Agreement Between Bioelectrical Impedance Analysis and Dual-Energy X-ray Absorptiometry to Estimate Fat Mass in Hispanic Adults With Type 2 Diabetes Mellitus: A Cross-Sectional Study

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ABSTRACT

BACKGROUND: Adipose tissue excess is associated with adverse health outcomes, including type 2 diabetes. Body mass index (BMI) is used to evaluate obesity but is inaccurate as it does not account for muscle mass, bone density, and fat distribution. Accurate measurement of adipose tissue through dual-energy X-ray absorptiometry (DXA) and computed axial tomography (CT) is crucial for managing and monitoring adiposity-related diseases. Still, these are not easily accessible in most hospitals in Mexico. Bioelectrical impedance analysis (BIA) is non-invasive and low-cost but may not be reliable in conditions affecting the body's hydration status, like diabetes.

OBJECTIVES: To assess fat mass concordance between BIA and DXA in Hispanic-American adults with type 2 diabetes mellitus (T2DM).

METHODS: Cross-sectional study of a non-probabilistic sample of subjects over 18 years with type 2 diabetes. We used DXA as the reference method.

RESULTS: We evaluated the accuracy of FM estimation through BIA and DXA in 309 subjects with type 2 diabetes. Results showed a trend of overestimating the diagnosis of obesity using BIA, especially in individuals with a higher fat mass index (FMI). At the group level, we found BIA accurate; however, at the individual level, it is not. The bias between the 2 methods showed a statistically significant overestimation of body fat by BIA ($P \leq .01$) in both sexes. BIA demonstrated high precision in estimating fat mass. We were able to provide a correction factor of 0.55 kg in men.

CONCLUSION: BIA is inaccurate compared to DXA for body composition assessment in patients with diabetes. Inaccurate measurements can result in misclassification. However, BIA is precise for body composition assessment in patients with diabetes, so it is reliable for tracking patient progress over time.

PLAIN LANGUAGE SUMMARY

Agreement between bioelectrical impedance analysis and dual-energy X-ray absorptiometry to estimate fat mass in adults with type 2 Diabetes Mellitus

This study compares 2 methods for measuring body composition in patients with diabetes in Mexico. The first method is Bioelectrical Impedance Analysis (BIA), which is non-invasive, low-cost, and easy to use but may not be reliable in conditions that affect the body's hydration status, like diabetes. The second method is Dual-energy X-ray Absorptiometry (DXA), which is more accurate but less easily accessible. The study was a cross-sectional evaluation of 309 participants over 18 years with type 2 diabetes mellitus (T2DM) by HbA1C levels. The present study found BIA to be precise for body composition assessment but not accurate compared to DXA as the reference method. The study showed a trend of overestimating the diagnosis of obesity using BIA, especially in individuals with a higher fat mass index. This study found BIA is accurate at the group level but not at the individual level. The bias between the 2 methods showed a statistically significant overestimation of body fat by BIA. We provided a correction factor of 0.55 kg in men but not women. BIA is not ideal for diagnosing obesity but is reliable for tracking patient progress over time.

KEYWORDS: Diabetes, bioelectrical impedance, dual-energy X-ray absorptiometry, body fat, fat mass

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Introduction

Type 2 Diabetes mellitus (T2DM) is a growing health concern with increasing incidence globally,[1] particularly in conjunction with obesity, as the 2 share common risk factors and pathophysiological pathways.[2] The increased prevalence of obesity and T2DM has led to the coining of the term "diabesity" to

describe these conditions' combined adverse health effects.[2] The etiology of T2DM is complex and multifactorial. Visceral adiposity affects metabolism through the secretion of proinflammatory substances, glycerol, leptin, cytokines, adiponectin, nonesterified fatty acids, and other molecular mechanisms, which can lead to β-cell dysfunction, insulin resistance and chronic inflammation in genetically predisposed individuals.[3,4]

According to the International Diabetes Federation, by 2021, diabetes affected 536.6 million adults worldwide, and by 2045, this prevalence will escalate to 12.2%, corresponding to 783.2 million individuals.[5] The 2020 National Survey of Health and Nutrition measured the epidemiology of T2DM in the Mexican population. This survey found that 15.6% of adults (20 years and older) have T2DM. Besides, 76% of women and 72.1% of men live with overweight or obesity, according to the World Health Organization criteria. Obesity prevalence is higher in women (40.2%) than men (31.5%).[6] According to the same survey in 2016, poor glycemic control was observed in 68.2% of the participants (HbA1c ⩾ 7%); 10.1% had not taken any hypoglycemic medication, including insulin; and only 21.8% reported being physically active or following a healthy diet.[7]

