The Bioelectrical Impedance Analysis (BIA) International Database: Aims, Scope, and Call for data

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Abstract

Background: Bioelectrical impedance analysis (BIA) is a technique widely used for estimating body composition and health-related parameters. The technology is relatively simple, quick, and non-invasive, and is currently used globally in diverse settings, including private clinicians' offices, sports and health clubs, and hospitals, and across a spectrum of age, body weight, and disease states. BIA parameters can be used to estimate body composition (fat, fat-free mass, total-body water and its compartments). Moreover, raw measurements including resistance, reactance, phase angle, and impedance vector length can also be used to track health-related markers, including hydration and malnutrition, and disease-prognostic, athletic and general health status. Body composition shows profound variability in association with age, sex, ancestry, geography, lifestyle, and health status. To advance understanding of this variability, we propose to develop a large and diverse multi-ancestry multi-country dataset of BIA raw measures and derived body components. The aim of this paper is to describe the 'BIA International Database' project and encourage researchers to join the consortium.

Methods: The Exercise and Health Laboratory of the Faculty of Human Kinetics, University of Lisbon has agreed to host the database using an online portal. At present, the database contains 277,922 measures from individuals ranging from 11 months to 102 years, along with additional data on these participants.

Conclusion: The BIA International Database represents a key resource for research on body composition.

Keywords: Reactance, Phase angle, Vector length, Body composition, Nutrition, Obesity, Consortium

Background

The use of bioelectrical impedance analysis (BIA) to investigate human body composition began in the 1960s, when Thomasett showed that total body water (TBW) could be estimated from whole-body impedance [1]. Subsequent development of this approach has substantially extended its capacity to provide information about tissue composition and function [2-5]. The feasibility, portability, and safety of BIA makes it relatively unique among body composition methods [6]. The technology is relatively simple, quick, and non-invasive, and is currently used globally in diverse settings, including private clinicians' offices, sports and health clubs, and hospitals, and across a spectrum of age, body weight, and disease states. In turn, this has resulted in an exponential increase in the availability of BIA data. As yet, however, the potential of this high data volume has not been comprehensively exploited to improve our understanding of human body composition variability, in relation to sex, age, health status, lifestyle and population.

Several different approaches can be used to extract information on body composition from BIA. In the single frequency approach (SF-BIA), through the application of a 50 kHz alternating current, BIA provides measures of impedance (Z, ohm) by conductive tissues such as blood, muscle/organs and cerebrospinal fluid. Z comprises a purely resistive component (resistance, R, ohm) that is related to water and electrolytes in fluids and tissues, and a capacitive component (reactance, Xc, ohm) responsible for the delay of the current entering cells, associated with cell membrane integrity and cell interfaces [7, 8]. While single-frequency 50 kHz BIA machines are popular, tetra polar multi-frequency BIA (MF-BIA) or bioelectrical impedance spectroscopy (BIS) instruments also provide frequency-specific readings at 50 kHz.

One approach to estimating body composition from raw BIA data is to predict TBW or fat-free mass (FFM) from the impedance index, calculated as the square of height (HT, cm) over impedance (HT^2/Z). Based on research studies, numerous such equations have been published for healthy populations and with diseases [1, 9-33]. This approach can be extended to the main compartments of TBW, extracellular water (ECW) and intracellular water (ICW), by exploiting the fact that whether the current passes only through ECW, or through both ECW and ICW, depends on its frequency [34, 35]. At the cellular level, BIA-derived body cell mass [18, 36, 37], and at the tissue level, skeletal muscle (SM) mass, can be

accurately predicted in healthy populations [38]. These components have a recognized implication in health and performance, specifically intracellular water [39-41], but also in disease susceptibility due to increased levels of fatness and loss of SM [42-45]. The latter is also a key characteristic of sarcopenia, a SM disease rooted in adverse muscle changes that accrue across a lifetime [46]. Indeed, for sarcopenia diagnosis, BIA has been recognized as a useful tool to estimate SM quantity and quality [46].

