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ORIGINAL RESEARCH

Calculation of BMI based on waist circumference, age, and height in the Peruvian population using a regression equation

Cálculo del IMC según circunferencia de cintura, edad y talla mediante ecuación de regresión en población peruana

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Abstract

Introduction: BMI is a potential indicator of health and, therefore, should be considered when assessing an individual's health.
Objectives: To develop a regression equation for calculating BMI in the Peruvian population based on waist circumference, height, and age, and to evaluate its predictive capacity to identify overweight/obesity cases (BMI≥25) compared to BMI determined using the Quetelet's index (weight and height).
Materials and methods: A cross-sectional analytical study was conducted with secondary data from the Peruvian population (≥18 years) obtained from the Demographic and Family Health Survey (ENDES) (n=60 192; 2022: 30 047; 2023: 30 145). A multiple linear regression model was run using data from the ENDES-2022 survey to obtain the regression equation. The equation's capacity to identify overweight/obesity cases (BMI ≥25) was compared to the Quetelet's index (sensitivity, specificity, positive predictive value, negative predictive value, positive likelihood ratio, and negative likelihood ratio).
Results: The regression equation obtained [BMI=9.007 + (-0.052*age) + (-0.396*waist circumference) + (-0.103*height)] was statistically significant (F=62768.475; p<0.001) and the R^2 value was 0.858. When used with data from ENDES-2023 respondents, an R^2 value of 0.845 was obtained and a homoscedastic distribution was observed with respect to the BMI values obtained with the Quetelet's index. The strength of the association between BMI calculated with the equation and BMI obtained with the Quetelet's index was high for ENDES-2022 (OR=73.54; 95% CI=67.961-78.55) and ENDES-2023 (OR=66.697; 95% CI=66.168-72.136) respondents. Sensitivity and PPV were >90% in both years.
Conclusions: It is feasible to determine BMI and classify overweight/obesity cases in the Peruvian population using the regression equation based on waist circumference, height, and age. This may be useful in areas with limited access to accurate scales, either for economic or geographical reasons.

Resumen

Introducción. El índice de masa corporal (IMC) es un potencial indicador de la salud y, por tanto, debiera considerarse al evaluar la salud de un individuo.
Objetivos. Desarrollar una ecuación de regresión para el cálculo del IMC en población peruana con base en la circunferencia de cintura, la talla y la edad, y evaluar su capacidad predictiva para identificar casos de sobrepeso/obesidad (IMC≥25) en comparación con el IMC determinado con la fórmula de Quetelet (peso y talla).
Material y métodos. Estudio analítico transversal realizado con datos secundarios de población peruana (≥18 años) obtenidos de la Encuesta Demográfica y de Salud (ENDES) (n=60 192; 2022: 30 047; 2023: 30 145). Se corrió un modelo de regresión lineal múltiple usando los datos de los encuestados de la ENDES-2022 para obtener la ecuación de regresión. Se evaluó la capacidad de la ecuación para identificar casos de sobrepeso/obesidad (IMC≥25) en comparación con la fórmula de Quetelet (sensibilidad, especificidad, valor predictivo positivo, valor predictivo negativo, cociente de probabilidad positivo y cociente de probabilidad negativo).
Resultados. La ecuación de regresión obtenida [IMC=9.007+(-0.052*edad)+(-0.396*circunferencia de cintura)+(-0.103*talla)] fue estadísticamente significativa (F=62768.475; p<0.001) y el valor de R2 fue 0.858. Cuando se usó con los datos de los encuestados de la ENDES-2023 se obtuvo un valor R2 de 0.845 y se observó una distribución homocedástica respecto a los valores de IMC obtenidos con la fórmula de Quetelet. La fuerza de la asociación entre el IMC calculado con la ecuación y el obtenido con la fórmula de Quetelet fue alta en la ENDES-2022 (OR=73.54; IC95%: 67.961-78.55) y la ENDES-2023 (OR=66.697; IC95%: 66.168-72.136). La sensibilidad y el valor predictivo positivo fueron >90% en ambos años.
Conclusiones. Es factible determinar el IMC y clasificar casos de sobrepeso/obesidad en población peruana usando la ecuación de regresión basada en circunferencia de cintura, talla y edad, la cual puede ser útil en lugares con acceso limitado a balanzas precisas, ya sea por razones económicas o geográficas.