Body mass index (BMI) is commonly used to assess obesity; however, it cannot differentiate between adipose tissue and lean mass.[7] Fat mass index (FMI) is an alternative tool, but accurate fat mass (FM) measurement is necessary. Computed axial tomography (CT), magnetic resonance imaging (MRI), and dual-energy X-ray absorptiometry (DXA) are accurate methods for quantifying FM. However, they may not be feasible in clinical practice due to cost[8] or accessibility. Bioelectrical impedance analysis (BIA) is a non-invasive, non-expensive technique for measuring body composition that could be used in clinical practice.[8]

Nevertheless, impedance methods rely on various assumptions to estimate body composition, such as the hydration factor (HF) in BIA, defined as the ratio of total body water to fat-free mass (~0.73, calculated from chemical analysis of cadavers).[9,10] This assumption can be affected by age, sex, ethnicity, and health conditions such as diabetes, leading to potential inaccuracies in BIA results. For instance, Nickerson et al[11] discovered discrepancies in Hispanics at free mass characteristics compared to cadaver reference values and when contrasting Hispanics with non-Hispanic Caucasians. Additionally, BIA outcomes in people with obesity or diabetes might be impacted by fluid overload, modifications in exchangeable potassium, and changes in body size, shape, and fat distribution.[12-16] This margin of error of BIA in estimating fat mass is linked to abnormal tissue conductivity. Changes in electrical conductivity are affected by tissue hydration and electrolyte alterations.[10]

Given the significant impact of diabetes and obesity on the healthcare system and associated morbidity and mortality,[2] it is crucial to have access to objective, reproducible, standardized, and validated tools to assess adipose tissue in specific populations. Our research's main goal was to evaluate the fat mass agreement between BIA and DXA in Hispanic-American adults with T2DM.

Subjects and Methods

We produced this secondary analysis from several studies with a cross-sectional design. The baseline data was collected in the Salvador Zubirán National Institute of Medical Sciences and Nutrition Body Composition Laboratory. The study was conducted from November 2018 to February 2022. All volunteers gave their informed consent and signed it. The Human Research Ethics Committee of the Instituto Nacional de Ciencias Médicas y Nutrición Salvador Zubirán approved this study.

Data curation

This study included information from non-institutionalized Mexican City residents. Our inclusion criteria were adults at least 18 years old with T2DM, measured by an HbA1C of more than 6.5%. We excluded incomplete data, specifically records missing measurements from DXA and BIA, age, and sex. The BIA device (SECA mBCA 514, Hamburg, Germany) was calibrated following the manufacturer's instructions. BIA was used to record the subject's height and body weight while positioning the subject's head according to the Frankfort plane. We applied predictive equations for percentage body fat based on BMI, sex, age, and ethnicity from Stachenfeld.[17] Trained personnel measured subjects who had fasted for 8 to 12 hours and were in a supine position. They applied a low-intensity electric current using electrodes placed on both the feet and hands of the subjects. We instructed subjects to remove any metallic objects. All measures were taken on barefoot people, wearing just the bare minimum of clothing and having an empty bladder. After that, we determined the BMI. Following the manufacturer's recommendations, the team collected fat and fat-free mass data from BIA and DXA. Trained personnel conducted the DXA scans using a GE Healthcare machine equipped with CoreScan software version 16. DXA machine was calibrated daily. Measurements were made on the same day using the same technique. We performed the BIA measurement on a single occasion. BIA is a doubly indirect method. It allows us to estimate FFM and TBW, with FM being calculated by the difference of fat-free mass from total mass, which is important to mention because it is prone to error propagation.

Statistical analysis

This study used STATA 16 for statistical analysis. To evaluate the data's behavior and spot outliers, we carried out an exploratory study of the primary data. Skewness, kurtosis, and a normality plot were used to test for normality. The data was

displayed as mean standard deviation. A two-sample independent *t*-test was used to assess gender differences.