A second approach focuses on direct measures provided by BIA that have been widely used to explore malnutrition, growth and development, athletic performance, sexual dimorphism, pregnancy, and ageing in several populations [47-55]. Indeed, the raw BIA parameter phase angle (PhA), representing the arc tangent of Xc/R, is a compound indicator of the distribution between intra and extracellular fluids and of body cell mass [8, 53]. There has been growing interest in the use of such raw BIA parameters as proxy markers of health, physical fitness and function, and disease status, avoiding the need for prediction equations [56-64]. However, the practical application of PhA measurements to define nutrition status still requires normative values. To date, reference data for PhA are available for healthy American [65, 66], German [67] and Swiss [68] adult populations, as well as athletes [69] and UK children [70], but given the large inter individual variability associated with factors such as age, sex and ethnicity, consensus on the normal range is still lacking and more comprehensive standards are required.

An interesting extension of the insights from research on PhA is represented by bioelectrical impedance vector analysis (BIVA) [71], which in turn has been developed in different ways. BIVA [71, 72] analyzes R and Xc, and the derived variables PhA and vector length (i.e., Z,) without relying on assumptions of a fixed FFM hydration, or on constant body geometry and resistivity values. Particularly, PhA describes the direction of the vector on the R-Xc graph and represents the distance from the vector to the X axis. Classic BIVA adjusts raw BIA parameters for HT, whereas specific BIVA standardizes on the basis of estimated body volume, derived from data on both height and cross-sectional area. This means that specific (sp) BIVA parameters (R_{sp}, Xc_{sp}, Z_{sp}) are influenced by the properties of the tissues rather than body size and shape. BIVA allows a better understanding of body composition variability than does PhA alone independent of vector length, or R independent of Xc. In classic BIVA, variation in vector length indicates different hydration conditions for a given PhA [71], whereas in specific BIVA it indicates different levels of FM% [72-74]. Hence, both classic and specific BIVA can be used

simultaneously [75]. Population-specific reference values for classic and specific BIVA are available for U.S. children, adolescents, and adults, Italian children and adolescents, Italian-Spain young adults and elderly Italians [72-74, 76-79], but factors such as ancestry, lifestyle, socio-economic status have not yet been considered in depth.

Body composition shows profound variability in association with age, sex, ancestry, geography, lifestyle and health status. In turn, this incorporates variability both in bio-conducting tissues, and also in total and regional body composition [52, 80-82]. To date, due in part to the difficulty of applying most methods at scale, we lack a large representative body composition database that incorporates variability in age, sex, ancestry, lifestyle, environment, socio economic factors and athletic status.

Developing such a database for BIA would allow a range of potential applications. Among these we highlight:

- Developing a comprehensive integrated model of healthy body composition by pooling BIA data across multiple populations.
- Relating BIA data to other phenotype data on health, lifestyle and disease state.
- The capacity for BIA data to guide clinical management across a wide range of disease states.
- The capacity for BIA data to help assess the efficacy of large public health interventions.
- The capacity for BIA data to be routinely collected by individuals in the home, gyms and healthy clubs, in order to help them maintain healthy weight and body composition.
- To contribute to academic training and teaching by enabling quality data.

Beyond the direct implications for health, increasing the capacity to measure body composition at scale may have substantial economic benefits, through increasing the success of lifestyle interventions, optimising drug dose calculations, and improving the efficiency of healthcare.

The aim of this project is therefore to build a large and diverse multi-ancestry dataset of BIA raw measures and derived body components by pooling data from multiple countries. These data can be shared for research investigations to enable a better understanding about body composition variability in association with age, sex, ancestry, geography, lifestyle and health status and to develop robust normative values. Here, we describe this ongoing 'BIA International Database' project and encourage researchers, especially those from low- and middle-income countries, to contribute data.