Introduction

Body mass index (BMI) is a mathematical ratio that correlates an individual's weight and height to obtain an estimate of body fat.[1,2] It is used to classify adults into underweight, normal weight, overweight, and obese according to the Centers for Disease Control (CDC),[1] or into severely underweight, underweight, normal weight, overweight, and obese (moderate or class I, severe or class II, and morbid or class III) according to the World Health Organization (WHO) and National Institute of Health standards.[2]

BMI is a potential indicator of health and should be considered along with other factors when assessing an individual's health.[1] Having an elevated BMI has been associated with an increased risk or frequency of diabetes mellitus,[3] cancer,[4,5] high blood pressure,[6] dyslipidemia,[6] obstructive sleep apnea,[7] gastroesophageal reflux disease,[8] impaired female reproductive function,[9] among other conditions.

Waist circumference (WC) is an anthropometric parameter that provides independent and additive information to BMI to predict morbidity and risk of death. Therefore, it has been reported that BMI alone is insufficient to properly assess the cardiometabolic risk associated with increased adiposity in adults and that WC measurement is an easily standardized and clinically applicable method to assess abdominal adiposity.[10] Assessing adiposity is relevant because adipose tissue, in addition to its role in fat storage and energy generation, has a significant impact as an endocrine tissue and immune mediator.[11]

Although BMI can be determined objectively with common calculators or on web pages[1] using the formula "person's body weight (in kilograms) divided by the square of their height (in meters)", weight measurements could be inaccurate due to the use of scales (mechanical or digital) that are defective or poorly calibrated due to poor maintenance. This situation may occur in health centers with precarious conditions that provide medical care in rural and remote areas, particularly in developing countries such as those in Latin America, where, besides the usual challenges faced by health systems, there are evident health inequities in rural and remote areas in terms of service coverage, infrastructure, financing, availability of equipment and human resources, among others.[12-17] The foregoing hinders the possibility of obtaining accurate information on the presence of overweight and obesity in these patients and population groups, negatively impacting their health status.

Accordingly, replacing weight in the BMI formula with other parameters that do not require the use of scales, such as WC (which only requires a measuring tape) and age, would allow establishing BMI in a more widespread and accessible way in low-income populations and/or in rural areas where inaccuracies may exist when measuring weight due to poorly calibrated or defective scales. This is particularly true in countries such as Peru, where health inequities are notably severe,[17] as there is a high percentage of people living in rural and remote areas (16.9% in 2024 according to estimates by the National Institute of Statistics and Informatics [INEI])[18] and higher poverty rates compared to urban areas (39.8% vs. 26.4%).[19]

For this reason, the objectives of this research were to develop a regression equation for the calculation of BMI in the Peruvian population based on WC, height, and age, and to evaluate its predictive capacity to identify overweight/obesity cases (BMI≥25) in comparison with BMI determined using the Quetelet's index (weight and height).

Materials and methods

Study design and data analyzed

Cross-sectional analytical study carried out with secondary data obtained from the databases of the Peruvian Demographic and Family Health Survey (ENDES) conducted in 2022[20] and 2023,[21] which is a complex, probabilistic, two-stage and independent national sampling survey that assesses every year the demographic and health dynamics of the Peruvian population depending on the area of residence (urban and rural). The ENDES was administered by the INEI in 35 287 and 35 678 households (out of 36 650 and 36 760) in Peru in 2022 and 2023, respectively.[20,21]

Sampling was purposive. Respondents of legal age (≥18 years) who underwent anthropometric measurements for weight, height, and WC (N=68 837; 2022: 34 301; 2023: 34 536) were considered eligible. Respondents with incomplete data for the variables of interest or inconsistent data (values that lacked logical plausibility such as weight of 1 000kg, height of 9 999cm, or age of 9 999 years) were excluded, thus obtaining a sample of 60 192 individuals (2022: 30 047; 2023: 30 145) (Figure 1).