The statistical methods we employed in this study are based on the methodology outlined by González-Arellanes et al, among other authors.[18-21] The following description is an exact representation of their approach:

- Group-level accuracy was assessed through a two-way analysis of variance (ANOVA) incorporating sex and method as factors. If there was no significant difference ($P \geq .05$) in mean FM values obtained through BIA and DXA, BIA was considered accurate for estimating FM at the group level.
- Individual-level accuracy was evaluated through a simple regression procedure, with FM measured by DXA as the dependent variable and FM estimated by BIA as the independent variable. BIA's accuracy in estimating FM at the individual level was confirmed if the intercept was not significantly different from zero ($P \geq .05$) and the slope significantly differed from zero ($P < .05$, assuming it was not significantly different from 1.0).
- Precision was determined by examining the R^2 and root-mean-square error (RMSE) values derived from the regression analysis. The equation was considered precise for estimating FM if the R^2 value exceeded .90 and the RMSE value was below 5.0.
- The agreement between BIA and DXA was evaluated through Bland and Altman's plots. The difference in FM in kilograms (kg) was treated as the dependent variable, and the average FM in kg between BIA and DXA was considered the independent variable. We calculated Limits of agreement (LOA) using ±2 standard deviations (SD) from the mean value of the dependent variable. Method agreement was considered if the mean value of the dependent variable did not differ from zero according to a paired *t*-test ($P > .05$). To determine the persistence of the bias regardless of adiposity levels (independent variable), we examined the homogeneity of the dependent variable using a simple linear regression analysis with the *P*-value of the beta (β) parameter. Homogeneity was acknowledged when the *P*-value of the β-parameter exceeded .05.

Results

The initial sample comprised 313 participants. We excluded 4 volunteers due to incomplete data. After removing these subjects, we included 309 subjects with complete data. The sample consists of 204 women (66%) and 105 men (34%), with a mean age of 49 years (age range: 24-65 years). According to the BMI, 44 subjects (14.2%) were classified as normal, 121 (39.1%) were overweight, and 144 (46.6%) were obese. Table 1 lists the main demographic characteristics of the study's participants.

Table 1. Characteristics of the sample.

VARIABLES	MEN (*N* = 105)	WOMEN (*N* = 204)	TOTAL (*N* = 309)	P
Age, y	46.9 ± 8.2	50.3 ± 7.8	49.2 ± 8.09	.0004
Weight, kg	84.4 ± 17.2	73.8 ± 14.5	77.4 ± 16.2	<.0001
Height, m	1.69 ± 0.06	1.56 ± 0.06	1.6 ± 0.08	<.0001
BMI, kg/m²	29.4 ± 4.7	30.3 ± 5.7	30.0 ± 5.4	.1691
FMI BIA	9.5 ± 3.4	13.2 ± 4.1	12.0 ± 4.2	<.0001
FMI DXA	9.3 ± 3.3	12.7 ± 3.9	11.6 ± 4.1	<.0001

Abbreviations: BIA, bioelectrical impedance analysis; BMI, body mass index; DXA, dual-energy X-ray absorptiometry; FMI BIA, fat mass index BIA; FMI DXA, fat mass index DXA.

Table 2. Body fat mass (kg) by different methods in men and women with diabetes.

TECHNIQUE	COMBINED	WOMEN	MEN
DXA	29.5 ± 10.2	30.9 ± 9.5	26.8 ± 10.8
BIA	30.5 ± 10.5	32.2 ± 10.0	27.3 ± 10.9

Abbreviations: BIA, bioelectrical impedance analysis; DXA, dual-energy X-ray absorptiometry.
Comparison of group mean body fat mass between DXA and BIA. The data underwent a two-way analysis of variance considering gender and method. There was a significant main effect of sex but no significant effect of the method.

We used FMI cut-off points published by Kelly et al[22] to classify excess fat (men >6–9 kg/m², women >9–13 kg/m²) and obesity (men >9 kg/m², women >13 kg/m²). According to these data, FMI measured by BIA detected 156 subjects (50.59%) with obesity and 115 subjects (37.22%) with excess fat, compared with DXA, which classified 137 subjects (44.34%) into the obesity category and 125 (40.45%) in the excess fat category. BIA classified an additional 19 subjects as having obesity compared to DXA.