Call for data

The BIA International Database had its genesis in 2017 at a Summer School training workshop in Sardinia, Italy (https://sssnsa.wordpress.com/), when the idea and benefits of compiling all published BIA measurements on humans was proposed. Alone, each individual dataset is unable to tackle relevant questions in sports, nutritional, and medical sciences, whereas combining information across studies offers many new opportunities.

The application of BIA to humans vastly increased since 2000 [83], with 19713 publications between 1960 and 2021 based on a search in the ISI Web of Science core collection using the search string ((Bioeletrical impedance analysis) OR BIA OR bioimpedance), as illustrated in **Figure 1**.

INSERT FIGURE 1

This large-scale application of BIA demonstrates the data that is potentially available for pooled analysis. We therefore invite contributions from researchers worldwide. The Faculty of Human Kinetics of University of Lisbon agreed to host the database, and a total of 276,410 measurements (1 record = 1 measurement on 1 person) have been initially uploaded to the website. The URL of the website is https://bit.ly/fmh_ulisboa.

Overall Approach and Procedures

This is an ongoing project, soliciting collaboration among researchers for sharing BIA datasets with particular emphasis on low-income countries to complement the extensive data from high-income countries already received and published in the literature. All

participants included in the final dataset have provided their consent to participate in the study conducted by each contributor, following the approval granted by the institution's ethics committee.

We will address the following steps:

Step 1: Building a large database of BIA raw and derived parameters, with the following characteristics:

1. ***Minimal BIA and associated data***: age, sex, anthropometry (body mass and height), R, Xc, Z, and PhA, population, year of data collection, device characteristic (SF-BIA, MF-BIA / BIS), ancestry (White, Black, Hispanic, Asian, Other), and health status.

2. ***Additional data f***or BIVA: segmental raw BIA measures (R, Xc, PhA, Z) and for specific BIVA, arm, waist and calf circumferences.

3. ***Desirable additional data:*** to explore links between BIA raw parameters and other outcomes: other body composition data (e.g., dual-energy X-ray absorptiometry- DXA total and regional estimates), physiological/metabolic data (e.g., glucose, lipid, and protein metabolism, hormones), and physical function (e.g., strength and physical performance), athletic status, education, socio-economic and lifestyle characteristics (e.g., physical activity, diet). Specific guidelines for preparing the database for providing these additional variables will be detailed on the website https://bit.ly/fmh_ulisboa.

All data are anonymised, being either the data of partners or collaborators of the consortium, or open-access public use files from international databases (e.g., NHANES). In order to integrate disparate and heterogeneous data, we will compare and harmonise different acquisition technologies and operation procedures of BIA, including the calibration and standardization of methods (data quality assessment) while also taking into consideration the position in which the exam was performed (i.e., standing, sitting, and lying). The end result of this step will comprise information on representative groups of children, adults, and elderly people; it will be a large and homogeneous database of BIA raw and derived parameters, demographics, anthropometrics, and when available,

metabolic variables, education, lifestyle, and socio-economic information, performance-related information, and data on other body components such as those derived from DXA.

Step 2. Data Management

The data will be deposited at the research database at Lisbon. The site is interactive and contains the number and type of measurements made in any target country.

Regarding data security, all included datasets will be part of projects approved by the respective ethics committee of each research group. After confirmation of inclusion by the management group, each individual in each database will be given a new code (related to the current project) to further guarantee confidentiality and privacy. Hence, the received databases have already codified data without any personal identifier, making the data untraceable to the corresponding individual, and complying with the GDPR key requirements. Furthermore, all received data will be converted into password protected files and stored at FMH server, with access limited to the chairman of the management group, Analiza M Silva, or designated members.

Access to the whole or part of the database will be supervised, as authors aiming to use the database must first obtain the approval by the management group, providing their intended analysis (i.e., scope and aim of the analysis, the intended variables and sample characteristics, as well a list of authors and a brief chronogram) and assuring that rules of privacy and data protection will be complied with. After following these steps, and if accepted by the management group, a separate password-protected file will be generated including the selected columns of interest. A detailed record will be created to monitor this data-sharing process.

