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Differences in wasting assessment through Middle-Upper Arm Circumference (MUAC) adjusted by sex, age and geographic origin for children aged 6–59 months: New reference based on anthropometric surveys from 22 low-and-middle-income countries

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Abstract

Objectives: The Middle Upper Arm Circumference (MUAC) bracelet is a widely used instrument in public health assessments and humanitarian assistance projects. The WHO guidelines present a universal cut-off point of 115 mm to determine whether a child has severe acute malnutrition. The objective of this study is to analyze the existing differences in the MUAC for boys and girls aged between 6 and 59 months, from 22 countries distributed in three different continents, in contrast to the use of this single cut-off point. In addition, the creation of MUAC growth charts is presented for reference use.

Materials and Methods: This study was carried out with a database developed by Action Against Hunger, composed, after the data pre-processing phase, of 97 921 individuals without anthropometric failure from African, Asian, and American continents. MUAC measurements were compared between countries, dividing by sex and age groups. A *k*-means method was used to create country clusters to allow comparisons and the variability was resumed using a Principal Component Analysis. For each cluster, growth curves were created and smoothed using the LOESS method.

Results: Our research has revealed the existence of differences in the MUAC between countries in both, males and females, although with different trends. The evidence was confirmed with the creation of two clusters using the *k*-means method, which, when graphically represented by the Principal Component Analysis, showed that the MUAC was clearly different. There were also differences between males and females within each cluster, where growth curves did not overlap in any age group.

Conclusions: All statistical analysis indicate that there are differences in the MUAC values for children without anthropometric failure between countries, but also between sexes. With this research, a new reference is proposed that consider the existing variability between human populations to improve the precision in the determination of severe acute malnutrition in children.

1 | INTRODUCTION

Curves and growth charts show the ontogenetic evolution of body dimensions and are used to evaluate the nutritional status of children. Some of the most used growth charts worldwide are those created by the World Health Organization (WHO, 2007a), who developed standards for height-for-age (HAZ), weight-for-age (WAZ), weight-for-height (WHZ), and BMI-for-age (BMIZ) for children under 5 years of age, to which the mid-upper arm circumference-for-age (MUACZ) was added later (WHO, 2007b).

HAZ informs on chronic malnutrition or stunting (i.e., low height for age), WAZ on global malnutrition or underweight (i.e., low weight for age), and both, WHZ and MUAC, on acute malnutrition or wasting (i.e., low weight for height). For the evaluation of MUAC in public health assessments and humanitarian assistance programs, a bracelet with colored stripes was developed, that allows classifying children from 6 to 59 months of age as: normally nourished (green: upper arm circumference ≥125 mm), with moderate acute malnutrition (yellow: circumference ≥115 < 125 mm) or with severe acute malnutrition (SAM) (red: circumference <115 mm). Since the band that uses MUAC values to determine the nutritional status of the children is intended for international cooperation and humanitarian aid contexts, it only considers anthropometric failure by default, not by excess, and therefore does not have an upper limit for the MUAC value. Certain MUAC bracelets also have in the reverse side, instructions and diagrammatic drawings representing the steps in taking MUAC measurement (UNICEF, 2020). These static cut-off points facilitate the diagnosis in the field work (Goossens et al., 2012; WHO, 2013), but the fact that they are identical for boys and girls between the ages of 6 and 59 months may detract the precision (Natale & Rajagopalan, 2014). Despite recommending its use in a general way, the WHO itself questioned this aspect (WHO, 2013) and most of the studies have revealed SAM diagnostic mismatches between WHZ and MUAC (Ahn et al., 2020; Grellety & Golden, 2016). In addition, the degree of disagreement in the diagnosis seems to be affected by population-type factors such as body shape and proportionality (Laillou et al., 2014). Furthermore, the diagnostic differences are not exclusive to the WHZ and MUAC indicators, and comparative studies have shown that there are differences in growth patterns at the international level (Martín-Turrero et al., 2021).

Moreover, both global type standards and single cut-off points have been questioned by some authors (Reilly, 2016) and others have proposed the need for growth patterns to adapt to the sex and age variability (Fiorentino et al., 2016), and population (Alvarez et al., 2018; Thi et al., 2015) and, in this line of research, our hypothesis is that the development of MUAC is affected by factors such as age, gender and geographical origin of the child. This variability is not exclusive to the measurements themselves, but differences in sexual dimorphism have also been found between populations of different geographic origin (Kryst et al., 2021). Although this aspect is not explored in depth in our research, it is important to consider the possibility of inter-generational changes within the same population, a situation that has already been reported for other regions (Żegleń et al., 2020).