Based on the findings, according to the FMI, 52.3% of men and 49.5% of women were obese according to BIA, whereas 48.5% and 42.1%, respectively, were determined obese using DXA. This data demonstrates a recurrent pattern of overestimating the diagnosis of obesity in people with diabetes using the FMI by BIA.

According to the two-way ANOVA, Table 2 shows that the comparisons of FM in kg by DXA and BIA had no significant effect on the term method ($P = .30$). Thus, BIA is accurate at the group level for estimating FM in comparison with DXA. The ANOVA analyses showed an effect for the term sex ($P \leq .05$) that indicated that FM is higher in women than men.

In the case of the regression analysis, Table 3 shows that the slope ($\beta = .93$, close to 1) differed statistically ($P < .05$) from 0, and the intercept value was statistically different ($P = .01$) from 0. These results suggest that BIA is inaccurate for estimating FM at the individual level when compared to DXA in the total

Table 3. Validation of BIA against DXA for the estimation of fat mass in kg.

GROUP	FAT MASS (KG) (DXA)	FAT MASS (KG) (BIA)	INTERCEPT	SLOPE	RMSE	R^2	BIAS (KG)	−2SD	+2SD	DISTRIBUTION OF ERRORS (β VALUE)
Women	30.9 ± 9.5	32.2 ± 10.0	0.56 (P = .42)	0.95 (P = .0)	2.62	0.92	1.21 (P ⩽ .01)	−4.27	6.71	β = .048 (P = .01)
Men	26.8 ± 10.8	27.3 ± 10.9	1.44 (P = .02)	0.91 (P = .0)	2.68	0.93	0.55 (P = .04)	−4.87	5.97	β = .010 (P = .66)
Total	29.5 ± 10.2	30.5 ± 10.6	1.15 (P = .013)	0.92 (P = .0)	2.64	0.93	0.99 (P ⩽ .01)	−4.5	6.48	β = .038 (P = .01)

Abbreviations: BIA, bioelectrical impedance analysis; CI, confidence interval; DXA, dual-energy X-ray absorptiometry; RMSE, root mean square error; SD, standard deviation.