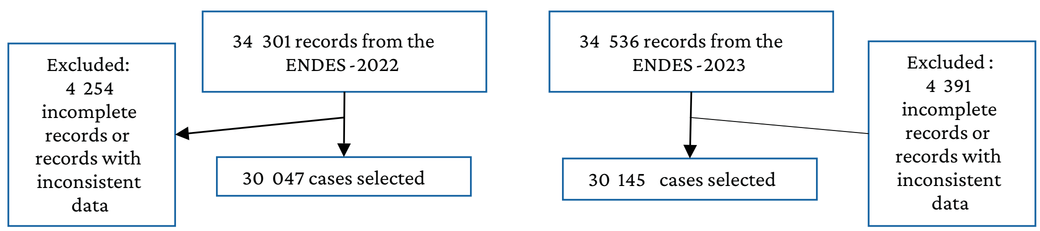

Figure 1. Sample selection flowchart (ENDES-2022 and ENDES-2023).
ENDES: Demographic and Family Health Survey.

Variables and measurements

Information on the following variables was obtained from the ENDES-2022 and ENDES-2023 databases: weight, height, age, and WC. WC was measured by trained anthropometrists at the National Center for Food, Nutrition, and Healthy Living using a measuring tape at the midpoint between the last rib and the upper edge of the iliac crest with the person standing.[22]

Furthermore, since the ENDES does not provide data on BMI, this parameter was calculated using the Quetelet's index in the SPSS Statistics 25.0 software through the <transform-calculate variable> path.

Statistical analysis

Data are described using absolute and relative frequencies for qualitative variables and means, medians, standard deviations, and interquartile ranges for quantitative variables according to the distribution of the data (Kolmorogov-Smirnov test).

To obtain the regression equation to determine BMI based on WC, age, and height, a multiple linear regression model was constructed using the data from the ENDES-2022 respondents. This regression model was used because it estimates the linear relationship between a quantitative dependent variable and two or more independent variables.[23]

To determine the presence of multicollinearity in the model, and due to the non-normal distribution of the data (Kolmorogov-Smirnov test), the Spearman correlation coefficient (Rho) was calculated, as it is a statistical method that evaluates the linear relationship between two continuous variables,[24] in this case between the dependent variable (BMI) and the independent variables (age, height, and WC). It was established that if the correlation with height was >0.9,[25] there was multicollinearity, since height is a parameter considered in the Quetelet's index for calculating BMI.

Furthermore, to evaluate the accuracy of the statistical model for predicting the outcome (in this case BMI), the coefficient of determination (R^2) was calculated. This is a number between 0 and 1 that is interpreted as the proportion of variation in the dependent variable predicted by the statistical model.[26]

On the other hand, to evaluate homoscedasticity of the model, the BMI values of the ENDES-2023 respondents calculated using the Quetelet's index were compared with the BMI values obtained with the regression equation using a scatter plot of points. This evaluation also included the calculation of the coefficient of determination R^2.

Finally, the BMI values obtained with the regression equation and the Quetelet's index were dichotomized into <25 and ≥25 (overweight/obese) to determine the capacity of the equation to identify overweight/obesity cases in comparison with the Quetelet's index, estimating its sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), positive likelihood ratio (LR+), and negative likelihood ratio (LR-). Likewise, the strength of the association between the BMI obtained using the Quetelet's index and the BMI obtained using the regression equation was determined by calculating odds ratios (OR).

Statistical analyses were performed in the SPSS Statistics 25™ software and all were considered to have a statistical significance value of $p<0.05$ with a 95% confidence interval (CI).

Ethical considerations

The study adhered to the ethical principles for biomedical research involving human subjects established in the Declaration of Helsinki.[27] The database was obtained from a secondary source of the Peruvian government (https://www.datosabiertos.gob.pe/) in which, according to memorandum 001-2023-UDT-OTIC/INS of November 11, 2023, data are available in a simple, secure, reliable and anonymous manner, requiring neither authorization documents to use this information nor authorization from an institutional ethics committee. The ENDES-2022 and ENDES-2023 databases are available online.[20,21]

Results

BMI (calculated with Quetelet's index) values (mean and SD, and median and IQR), weight, height, age, and WC of respondents in the ENDES-2022 and ENDES-2023 are presented in Table 1. On the other hand, the median BMI calculated with the regression equation was 27.01kg/m² (IQR: 6.10) for the ENDES-2022 and 26.82kg/m² (IQR: 6.50) for the ENDES-2023.