Based on all this evidence, our research aims to deepen the understanding of the variability of MUAC among normal-nourished children of different sex, age and geographical origin, checking if there are significant differences and elaborating reference tables in case there are any.

2 | MATERIALS AND METHODS

2.1 | The sample

For this work, a database provided by the non-governmental international organization Action Against Hunger (AAH) was used. Originally, it was composed of 368 408 children from 22 countries (with their respective International Organization for Standardization [ISO] codes) distributed in three different continents (Table 1).

TABLE 1 Sample distribution by sex and country of origin (with their respective International Organization for Standardization [ISO] codes, available at: https://www.iso.org)

Country	ISO code	Continent	Males	Females	Total
Afghanistan	AFG	Africa	1889	2064	3953
Angola	AGO	Africa	40	90	130
Burundi	BDI	Africa	267	314	581
Central African Republic	CAF	Africa	682	782	1464
Democratic Republic of the Congo	COD	Africa	9586	11 407	20 993
Ethiopia	ETH	Africa	1012	1093	2105
Guinea	GIN	Africa	745	778	1523
Haiti	HTI	America	2265	2311	4576
Kenya	KEN	Africa	1592	1728	3320
Liberia	LBR	Africa	228	331	559
Mali	MLI	Africa	735	682	1417
Myanmar	MMR	Asia	642	732	1374
Mauritania	MRT	Africa	175	151	326
Niger	NER	Africa	891	955	1846
Nepal	NPL	Asia	123	210	333
Pakistan	PAK	Asia	783	941	1724
Sudan	SDN	Africa	18 355	20 563	38 918
Sierra Leone	SLE	Africa	861	927	1788
Somalia	SOM	Africa	328	299	627
Chad	TCH	Africa	1580	1716	3296
Tajikistan	TJK	Asia	103	145	248
Uganda	UGA	Africa	3163	3657	6820
Total			46 045	51 876	97 921

The data were taken in different surveys to assess the prevalence of acute malnutrition in the context of humanitarian assistance. All the work was conducted by health care personnel and qualified anthropometrics previously trained in the SMART methodology (SMART, 2006). This research was conducted in accordance with the World Medical Association Helsinki Declaration of 1975 as revised in 2001 (WHO, 2001).

2.2 | Dataset preprocessing

All analyses were realized with the software R (R Core Team, 2020). The first step was to exclude from the database all children with nutritional failure, by default or by excess. Nutritional failure was considered to exist in cases that presented edema (a somatic sign of SAM), those that presented a z-score lower or equal to -2, as well as those with values greater than 1 z-score in the MUAC values (i.e., considering the standard deviation of the MUAC values themselves with respect to the mean).

The second step was to search for outliers in the database. As a first approximation, those values above the third quartile or below the first quartile were eliminated (calculating the interquartile ranges for each age group for each sex). Second, the especially low values (those who lowered the group mean with respect to the previous age group mean) for the MUAC were eliminated not only considering that group but the entire series. In the outlier selection process, it was decided to be especially strict, assuming the existence of false positives in the elimination of outliers but achieving a more robust sample with less internal error. Finally, there was a sample of $N = 97\,921$ normonourished children (Table 1) who were categorized by sex and age in 3-month groups.

This is a significant reduction in sample size, so we have considered it relevant to include as supplementary information a table (Supplementary Table 2) that breaks down each of the preprocessing steps, indicating in detail the reduction of the database in the different steps. The greatest filtering occurred when selecting only individuals who were not malnourished. This is largely a result of the humanitarian aid context in which the data were collected, which is dominated by children who are not normo-nourished.

After all this process, Tajikistan and Angola are present to a lesser extent in the total sample (with an n of 248 and 130, respectively), but we consider that including them has the value that increases the human variability contained in the overall sample allowing the application of the reference proposed here in these countries, which are frequently the scene of international cooperation projects.