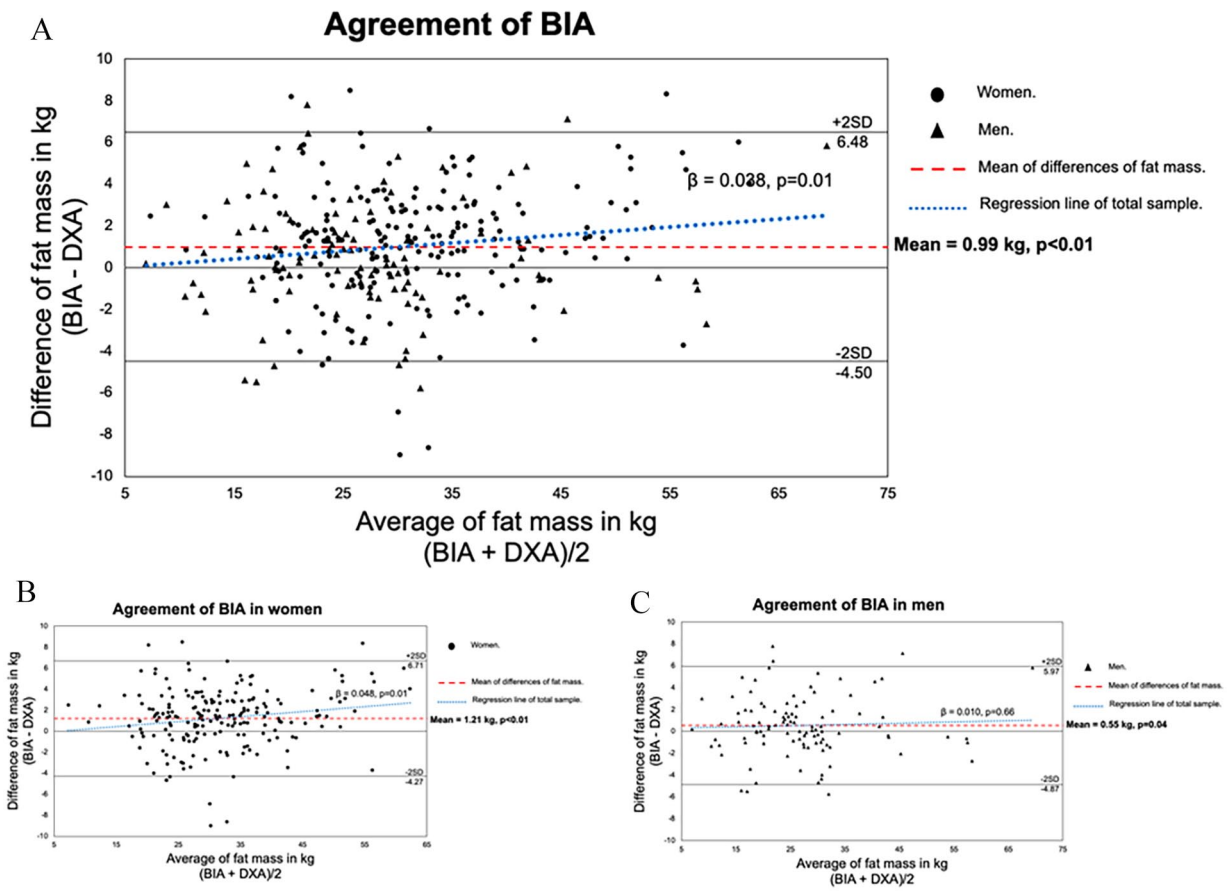

Figure 1. Bland and Altman plots and simple linear regression of the selected equations in men and women. The behavior of the mean difference against the mean of the measurements between the corrected equations and their respective reference method. The solid blue dot indicates the regression line. A solid red line indicates the mean difference. (A) Agreement of BIA. (B) Agreement of BIA in women. (C) Agreement of BIA in men.

sample. However, the R^2 and RMSE values permit us to infer that the BIA was precise in estimating FM compared to the DXA. BIA explained 93% of the variance in FM by the DXA, and the estimates had an RMSE of 2.64 kg in the total sample.

Notably, the results show that in women, BIA is not accurate (β = .92, $P < .01$, and intercept value was 1.44, $P = .02$) for estimating FM at the individual level when compared to DXA but is precise ($R^2 = .92$, and RMSE = 2.62). On the other hand, in men, BIA is accurate (β = .9, $P < .01$, and intercept value was 0.56, $P = .42$) at the individual level, and precise ($R^2 = .93$ and RMSE = 2.68) for estimating FM when compared to DXA.

The analysis of agreement in the total sample showed that the BIA and DXA are not in agreement in assessing FM in subjects included; the bias (0.99 ± 2.74 kg) among methods did differ from zero ($P < .01$). Furthermore, the regression line indicates that bias was not distributed homogeneously (β = .038, $P = .01$) over the range of average FM values (Table 3). The mean difference (bias) in FM estimation between BIA and DXA in men was 0.55 kg ($P = .04$) and 1.21 kg ($P = < .01$) in women (Table 3). However, in men, the bias distribution is homogeneously (β = .010, $P = .66$), providing the opportunity to calculate a correction factor for the bias (Figure 1).

Discussion

The study aimed to assess the agreement between BIA and DXA in estimating fat mass in Hispanic adults with type 2 diabetes mellitus. According to our results, we could overestimate fat mass and the obesity prevalence among both sexes using BIA compared to DXA. BIA is precise and accurate at the group level, so it could be helpful for studying populations, but it is not accurate at the individual level. This inaccuracy could be because elevated serum glucose levels can lead to decreased hydration in the body, altering the BIA results. While DXA is also affected by hydration status, its reliance on attenuation coefficients is based on different physical principles, and the impact of water on tissue attenuation is less pronounced.[23] Abnormalities in tissue hydration or electrolyte status can cause alterations in the conductive capacity and might be responsible for the inadequacy of BIA equations under these circumstances.[10] BIA's methodology is more directly affected by changes in tissue conductivity, mainly due to variations in water content, while DXA operates on distinct physical principles.

Even though BIA is precise at an individual level, despite the previously commented limitation, it has clinical utility for patient follow-up due to its accessibility, low cost, and ability to provide precise body composition measurements within the same patient over time. Our results suggest that the overestimation of body fat through BIA compared to DXA is statistically significant, although further research is required to determine its clinical relevance. Additionally, we found that overestimation increases with the amount of body fat and remains in both sexes.