Table 1. BMI, age, weight, height, and waist circumference in the Peruvian population according to the ENDES-2022 and ENDES-2023.

	ENDES-2022 (n=30 047)				ENDES-2023 (n=30 145)			
	Mean	**SD**	**Median**	**IQR**	**Mean**	**SD**	**Median**	**IQR**
BMI (Quetelet's index)	27.02	5.14	26.71	6.3	26.78	4.51	26.78	7.2
Weight	67.09	13.87	65.6	18	65.67	12.33	64.70	17
Height	156.92	8.70	156.4	13	156.53	8.55	156.10	12
Age	38.78	16.38	35	2.1	39.48	16.76	36	23
Waist circumference	91.51	11.92	91.2	15.8	90.05	11.10	90	16

BMI: body mass index; SD: standard deviation; IQR: interquartile range; ENDES: Demographic and Family Health Survey.

Concerning the evaluation of multicollinearity, performed prior to the construction of the regression equation, the Spearman correlation coefficient between BMI and height was -0.060 (p<0.001); in other words, there was no multicollinearity (Table 2).

Table 2. Correlation between BMI and height, waist circumference, and age in the Peruvian population of the ENDES-2022.

BMI (Quetelet's index)	Height	Waist circumference	Age
Rho	-0.060	0.890	0.198
p-value	<0.001	<0.001	<0.001

BMI: body mass index; Rho: Spearman's correlation coefficient; ENDES: Demographic and Family Health Survey.

The regression equation obtained is:

*BMI=9.007+(-0.052*age)+(0.396*waist circumference)+(-0.103*height)*

Where: the BMI value decreases by 0.052 for each year of age, increases by 0.396 for each centimeter of WC, and decreases by 0.103 for each centimeter of height.

The regression equation was statistically significant (F=62768.475; p<0.001). The R^2 value was 0.858, indicating that 86% of the change in the dependent variable can be explained by the model based on WC, age, and height (Table 3).

Table 3. Multiple linear regression analysis for the estimation of BMI from waist circumference, age, and height in the Peruvian population (ENDES-2022).

	β	Standard error	p-value
(Constant)	9.077	0.203	<0.001
Age	-0.052	0.001	<0.001
Waist circumference	0.396	0.001	<0.001
Height	-0.103	0.001	<0.001
Model statistics: F=62768.475; R^2= 0.858			

β: Beta coefficient; ENDES: Demographic and Family Health Survey.

A mostly homoscedastic distribution was observed in the scatter plot of points (Figure 2) used to compare the BMI values calculated by Quetelet's index with the BMI values obtained using the regression equation in the ENDES-2023 respondents. Moreover, a linear R^2 of 0.845 was obtained, which implies that 85% of the variation in BMI values calculated with the Quetelet's index can be explained by the BMI values obtained with the regression equation.