2.3 | Differences by country

In each category of sex and age, a Kruskal–Wallis test preceded by a Levene's test for homogeneity of variance across groups was applied to compare the MUAC means between countries (at a level of significance of 0.05). The Kruskal–Wallis test was chosen because in some groups there was no normal distribution of the data. To give the test robustness, the Bonferroni post hoc test was applied. With this workflow, it was guaranteed that the differences between countries were not obtained at random. It is important to point out that in this way it is not intended to assess the differences in the growth pattern or the trend throughout the time series of each country, but rather the differences between individuals of the same age and sex, but from different countries.

2.4 | Sample clustering

After analyzing the differences between countries, clusters were identified to avoid the absolute atomization of the sample. The clusters were created using the k-means method (Hartigan & Wong, 1979), using the median value of each country in each age group (each sex independently) for clustering. The clusters were decided through an iterative process that evaluated all the possible cluster configurations establishing the final number based on the value of the within sum of squares. To ensure the internal coherence of the clusters, a study of the silhouette coefficient was carried out. To summarize the variability, a Principal Component Analysis (PCA) was performed (prcomp function from R, 2020) for both the male and female samples based on the median values of each age group. This PCA also allows to check the overlap between the two clusters created.

Once the clusters were established, the median was calculated for the different age groups, drawing up the growth curves for the MUAC, which were smoothed by the LOESS method (Jacoby, 2000). These curves were used to compare the differences between clusters.

3 | RESULTS

The sample was split by sex and, for each month, all possible pairings among countries (21) were made to check how many pairs had statistically significant differences (at a $p < .05$ level). The result can be seen in Figure 1A (boys) and B (girls). A great variability is revealed, especially notable at 36, 58, and 59 months in the male series and in the range of 10–18 months in the female series. Visually, these graphs show opposite trends for males and females. While the differences in females seem to be concentrated in the first months, for males the differences are heterogeneously expressed at different ages.

From this information, homogeneous clusters for country datasets were established (those with the least difference for MUAC) within the male and female series respectively. For the creation of these clusters, the lowest total value of within cluster sum of squares (3943.2 and 2908.3 for males and females, respectively) was obtained for $k = 2$ in both sexes. This choice was validated using the silhouette coefficient method, which confirmed that it was a robust clustering.

The clusters created are shown in Figure 2A (boys) and B (girls), represented as a PCA of the medians for each age group, and are composed of the following countries: In boys, cluster 1 included Angola (AGO), the Central African Republic (CAF), The Republic of Guinea (GIN), The Republic of Haiti (HTI), The Republic of Kenya (KEN), The Republic of Liberia (LBR), The Islamic Republic of Mauritania (MRT), The Federal Republic of Somalia (SOM), and The Republic of Tajikistan (TJK) and cluster 2 all the other countries studied. In girls, cluster 1 was composed by AGO, CAF, GIN, HTI, KEN, LBR, MRT, The Republic of Sierra Leone (SLE), SOM and the cluster 2 by all the others. That an unsupervised process groups the same countries in each group for both boys and girls (with the exception of TJK and SLE) is an indicator of the robustness of the model and, probably, of a geographical factor directly affecting the development of MUAC in these children.

It should be noted that the Principal Component (PC) expresses a different amount of variability, being in both cases PC1 the most illustrative of the existing diversity. Specifically, the explained variance is 70% and 63% for PC1 and 11% and 14% for PC2 (in males and females, respectively), being the amount of variability reflecting the difference between Principal Component 1 and 2. In the creation of these PCAs, the cluster generated with the