Step 3. Data Analysis

A short description of the types of data already available in the database is displayed in **Figure 2**, including the geographical distribution of where the data was collected, the sex and age distribution of the sample.

INSERT FIGURE 2

An overall description of the types of data available in the database can be also found on the website under the “data overview tab”. A more comprehensive understanding of the

329 database contents can be obtained by downloading the excel file example including
330 details on the variables included in the main database.

331 So far, the database includes 277,922 measurements of children and adult male
332 (n=59,450) and female measurements (n=218,472) aged between 11 months up to 102
333 years, mainly healthy. As an indication of the size of the database and the variability in
334 the data it contains, **Figure 3** illustrates data from heathy individuals, stratified by sex
335 and age (<18 and ≥18 years) for the relationship between impedance index (cm^2/kHz) and
336 FFM (assessed by DXA).

337 **INSERT FIGURE 3**

338 The plots illustrated in Figure 3 show the strong association between impedance index
339 and FFM assessed by DXA in both sexes and age categories, particularly in children,
340 underscoring the relevance of the impedance index as an indicator of volume, though a
341 large inter individual variability is observed in males and females among age categories.

342 **Step 4. Data access**

343 If the contributors wish to perform an analysis in the database several steps are required.
344 Briefly, contributors should: i) Examine the list of planned analyses; ii) check out sample
345 data set to determine if there are sufficient data; iii) download and fill out a template form
346 with a succinct summary, including the variables from the dataset that will be required;
347 iv) agree up front to the publication policy and approve the manuscript within 21 days.
348 The management group will discuss the idea and will provide feedback within 4 weeks
349 along with a form to be signed and returned. If the analysis is not performed within 18
350 months of approval the application will be removed from the planned analyses.

351 **Step 5. Publication policy**

352 The new knowledge provided by the BIA International database will be disseminated
353 through scientific publications as a key performance indicator for academic partners,
354 remaining a priority for the project, subject to intellectual property restrictions and the
355 publication management model.

356 Individuals submitting data will be acknowledged as authors on publications from the
357 database that use the data they contributed, allowing up to 2 authors per contributed

dataset. Manuscripts using the database must adhere to a number of rules that have been agreed upon by the management group, including that draft manuscripts must be approved by the management group, though the authors still maintain the authority and ownership of their own dataset, allowing them to use their dataset for other purposes. This may generate a large author list but follows the common practice in many multi-laboratory collaborations.

Discussion

This paper describes the BIA International Database goals, scope, and issues a "call for data". Through pooling BIA raw and derived population-based data from several countries, our consortium will be able to break new ground exploring human body composition variability and its potential associations with environment, lifestyle, socio-economic factors, disease-related malnutrition, and sports-related outcomes, while also providing normative values for diagnostic purposes.

We anticipate the impact of this project in several different contexts. First, we expect to improve understanding of the factors that drive the individual variability evident in figure 3 plots. Evidence has been accumulating underlining the influence of the life cycle, sexual dimorphism, ancestry, athletic and disease status [47, 48, 50, 51, 55, 59, 60, 84, 85] on variability in raw BIA variables among populations. A comprehensive appreciation of these factors is required for a better understanding of the wide variability in body composition, with emphasis on regional and total fatness and SM.

Second, by providing a target to achieve a "healthier" body composition, this project will contribute to the design of appropriate lifestyle interventions, enabling personalised exercise or dietary interventions and improving optimal clinical decision making. For instance, by proposing robust normative values for BIA-derived SM, cancer treatment doses can be optimized and the benefits of chemotherapy maximized, as SM loss is associated with an increased toxicity of chemotherapy and thus poorer prognosis [86]. Drug clearance rates depend on body composition and, consequently, we expect that normative values for BIA-derived body components may advance therapeutic options. Individualized prevention of non-communicable diseases and risk factors may also benefit from personalized data at the population level.

