression. As expected, multiple regression analysis demonstrated a strong linear relationship between ASCFT and AW. Thus, PMCT can be applied in determining the weight of a cadaver in the Malaysian population.

METHODS

Subject Recruitment

Data were collected retrospectively from cadaveric PMCT scans between 2014 and 2017. The data consist of 90 males and 17 females, Malaysians aged between 22 and 68 years, comprising about 27.1% Malay, 16.8% Chinese, 28.9% Indian, and 27.1% other unidentified racial groups. All the bodies underwent a whole-body MSCT examination before autopsy. Subjects were selected based on study-defined criteria.

Selection Criteria

Subject selection was made based on established eligibility criteria, and only corpses that met these criteria were included in the study. All PMCT scans for corpses available between 22 and 68 years of age were included in this study, whereas those with poor image quality and PMCT scans that may not be from Malaysian subjects were excluded.

Sampling Frame

A complete list of PMCT scans conducted on cadaver bodies at the Radiology Department of the National Institute of Forensic Medicine (IPFN) was obtained from the Radiology Information System (RIS) with written permission.

Determination of Sample Size

GPower software was used to determine the sample size in this study. Based on the GPower output and by entering an effect size of 0.15, a power (1-beta error probability) of 0.95, and 3 predictor numbers for multiple linear regression (MLR), a total of 119 sample records are required for this study. However, while collecting samples from the RIS in the hospital records, we observed only about 107 samples. Therefore, we used the entire 107 as our sample for the study.

Pro-forma and Processing of PMCT Images

A proforma was used to collect socio-demographic information on the study subjects, covering age, gender, nationality, weight, height, and date of death. Anthropometric parameters were also collected using this proforma. Parameters included the length of each corpse from PMCT topogram length (TL), sternum length (SL), thoracic column length (TCL), autopsy length (AL), anterior subcutaneous fat thickness (ASCFT), and autopsy weight (AW). All images obtained from the National Institute of Forensic Medicine (IPFN) Kuala Lumpur were read and analyzed using Syngo software at the Nuclear Diagnostic Imaging Center (PPDN), Universiti Putra Malaysia. The instrument used for image analysis was a computerized tomography scanner (CT scanner), and the images were measured using an image processing application (OsiriX) to view the correct image, fully compliant with DICOM standards for image communication and file format conversion.

Post-mortem CT Imaging Protocol

Post-mortem imaging was performed on a 64-piece CT unit (Toshiba, Aquilion 64 CFX, Medical Systems Corporations, Tochigi, Japan). Whole-body data acquisition was performed with the following techniques: lying with feet first, direction: craniocaudal, kVp: 120, mAs: Auto set (Caredose mAs), FOV: 500 (LL), detector arrangement: 1.0 x 32 raw, pitch: 0.844/standard, focus: large, reconstruction: sheet thickness 2.0 mm, reconstruction interval 1.6 mm (for soft tissue standard), scan time 120-150s. All subjects were scanned in a radiolucent body bag and in a supine position from head to toe, with hands on the sides or on the body depending on the mortis of body rigidity. Multi-planar reconstruction (MPR) in hardcore (high bone resolution) and softcore (soft tissue standard) was performed.

Post-mortem CT Spinal Morphometry

Spinal measurements were based solely on the method described by[17] with minor modifications. Three types of measurements were used to measure the length of the spine: the first method measured the length by area, from cervix C1 to thorax T1, from thorax T1 to lumbar spine L1, and from lumbar spine L1 to sacrum S1 in a straight line. The second method involved measuring the length of the spine in a straight line from the first cervical vertebra to the last lumbar vertebra. The third method measured the length of the complete spine from the first cervical vertebra to the last lumbar vertebra using curved lines (ellipses) according to the lordosis and kyphosis of the vertebral column. The mean for these three methods was calculated to reduce or minimize error.