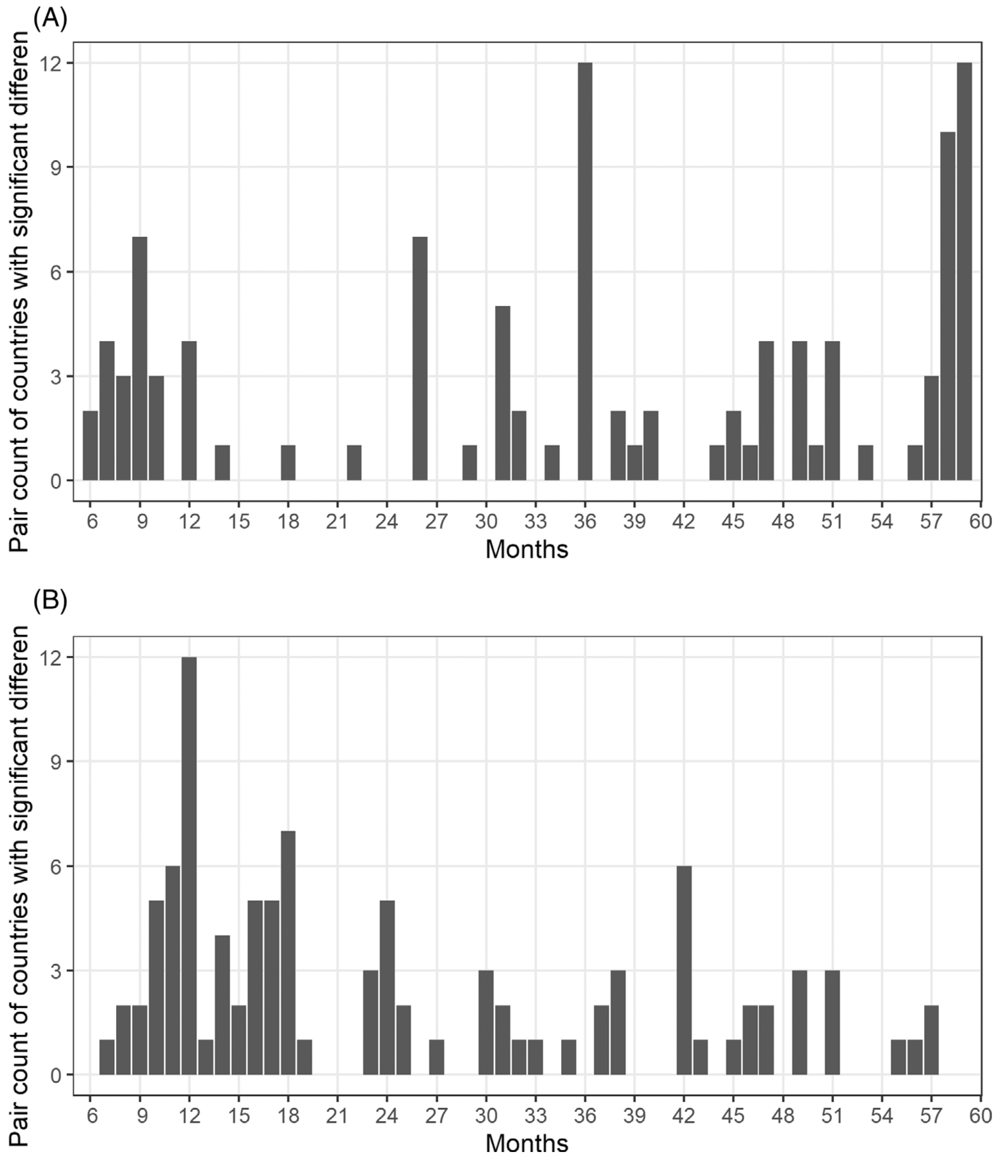

FIGURE 1 (A) Pairs of countries with significant differences between the MUAC measure for males without anthropometric failure, based on a Kruskal–Wallis test. (B) Pairs of countries with significant differences between the MUAC measure for females without anthropometric failure, based on a Kruskal–Wallis test

k-means method was not included as a classification factor, so there is no bias in this regard and its representation in Figure 2A,B is merely illustrative of the differentiation of these clusters for both boys and girls.

In each of these clusters, the median was calculated for the different age categories, which allowed creating the corresponding growth curves for the MUAC in boys and girls (Figure 3A,B). In both sexes, it is confirmed that the clusters are different to the point that the confidence interval generated for the LOESS smoothing does not overlap between clusters in any age group. The differences by sex between Group 1 and 2 are clearly seen in Figure 3A,B. While for boys the MUAC is higher in Group 1 than in Group 2 throughout the time series, this circumstance is reversed in the case of girls, where Group 2 presents higher values for all ages. On the other hand, observing the growth curves in one or another cluster it is proven that MUAC increases with age. For this reason, from this LOESS smoothing analysis, tables have been created for each cluster providing the cut-off points corresponding to the median and ±1, ±2, and ±3 *z*-scores by sex and for every month from 6 to 59 (Supplementary Table 1).

4 | DISCUSSION

The simplicity of MUAC and its high correlation to risk of death is a good argument for its use in SAM identification. Nevertheless, according to the results of this study, using a single cut-off point for all human groups (115 mm) may decrease effectiveness when diagnosing wasting at the individual level and have consequences when calculating prevalence at the population level to take epidemiological measures.