In addition, we offered a valid correction factor for men, which could be a valuable tool for epidemiological studies.[20] A correction factor was not possible for women; a potential explanation is that in this study, the average age among women was 50 years, and the menopausal transition begins on average between 45 and 47 years. Estrogen and progesterone are essential in body fluid homeostasis, among other physiological processes. Evidence suggests that menopausal women are at an increased risk of body fluid disturbances, particularly of dehydration since the body fluid replenishment rate slows down as a result of hormonal changes, the addition of blunted thirst signals and restricted access to free water play a significant role in the increased risk of dehydration in this population.[17]

Previous data suggest that BIA is suitable for measuring FFM and FM in healthy subjects with stable water balance. However, clinical use in subjects with abnormal hydration is not recommended until validation is provided.[10,24] Despite these recommendations, BIA is widely used in people with diabetes, a known state of abnormal hydration. Other studies have assessed different methods and ethnic groups, such as Hispanic obese and older adults, being able to provide correction factors or predictive equations.[19] However, the most easily accessible methods, like BIA and the Hispanic population with diabetes, have been poorly studied.

The standard method of DXA and the secondary analysis of several protocols increase the generalizability of the results for the Mexican population, which is a strength of this study. We performed a thorough statistical analysis, which includes a regression analysis to evaluate the precision and accuracy at an individual level of body fat mass estimate, a Bland and Altman process to check the agreement between the BIA and DXA methods, and a linear regression analysis to determine homogeneity of bias. The possibility of including a correction factor for men is another benefit. While the variances in glycemic control among the diabetic group may have contributed to the differences in outcomes between DXA and BIA in our investigation, our data are insufficient to support this association definitively.

Some limitations include the fact that the study only includes data from Mexican adults with diabetes, which may limit the generalizability of the results to other populations. Another limitation of this study is the lack of a formal power analysis to determine the sample size. We based our sample size on the availability of subjects who met the inclusion criteria within the study's timeframe. Besides, it only assesses the agreement between BIA and DXA in estimating body fat mass, and it does not compare the results to other methods, which may provide a more accurate reference for body fat mass estimation. Despite the limitations, this study provides valuable insights into the accuracy and precision of BIA in assessing body composition in the diabetic population and its implications for patient follow-up, which is relevant to the growing concern of diabetes and obesity and the need for accurate and non-invasive methods to assess body fat mass in specific populations.

Conclusion

This study investigated the agreement between BIA and DXA for estimating fat mass in Hispanic adults with diabetes. Results showed that BIA is precise and accurate at a population level but may be inaccurate at an individual level and might overestimate fat mass in both sexes compared to DXA. It is also less accurate in women, but in men, we were able to provide a correction factor of 0.55 kg. These results underscore the unsuitability of BIA for individual clinical assessments due to its significant potential for error. However, BIA exhibited consistency at the group level, making it viable for epidemiological studies. BIA also shows a high level of precision, which makes it suitable for monitoring changes in the body composition of the same individual over time. This study highlights the importance of using objective and validated tools for measuring body composition in people with diabetes. Clinicians must recognize the limitations of BIA when interpreting their results. However, BIA is a valuable technique for studies in populations, and this study suggests that BIA could be a feasible option for the follow-up of our patients as it is non-invasive and cost-effective.

Declarations

Ethics approval and consent to participate

The Ethical Review Committee of the Instituto Nacional de Ciencias Médicas y Nutrición Salvador Zubirán approved the primary studies. All volunteers provided and signed their informed consent. Ethical approval number: 0361.

Consent for publication

Not applicable as this manuscript does not contain any patient image or data.

Author contributions

Conceptualization, C.C.C., R.G.A., and A.J.M.; methodology, C.C.C., R.G.A, and A.J.M.; data curation, C.C.C., C.G.C.M., and H.R.F.E.; data analysis, C.C.C., and R.G.A.; writing—original draft preparation, C.C.C., F.D.R.O., C.G.C.M., and H.R.F.E.; writing—review and editing, C.C.C., R.G.A., C.A.A.S., and A.J.M.; supervision, A.J.M., and C.A.A.S.; project administration, A.J.M.; All authors have read and agreed to the published version of the manuscript.

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Availability of data and materials

All data is available on request.

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