Third, this project will contribute to stimulating research, technology development and innovation. The large database will contribute to strengthening of scientific knowledge and to the academic training of young researchers. This new knowledge will benefit the research community by providing a simple and practical way of using quality data. Additionally, the BIA International Database findings will contribute to developing potential technological outputs, with benefits for a wide range of stakeholders, including fitness and sports fields, the healthcare system and the general public that can benefit from potential applications of the findings into technological products and services.

Finally, we expect environmental and social impacts from this project. The social value of the BIA international outputs is potentially substantial. The project will include and analyse data from both high- and low-income populations, helping understand the social determinants of body composition variability [87]. We look forward in particular to receiving data from vulnerable populations in countries with weaker health systems and those facing existing humanitarian crises, in order to identify new opportunities whereby body composition assessment can aid in describing and combating the emerging double burden of malnutrition at the individual level [88]. More generally, the project provides a new basis for personalized medicine, addressing age, ethnicity, disease-related malnutrition, environment, and socio-economic factors. This is challenging across worldwide populations that are facing an obesity epidemic, related non-communicable diseases and demographic changes due to e.g., ageing and migration. This contributes to healthier communities, enables informed disease prevention, ultimately reducing healthcare costs that represents an increased proportion of overall state spending.

Conclusion

The goals, scope and procedures of the 'BIA International Database' project are described and we issue a "call for data". The consortium aims to pool raw and derived population-based BIA data from multiple countries to enable analyses that capture the heterogeneity of the global population. We expect this project to provide a comprehensive integrated model of healthy body composition, clarify its wide variability, and contribute to developing and improving diagnostic tools.

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Author Contributions

All authors contributed to the drafting and editing of the manuscript and to construction of the BIA International database.

Statement of Ethics

The authors have no ethical conflicts to disclose for this review because there were no humans or animals involved directly.

Disclosure Statement

Authors of this manuscript may provide consultancy services or receive funding from impedance companies but no company has been involved at any stage of this initiative.

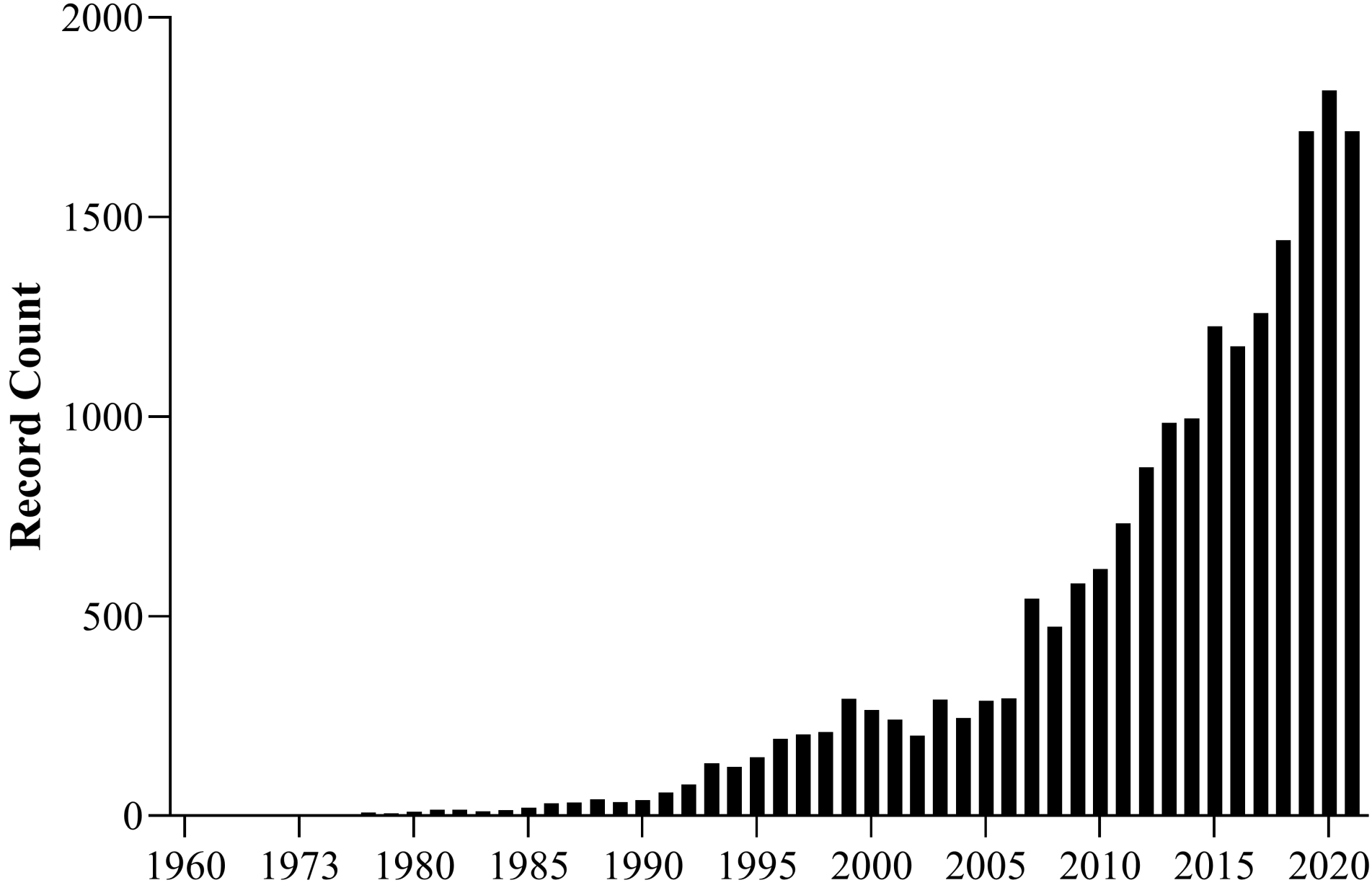
The authors have no conflicts of interest to declare.