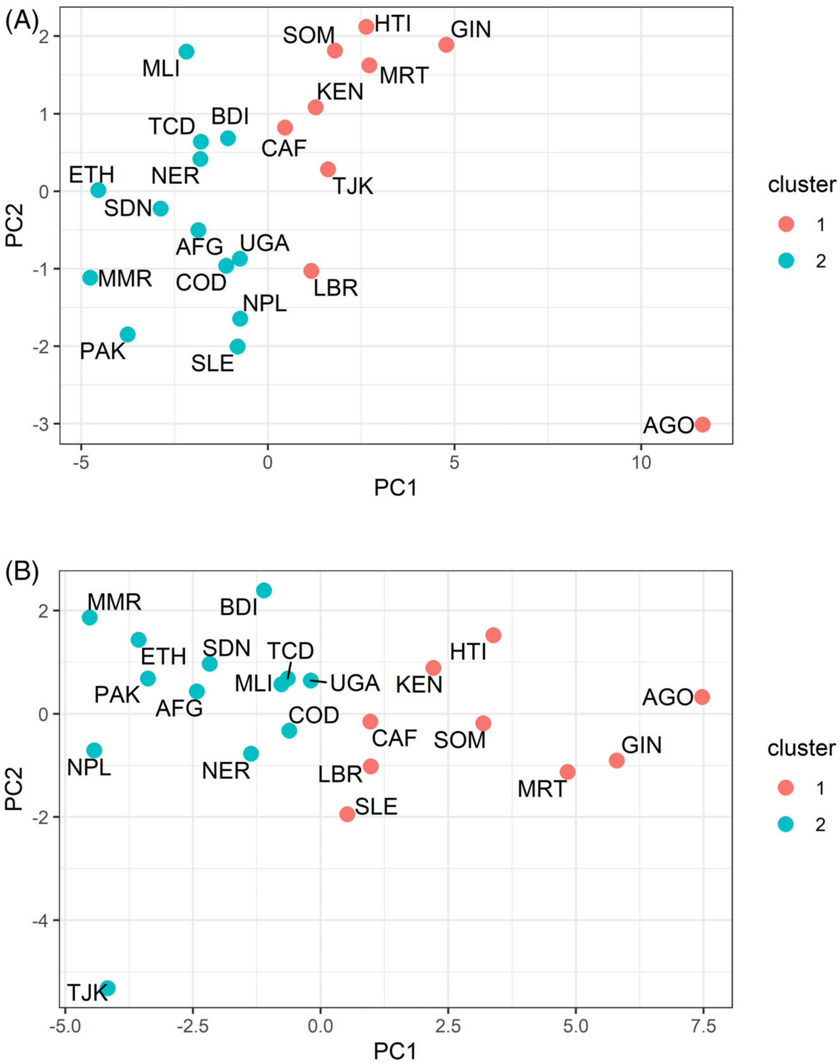

FIGURE 2 (A) Principal component analysis of MUAC median values for each age group (males). (B) Principal component analysis of MUAC median values for each age group (females)

The WHO growth standards for children from 6 to 59 months old are a useful tool for nutritional assessment and have been adopted universally for this purpose in the field of humanitarian aid. However, some systematic reviews and other studies (Hruschka, 2020; Tian et al., 2020) have highlighted notable differences between WHO standards and national or regional references obtained with the same inclusion criteria (Natale & Rajagopalan, 2014). The lack of diagnostic agreement is evident and, in addition, the WHO itself warns that the proportion of children who in successive studies, are below the limits of normality (±2 SD of the WHO standards), correspond more frequently to Asiatic populations (Ahn et al., 2020). Without a doubt, the type of diet, health and general living conditions, influence growth patterns and body dimensions. For example, height is a highly heritable trait and regulatory epigenetic and genetic factors can be responsible of phenotypic difference in size and shape between populations (Benonisdottir et al., 2016; Masip et al., 2020; Padonou et al., 2014; Smith et al., 1993; Stewart et al., 2019; Wood et al., 2014). These studies are in line with the results obtained in our article. Specifically, Figure 1A,B show that there are differences between countries and how they vary throughout the development of children.