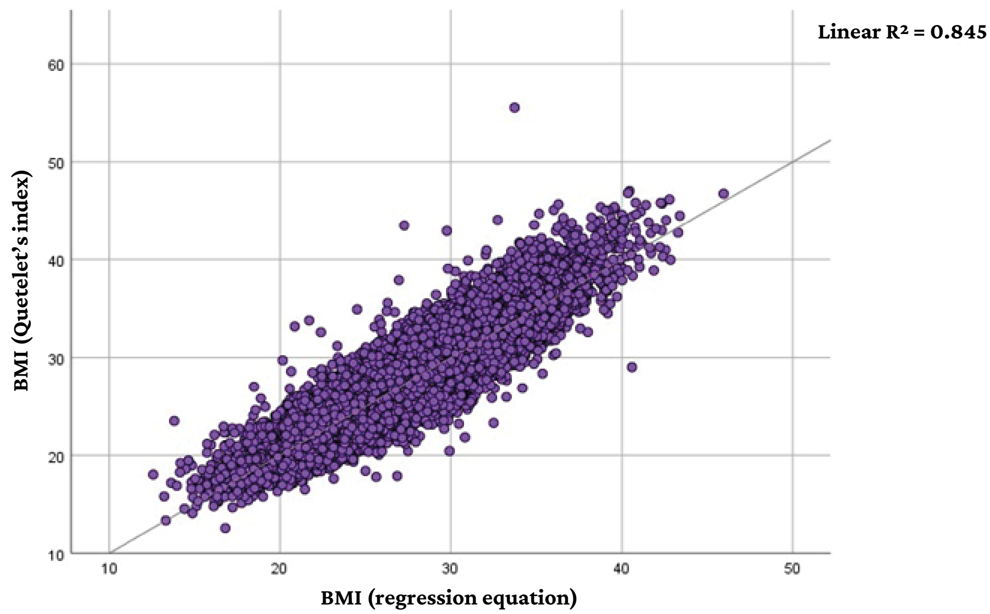

Figure 2. Comparison of BMI values calculated using the Quetelet's index with BMI values obtained using the regression equation (age, height, and waist circumference) in ENDES-2023 respondents.
BMI: body mass index; ENDES: Demographic and Family Health Survey.

Regarding the capacity of the regression equation to identify overweight/obesity cases (BMI≥25) compared to the Quetelet's index, it was found that 90.59% (ENDES-2022) and 91.10% (ENDES-2023) of the respondents classified as overweight/obesity cases with the regression equation were classified as overweight/obesity cases with the Quetelet's index (Table 4).

Table 4. Contingency table for the presence of overweight/obesity (BMI≥25) in the ENDES-2022 and ENDES-2023 according to the BMI calculation method.

ENDES-2022			ENDES-2023		
	BMI (Quetelet's index)			BMI (Quetelet's index)	
BMI (equation ENDES-2022)	≥25	<25	**BMI (equation ENDES-2023)**	≥25	<25
BMI≥25 (n=20 715)	18 765 (90.59%)	1 950 (9.41%)	**BMI≥25 (n=19 265)**	17 551 (91.10%)	1 714 (8.90%)
BMI<25 (n=9 332)	1 080 (11.58%)	8 252 (88.42%)	**BMI<25 (n=10 880)**	1 443 (13.26%)	9 437 (86.74%)
Total (n=30 047)	19 845 (66.05%)	10 202 (33.95%)	**Total (n=30 145)**	18 994 (63.01%))	11 151 (36.99%)

BMI: body mass index; ENDES: Demographic and Family Health Survey.

Finally, the regression equation developed for BMI calculation based on age, WC, and height showed, with respect to the use of the Quetelet's index, a sensitivity and PPV >90%, a specificity >80%, a NPV >85%, and a high LR+ for identifying overweight/obesity cases in both the individuals in the ENDES 2022 and the ENDES-2023. Likewise, the intensity of the association between BMI calculated with the regression equation and BMI calculated with the Quetelet's index was high in both the ENDES-2022 (OR=73.54; 95%CI: 67.961-78.55) and the ENDES-2023 (OR=66.697; 95%CI: 66.168-72.136) (Table 5).

Table 5. Diagnostic accuracy measures of the regression equation to identify overweight/obesity cases using the Quetelet's index in the Peruvian population (ENDES-2022 and 2023) and intensity of the association.

	OR (95%CI)	S	Sp	PPV	NPV	LR+	LR-
ENDES-2022	**73.54 (67.961-78.55)**	95%	81%	91%	88%	4.95	0.07
ENDES-2023	**66.697(66.168-72.136)**	92%	85%	91%	87%	6.01	0.09

OR: odds ratio; S: sensitivity; Sp: specificity; PPV: positive predictive value; NPV: negative predictive value; LR+: positive likelihood ratio;
LR-: negative likelihood ratio; ENDES: Demographic and Family Health Survey.

Discussion

The capacity of the regression equation to identify overweight/obesity cases (BMI≥25) is in high agreement with the Quetelet's index in the ENDES-2022 (90.59%) and ENDES-2023 (91.10%) surveys. These results suggest that the use of alternative equations can be an effective method in large populations, especially when direct weight measurements are limited.

This level of agreement supports the usefulness of the equation as an alternative tool in contexts where direct measurements may not be feasible or reliable. Even so, the slight variations between the values obtained with each method may be associated with inherent limitations of the regression equations, such as imperfect fit in individuals with atypical characteristics (very high or low heights or weights, or with non-standard body fat distribution). This is consistent with the findings of Pérez-Rodrigo *et al.*,[28] who reported in a study of 2 753 individuals over 3 years of age living in Spain to estimate the prevalence of overweight and abdominal obesity that even though national health surveys provide relevant information on weight, height, and health problems reported by respondents, this information underestimates the prevalence of obesity, with an error estimated at 2.0%-2.7% in men and 4.7%-5.9% in women compared with estimates based on measurements.