853 **Figure Legends**

854 **Figure 1.** ISI-indexed publications using bioelectrical impedance analysis.

855 **Figure 2.** Data collected by sex regarding age (A) and region (B).

856 **Figure 3.** Graphical representation of: (A) the relationship between impedance index
857 (cm^2/kHz) and FFM (assessed by DXA), stratified by age and sex, in (A) female children
858 and adolescents (<18 years, N=2190), (B) male children and adolescents (<18 years,
859 N=3574), (C) female adults (≥18 years, N=4741), and (D) male adults (≥18 years,
860 N=5205).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1500
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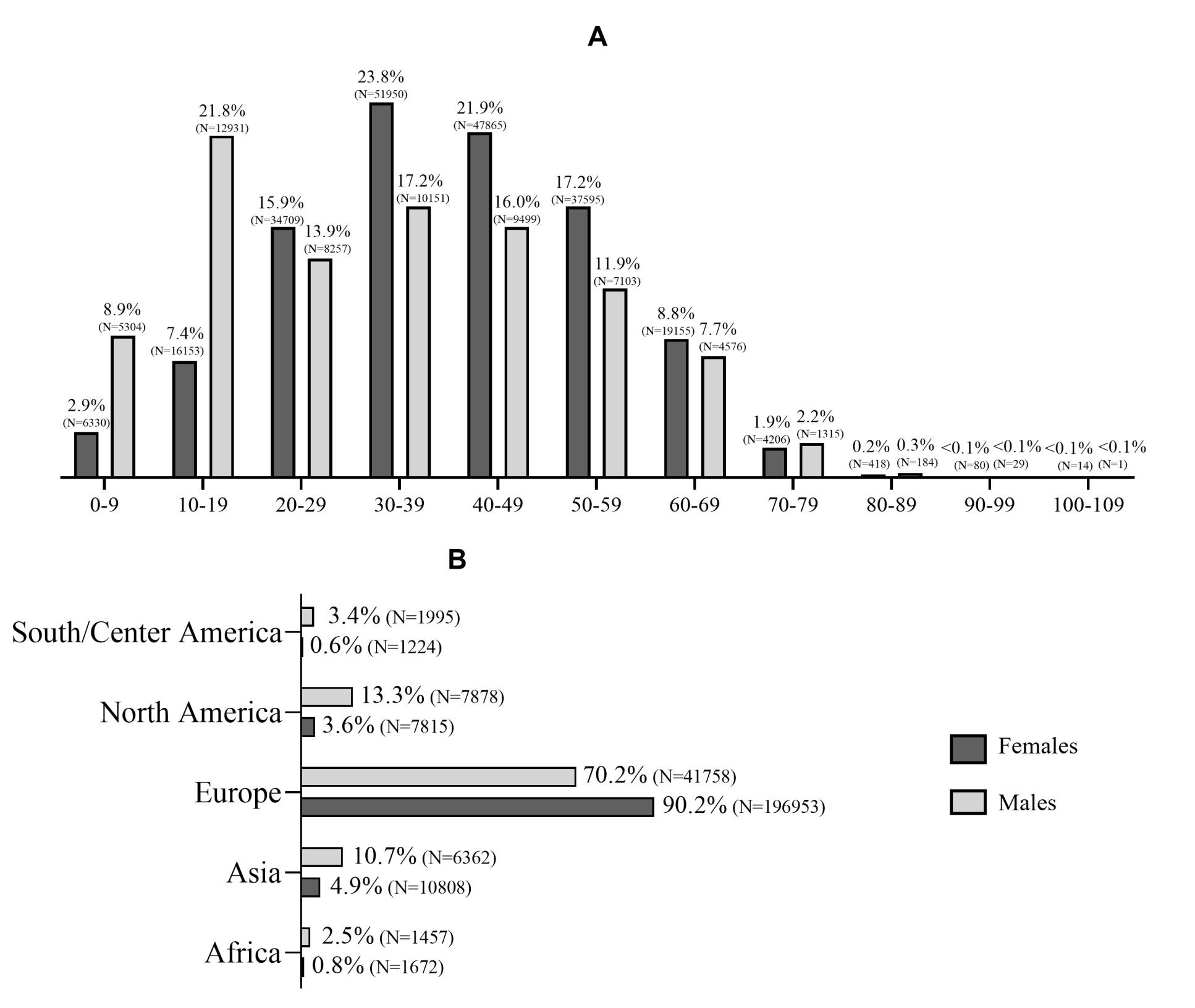
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2.9% (N=6330)
8.9% (N=5304)
7.4% (N=16153)
21.8% (N=12931)