These comparative articles are concerned about variables such as height, weight or head circumference, but usually not MUAC, which population variability has been analyzed in the present study. Mramba et al. (2017) already demonstrated that MUAC is age and sex dependent, a fact that is confirmed in the present research. Differences revealed in the age and sex variability of MUAC could be explained by differences in the growth patterns (WHO, 2007b).

The present study provides curves and reference tables constructed exclusively from data of normo-nourished children, that could be used as a reference for more accurate assessments of children's nutritional status based on MUAC cut-off points calculated by geographic origin, sex, and age between 6 and 59 months

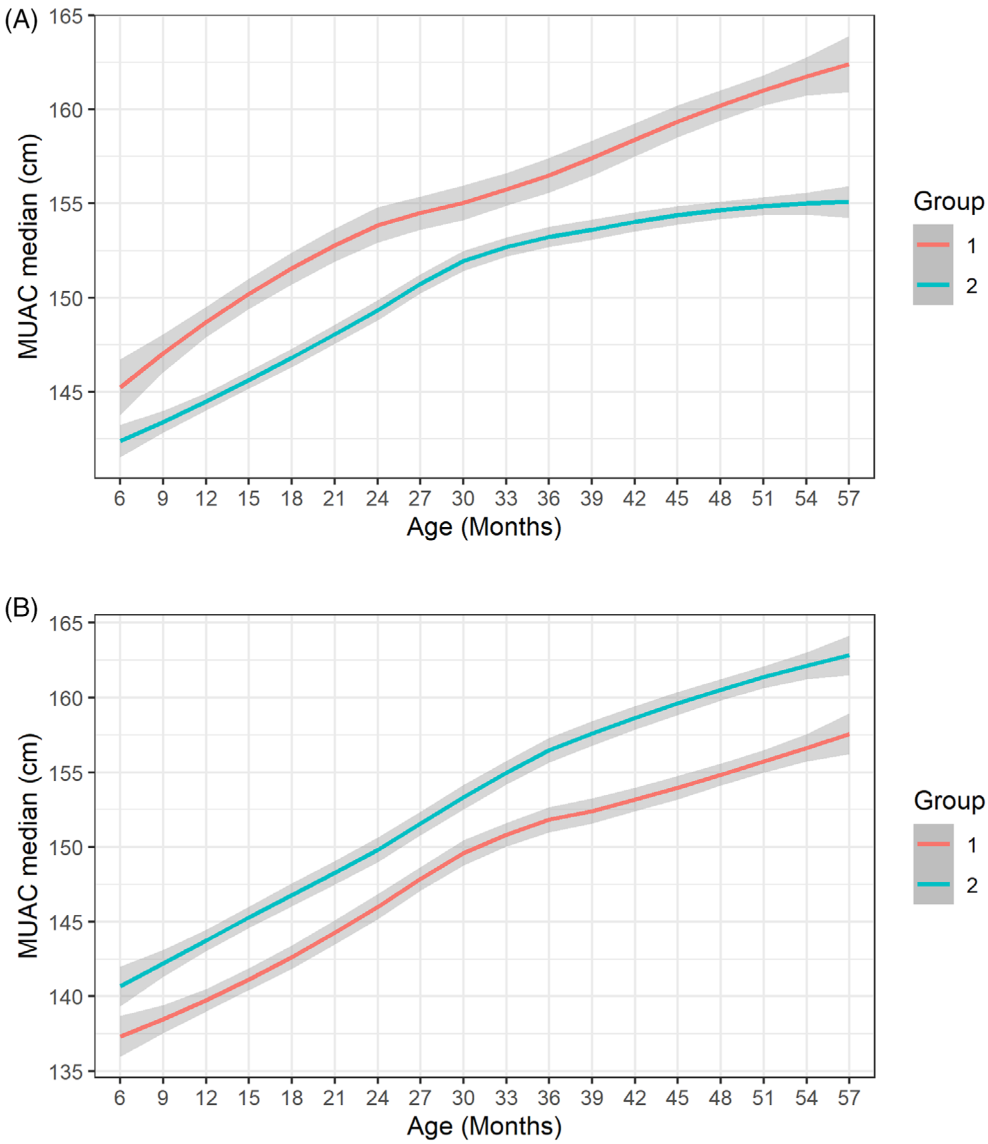

FIGURE 3 (A) MUAC median for the two clusters of countries after LOESS smooth process (males). (B) MUAC median for the two clusters of countries after LOESS smooth process (females)