Ethical Approval

Necessary approvals were secured from the Universiti Ethics Committee for Research involving human subjects, from the Research Management Centre (RMC), bearing the Reference ID: UPM/TNCPI/RMC/1.4.18.2(JKEUPM), along with the Institutional Medical Research Ethics Committee, Universiti Putra Malaysia (UPM). Additionally, the National Medical Research Register (NMRR) approved this study under the NMRR ID number: NMRR-13-408-14946. The Medical Research Ethics Committee (MREC) provided the final decision prior to the retrospective data collection.

Statistical Analysis

Syngo image viewer, a multimodality reading solution assembled on a client-server platform, was used to analyze PMCT images used in this study. Recorded measurements collected using the proforma were keyed into the Statistical Package for Social Sciences (SPSS) version 23. Descriptive statistics such as frequencies and exploration were used to describe the data and expressed as Mean $\pm$ SD. Pearson correlation coefficient (r) and both simple linear regression analysis (SLR) and multiple linear regression (MLR) were used to determine relationships. Multiple regression analysis (MLR) techniques were used to determine and evaluate significant correlations between TL, SL, TCL, and ASCFT with AW to derive the appropriate regression equation for cadaver weight estimates. The significance of such correlations was tested with a t-test, and a p-value < 0.05 was considered statistically significant.

RESULTS

Demographic characteristics of the subjects

Table 1 provides the demographic characteristics of the cadaveric bodies used in the present study. Cadavers from different ethnic groups, including Malay, Chinese, Indian, and others, were included in this study. The majority of the total corpses were Indian (29.9%), followed by Malay (27.1%), then others (26.2%), and lastly Chinese (16.8%). The age range of the cadaveric bodies (subjects) was between 22 and 68 years old at the time of death, with a mean of 44.39$\pm$11.22 years.

Differences in morphometry of Right and Left ASCFT

The difference between right and left ASCFT was determined by a Wilcoxon signed-rank test. The results showed a statistically significant difference between the median scores of ASCFT (right) and ASCFT (left) among the study population ($Z = 2.098$, $p = 0.036$) (**Table 2**), implying that the mean of ASCFT is more important to use to define ASCFT. To determine the differences in ASCFT among ethnic groups (Malay, Chinese, Indian, and Others), one-way ANOVA was conducted. The analysis showed that there were no significant differences among the population groups in terms of their right ASCFT $F(3, 103) = 1.464$, $p = 0.942$ and left ASCFT $F(3, 103) = 1.273$, $p = 0.926$). Thus, the null hypothesis, which states no difference between the means, was maintained. Therefore, there is no difference in ASCFT (right) and ASCFT (left) among ethnic groups in Malaysia (**Table 3**).

Level of ASCFT and autopsy weight (AW) among the ethnic groups:

Differences between mean ASCFT and autopsy weight (AW) among Malays, Chinese, Indians, and others were assessed without statistical differences between groups with one-way ASCFT ANOVA (mean) $F(3, 103) = 0.467$, $p = 0.701$ and weight autopsy (AW) $F(3, 103) = 0.771$, $p = 0.513$) respectively (**Table 4**), confirming the reason right or left ASCFT could be used in measuring cadaver ASCFT.

Relationship between ASCFT and autopsy weight (AW)

To determine whether there is a relationship between ASCFT (mean) and autopsy weight (AW), the Spearman correlation was carried out (**Table 5**). There was a significant and strong positive correlation between ASCFT and autopsy weight (AW) ($r = 0.565$, $p = 0.001$), meaning that the more fat deposits in the human body, the higher the autopsy weight (AW).