15.9% (N=34709)
13.9% (N=8257)
23.8% (N=51950)
17.2% (N=10151)
21.9% (N=47865)
16.0% (N=9499)
17.2% (N=37595)
11.9% (N=7103)
8.8% (N=19155)
7.7% (N=4576)
1.9% (N=4206)
2.2% (N=1315)
0.2% (N=418)
0.3% (N=184)
<0.1% (N=80)
<0.1% (N=29)
<0.1% (N=14)
<0.1% (N=1)
0-9
10-19
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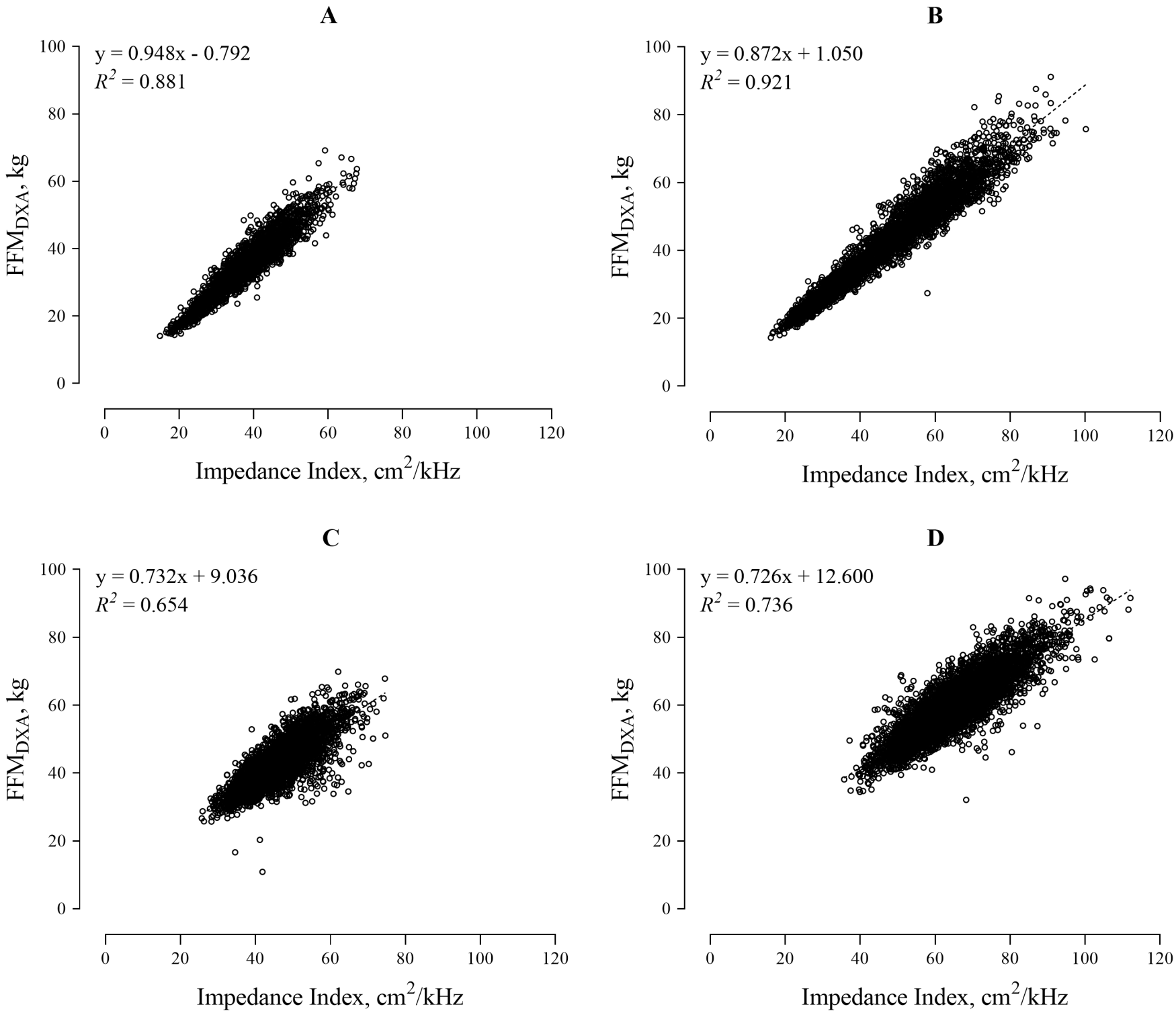
30-39
40-49
50-59
60-69
70-79
80-89
90-99
100-109
B
South/Center America
3.4% (N=1995)
0.6% (N=1224)
North America
13.3% (N=7878)
3.6% (N=7815)
Europe
70.2% (N=41758)
90.2% (N=196953)
Asia
10.7% (N=6362)
4.9% (N=10808)
Africa
2.5% (N=1457)
0.8% (N=1672)
Females
Males


A
y = 0.948x - 0.792
R^2 = 0.881
B
y = 0.872x + 1.050
R^2 = 0.921
C
y = 0.732x + 9.036
R^2 = 0.654
D
y = 0.726x + 12.600
R^2 = 0.736
FFM_{DXA}, kg
Impedance Index, cm^2/kHz
0
20
40
60
80
100
120