(with the values of the normo-nourished children being above −1 SD and below +1 SD). Thus, depending on the country of the sample to be assessed, the table corresponding to the cluster that includes that country could be chosen, providing better adequacy of the diagnosis beyond the adequacy by sex and age already provided by the WHO reference (WHO, 2007b), because the tables proposed in this study consider age, sex and geographic origin when diagnosing nutritional status. Few studies in the literature are based on a sample of individuals without anthropometric failure, to assess regional or sex differences in anthropometric indicators. Our research proposes a new perspective that revalidates, from another angle, a hypothesis that other authors have already stated: human variability especially in growing-age individuals, can hardly be contained in a single and static cut-off point. In addition, we have shown that these differences are not the same at all ages, with changes being observed between different months of age.

It should be noted that anthropometric diagnosis is the screening tool used to make clinical decisions such as admission or discharge from therapeutic food or supplementation treatment programs. In rural contexts with difficult access, community screening campaigns tend to be scarce and carried out by low-skilled personnel, generally volunteers with a low level of education (WHO & UNICEF, 2012). In these contexts, where material resources are also scarce, the use of MUAC as a screening tool is recommended even though it may not identify malnourished children according to weight-for-height (Briend et al., 2017). Even if it slightly complicates handling, the use of the MUAC bracelet together with the curves or specific reference tables for each sex and age can be an alternative that avoids leaving out these children. As an example, the study conducted in Somalia by

Custodio et al. (2018) shows that the prevalence of acute malnutrition detected by the MUAC/age (15.8%) was very similar to that of the WHZ (16.1%) and much higher than that detected by the MUAC with an absolute cut-off point. MUAC with an absolute cut-off point (7.8%).

As the main limitation of the study, it should be noted that not all countries are equally represented, being Tajikistan and Angola the countries most affected by this phenomenon, but which we have decided to keep in order to enable the use and application of the results obtained in our research in those countries. Other similar research analyzing the childhood anthropometry in low and middle-income countries pooling data from national and regional health surveys also show a significant disparity in sample sizes and includes countries with a total number of children even smaller than those of the present study (Heemann et al., 2021).

This is explained by the origin of the data coming from anthropometric assessments linked to humanitarian assistance programs. The database is built on samples of different territories for which the prevalence of child malnutrition wanted to be established. However, nationally, and regionally surveys are mixed, which causes an imbalance in the sample sizes by country.

In 2006, the World Health Organization (De Onis et al., 2009) published standards for children under 5 years of age, based on a sample of 7551 children from locations in six countries on different continents: Pelotas (Brazil) and Davis (United States) in America, Accra (Ghana) in Africa, Delhi (India) and Muscat (Oman) in Asia and Oslo (Norway) in Europe. The children were born to non-smoking mothers, breastfed for a minimum of 4 months to ensure optimal nutrition. The study was a semi-longitudinal study incorporating a longitudinal sample of 882 children (between birth and 24 months) and a cross-sectional sample of 6669 children between 25 and 59 months. The present study incorporates a significantly larger sample ($N = 97\,921$) and integrates a larger number of populations per country and continent, representing, to a greater extent, the possible variability of the human growth pattern.

All the results of our research statistically support the anthropological evidence that there is great variability among children from different countries, ages, and sexes, when they do not present anthropometric failure. This evidence contrasts with the generalized use of a single cut-off point taken as a reference for the determination of nutritional status (especially SAM). It is understandable that the development and application of the WHO standards responds to the need to carry out work within the framework of humanitarian assistance that could not wait for the construction of population-specific standards. However, even being fully aware of this reality, it is necessary to point out that there are important population differences between children from 6 to 59 months. Evidencing and assuming the existence of these differences allows progress in the construction of new standards or, at least, improve the precision of existing ones.

AUTHOR CONTRIBUTIONS

Javier Lescure: Conceptualization; data curation; formal analysis; methodology; software; visualization; writing – original draft. **Irene Martín-Turrero**: Methodology; software; writing – review & editing. **Noemí López-Ejeda**: Funding acquisition; project administration; resources; writing – review & editing. **Antonio Vargas**: Funding acquisition; project administration; resources; writing – review & editing. **María Dolores Marrodán**: Conceptualization; methodology; resources; supervision; writing – review & editing.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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