Table 1: Distribution of the cadaveric body according to socio-demographic characteristics (n = 107)

Variable(s)		%
Ethnicity		
Malay	29	27.1
Chinese	18	16.8
Indian	32	29.9
Others	28	26.2
Total	107	100.0
Gender		
Male	90	84.1
Female	17	15.9
Total	107	100.0
Age group (years)		
22-30	17	16.2
31-40	17	16.2
41-50	45	42.9
51-60	16	15.2
61-70	10	9.5

Table 2: Median score for Right ASCFT and Left ASCFT

Variables	Mean ± SD (cm)	Median (IQR)	Z statistic	value*
Right ASCFT	2.17±0.967	1.47(2.09, 2.77)	-2.098	0.036
Left ASCFT	2.13±0.974	1.44(2.03, 2.69)		

*Wilcoxon Signed Ranks Test

Determination of bodyweight estimation in cadavers

To determine and estimate the cadaveric body weight using regression analysis and understand the determining factors influencing body weight, spine length variables such as C1-T1, T1-L1, L1-S1, C1-S1 Line, C1-S1 Ellipse, AL anterior abdominal subcutaneous fat thickness (ASCFT), and autopsy weight (AW) were used to run a simple linear regression and measure their effects. The findings demonstrated that autopsy length (AL) (β= 0.483, p<0.007), L1-S1 length (β= 2.217, p<0.174), and ASCFT (β= 7.856, p<0.001) have positively contributed and explained the cadaveric body weight estimation. In addition, multiple regression analysis (Table 6) further confirmed that autopsy length (AL) (β= 0.605, p<0.001), L1-S1 length (β= 3.269, p<0.016), and ASCFT (β= 7.762, p<0.001) have significantly contributed to body weight estimation. The reported value of the F-statistic (F = 46.850, <0.001) fits the model data, and standardized regression coefficients explained the importance of predictors in predicting cadaveric body weight estimation. The R2=0.577 revealed that a combination of these predictors explained about 57.7% of the variance in body weight estimation. Therefore, the prediction model of cadaveric body weight estimation is: BW = -98.5458 + [0.605 x autopsy length (AL)] + [3.269 x L1-S1 length] + [7.762 x ASCFT]. In the case where the autopsy length was not known or provided in the

Table 3: Comparison of morphometric measurements of cadaveric ASCFT among the study population

Variables	Ethnicity	Mean ± SD (cm)	F statistic (df)	value*
Right ASCFT	Malay	2.29±0.94	1.464(3, 103)	0.942
	Chinese	2.30±0.97		
	Indian	2.06±0.97		
	Others	2.06±1.01		
Left ASCFT	Malay	2.19±0.97	1.273(3, 103)	0.926
	Chinese	2.31±0.91		
	Indian	2.08±0.99		
	Others	2.00±1.02		

*one-wayANOVA

Table 4: Comparison of the mean of ASCFT and autopsyweight (AW) among the study population

Variables	Ethnicity	Mean ± SD (cm)	F statistic (df)	value*
Mean ASCFT	Malay	2.25±0.94	0.467(3, 103)	0.701
	Chinese	2.30±0.93		
	Indian	2.06±0.97		
	Others	2.06±1.01		
Autopsy weight (AW)	Malay	69.43±14.73	0.771(3, 103)	0.513
	Chinese	74.42±16.50		
	Indian	71.09±15.60		
	Others	68.19±9.86		

Table 5: Correlation between ASCFT (mean) and autopsyweight (AW)

	Autopsy weight (AW)	
	r	-value*
ASCFT	0.565	0.001

*Spearman correlation

study, we can simply substitute the autopsy length (AL) from the above equation by replacing it with the formula given in section 4.1.3.1 [Autopsy length = 48.163 + 2.458 (T1-L1) + 2.246 (L1-S1)]. This will result in a newly derived formula for calculating cadaveric body weight as BW = -98.5458 + [0.605 x (48.163 + 2.458 (T1-L1) + 2.246 (L1-S1))] + [3.269 x L1-S1 length] + [7.762 x ASCFT]. Therefore, the above two formulas could be applied in estimating the body weight of the study population (Malay, Chinese, and Indian).