Regarding the properties of the regression equation developed here, the following was observed: 1) the distribution of the data (ENDES-2023) was mostly homoscedastic, since the scatter plot of the BMI values obtained with the equation did not show a significant variation with respect to the values calculated with the Quetelet's index (Figure 2); 2) the R^2 coefficients of determination were similar in both populations (ENDES-2022: 0.858; ENDES-2023: 0.845); and 3) the sensitivity and PPV for detecting overweight/obesity cases were >90%.

The variable with the greatest influence on the multiple linear regression model was WC, which replaced weight as the parameter for calculating BMI, and this is consistent with the high correlation observed between the two variables (Rho=0.890). This high correlation between BMI and WC has also been reported in studies from other countries. For example, Dagan *et al.,*[29] in a study of 403 healthy adults aged 25-65 years (men: 222; women: 181) who were administered the Periodic Examination Health Survey at a medical center in Israel, reported a statistically significant Pearson's correlation coefficient between BMI and WC (p<0.05) for both men (r=0.896) and women (r=0.889). Likewise, Gierach *et al.,*[30] in a study conducted in Poland with 839 adults diagnosed with metabolic syndrome (32-80 years), reported correlation values between BMI and WC of r=0.80 in women, r=0.76 in men, and r=0.78 for the entire study population (p<0.01). However, in a Nigerian study of 489 healthy adults (20-75 years), Chinedu *et al.*[31] found that this correlation was moderate (r=0.63). Therefore, the use of WC instead of weight to estimate BMI using regression equations may require adjustments to suit the anthropometric characteristics of the populations of each country, since the efficiency of the equation will be lower if the correlation between BMI and WC is moderate or low.

Despite the high correlation between BMI and WC, we chose to include height and age in the equation because the R^2 coefficient in a simple linear regression analysis with only WC was 0.701, while the coefficient with the inclusion of these variables increased to 0.858, representing a low but significant contribution to generate a model with a distribution that is as similar as possible to the Quetelet's index for calculating BMI. The contribution of age, which was in a downward direction, is consistent with studies showing that BMI tends to decrease with age due to a reduction in muscle mass.[32,33]

The regression equation developed in this study allows calculating BMI without using a scale and only requires a measuring rod and a measuring tape, or even a measuring tape alone (though it should be considered that they usually have a length of up to 1.5m), so it could be useful for detecting overweight/obesity in populations with limited or difficult access to accurate mechanical or digital scales, either due to socioeconomic or geographic limitations (e.g., rural population) or both. Furthermore, given that its diagnostic capacity was demonstrated in a representative population of Peru (ENDES-2022 and ENDES-2023), it can be used in population groups throughout the country.

The limitations of this study include the lack of randomization and sampling technique; however, the representative nature of the ENDES-2022 and ENDES-2023 (two-stage, independent probability sampling) allows generalizing the results to the entire Peruvian population. Moreover, although the regression equation provides values very close to those of the BMI calculated with the Quetelet's index, it does not provide exact results as the ones obtained with that index, so direct measurement instruments such as the scale are required. Likewise, this equation, as it has been designed for the Peruvian population, cannot be extrapolated to populations in other countries, making it necessary to reproduce linear regression equations depending on the anthropometric characteristics of each country or region. It is worth noting that, just as there is a possibility that mechanical and electronic scales may have defects such as being uncalibrated or defective, similar limitations could also arise when measuring height and WC with instruments such as the retractable measuring tape and the measuring rod, but the probability of error is much higher in scales due to their composition and mechanism of operation.

Conclusion

According to the R^2 values obtained in the ENDES-2022 and ENDES-2023 populations, it can be stated that the regression equation developed here allows estimating BMI in the Peruvian population based on WC, height, and age, with values very close to those obtained with the Quetelet's index. Likewise, the equation showed adequate predictive capacity to identify overweight/obesity cases; therefore, it can be used to estimate BMI and detect cases in low-income and/or rural populations in Peru with limited access to accurate mechanical or digital scales.

Conflicts of interest

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Acknowledgments

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