DISCUSSION

Postmortem imaging is currently recognized as one of the important techniques used in autopsy for a variety of diagnostic purposes and to resolve critical clinical situations [18,19]. PMCT is one of the major imaging modalities that has been widely used due to its high

Table 6: Summary of MLR analysis on cadaveric body weight estimation

Variable	Unadjusted (Simple regression)		Adjusted (Multiple regression)		
	B (β)	value	B (β)	value	VIF
AL	0.483 (0.138, 0.828)	0.007	0.605 (0.309, 0.900)	<0.001	0.941
C1-T1	0.906 (-1.963, 3.774)	0.532	-	-	-
T1-L1	0.630 (-1.601, 2.861)	0.576	-	-	
L1-S1	2.217 (-0.993, 5.427)	0.174	3.269 (0.633, 5.906)	0.016	0.982
C1-S1 Line	-0.032 (-0.648, 0.585)	0.919	-	-	-
C1-S1 Ellipse	0.350 (-0.927, 1.627)	0.588	-	<0.001	-
ASCFT	7.856 (5.886, 9.826)	<0.001	7.762 (5.828, 9.695)		
F value			46.850		
P-value			0.001		
Adj R2			0.565		

accuracy and wide compatibility in clinical settings [20]. This study aimed to use PMCT to describe and analyze the anterior subcutaneous fat thickness (ASCFT) of corpses and find its correlation with body height (BW). In addition to evaluating body weight (BW) and anterior abdominal subcutaneous fat thickness (ASCFT) comparing it with routine autopsy weight (AW), a predictive equation for body weight (BW) was generated using key parameters obtained from the sample.

In our findings, the data collection rate was based on the number of the study population of 107 and was found to be 100 percent with 90 males and 17 females with a range of ages between 22 and 68 years old. The cadavers used in this study were drawn from different ethnic groups in the Malaysian population as categorized [21] and arranged from the highest percent starting with Indian (29.9%), Malay (27.1%), other population groups (26.2%) and lowest percent ending with Chinese (16.8%), with all of them having different times and causes of death as discovered from their autopsy records [22]. The age range of the bodies was in the range of 41-50 years and numbered 45, followed by those aged between 31-40 and 22-30 totaling 17 dead bodies, those aged between 51-60 years numbered up to 16 corpses and finally those between 61-70 years numbered up to 10 corpses. Our findings are in agreement with previous studies on the Malaysian population that determined mortality rates using study variables of age, gender, and variation among Malaysians [23].

Measurement of cadaver autopsy weight was made across the study populations that comprised Malay, Chinese, Indian, and other ethnic groups. Differences between the right and the left anterior abdominal subcutaneous fat thickness (ASCFT) were evaluated among the study population using Wilcoxon signed-rank test. A statistically significant difference in median score between the right and the left ASCFT was obtained ($p < 0.05$). Furthermore, there was no significant difference in terms of ASCFT among Malay, Chinese, and Indian measured based on a one-way ANOVA test ($p > 0.05$). Moreover, differences between the mean of ASCFT and autopsy weight (AW) among Malay, Chinese, and Indian were evaluated and there was no significant difference between the groups by one-way ANOVA ($p > 0.05$). Likewise, ASCFT is strongly linked to autopsy weight (AW), implying that the thicker the subcutaneous fat in the body the more the autopsy weight (AW). This finding is in agreement with the previous studies conducted on the body weight (BW) estimation using a different approach to find a link between the autopsy weight (AW) and the lung weight (LW) [24,25]. Similar results were found in a study by [26], which stated that the body weight and height are accurate using three-dimensional 3D CT scan for the long bones from end to end to find the correlation with the body weight and height rather than freezing the corpse and thawing it as most of the organs lose their softening and fluidity, which results in shrinkage, shortening, and softening [26]. Cadaveric body weight estimation was further investigated using key factors such as body weight, spine lengths, anterior abdominal subcutaneous fat thickness (ASCFT), and autopsy weight (AW) into a simple linear regression model. We discovered that the autopsy length (AL) ($\beta = 0.483$, $p < 0.05$), L1-S1 length ($\beta = 2.217$, $p > 0.05$), and ASCFT ($\beta = 7.856$, $p < 0.05$) have significantly contributed and explained the cadaveric body weight estimation. Moreover, multiple regression analysis further confirmed that the autopsy length (AL) ($\beta = 0.605$, $p < 0.05$), L1-S1 length ($\beta = 3.269$, $p < 0.05$), and ASCFT ($\beta = 7.762$, $p < 0.05$) played a significant role in estimating the bodyweight of the cadaver in our study. Our findings here are in line with the previous study that evaluated the bodyweight estimation although they were using different methods [27]. Although there are similar studies conducted in Malaysia that derived formulas to estimate body weight using the variables such as body mass index BMI, body height, and sex [28] study such as this is the first of its kind to be carried out on the Malaysian population using autopsy weight (AW), and ASCFT to estimate the body weight (BW).

In the present study, the important role of PMCT in detecting the body weight for the cadavers with lost organs or accidental deaths, or long unknown corpses was indicated. We derived a linear regression formula that can be applied to estimate the bodyweight and anterior abdominal subcutaneous fat thickness (ASCFT). The prediction of body weight estimation for cadavers can be calculated using the established formula postulated based on the study variables; BW = -98.5458 + [0.605 × autopsy length (AL)] + [3.269 × L1-S1 length] + [7.762 × ASCFT]. However, further study needs to be carried out using large cohorts of cadaver samples to ascertain our claims and further explore insightful information. We, therefore, recommend for future work to be carried out to make a comparison between the body height and body weight estimation from the linear regression formula, with the autopsy weight. Likewise, the measuring should be carried out using a high computer program that is recommended for image processing segmentation of organs from the PMCT image in DICOM format and analyzes it to calculate the organs' weight by using Mac Pro occupying an Osirix A threshold-based volume segmentation, which used to make segmentation of the whole cadaver volumes [29,30]. We further suggest that the derived formula obtained in this study could be used for Malaysian patients in emergency situations to estimate their body weight arbitrarily.

Although post-mortem computed tomography (PMCT) in forensic pathology has diverse applications, it does have certain limitations such as lower resolution for soft tissues, the need to integrate nuclear magnetic resonance (MRI) technology, its high capital costs, and the need to enhance its accuracy.

ABBREVIATIONS

AL - Autopsy Length
ANOVA - Analysis of Variance
ASCFT - Anterior Abdominal Subcutaneous Fat Thickness
AW - Autopsy Weight
BMI - Body Mass Index
BW - Body Weight
CT - Computed Tomography
DICOM - Digital Imaging and Communications in Medicine
IQR - Interquartile Range
MLR - Multiple Linear Regression
MRI - Magnetic Resonance Imaging
MSCT - Multi-Slice Computed Tomography
MREC - Medical Research Ethics Committee
NMRR - National Medical Research Register
PMCT - Post-Mortem Computed Tomography
PM-MRI - Post-Mortem Magnetic Resonance Imaging
PPDN - Nuclear Diagnostic Imaging Center
RIS - Radiology Information System
RMC - Research Management Centre
SD - Standard Deviation
SL - Sternum Length
SPSS - Statistical Package for Social Sciences
TCL - Thoracic Column Length
TL - Topogram Length
VIF - Variance Inflation Factor

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AUTHOR'S CONTRIBUTIONS

All authors significantly contributed to this work, read and approved the final manuscript.

FUNDING

None.

AVAILABILITY OF DATA AND MATERIALS

Data and materials used and/or analyzed during the current study are available from the corresponding author on reasonable request.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Necessary approvals were secured from the Universiti Ethics Committee for Research involving human subjects, from the Research Management Centre (RMC), bearing the Reference ID: UPM/TNCPI/RMC/1.4.18.2(JKEUPM), along with the Institutional Medical Research Ethics Committee, Universiti Putra Malaysia (UPM). Additionally, the National Medical Research Register (NMRR) approved this study under the NMRR ID number: NMRR-13-408-14946. The Medical Research Ethics Committee (MREC) provided the final decision prior to the retrospective data collection.

CONSENT FOR PUBLICATION

Not applicable.

COMPETING INTERESTS

The authors declare that they have no competing interests.

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