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

Figure 3. [A1] Graphical representation of the relationship between impedance index (cm2/ Ω) and FFM (assessed by DXA), stratified by age and sex, in (A) female children and adolescents (<18 years, N=2190), (B) male children and adolescents (<18 years, N=3574), (C) female adults (≥18 years, N=4741), and (D) male adults (≥18 years, N=5205).

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Article

Nutrition and Health (including climate and ecological aspects)

The bioelectrical impedance analysis (BIA) international database: aims, scope, and call for data

Analiza M. Silva✉
Email : analiza@fmh.ulisboa.pt
Affiliationids : Aff1, Correspondingaffiliationid : Aff1
Francesco Campa Affiliationids : Aff2
Silvia Stagi Affiliationids : Aff3
Luís A. Gobbo Affiliationids : Aff4
Roberto Buffa Affiliationids : Aff3

Stefania Toselli Affiliationids : Aff5

Diego Augusto Santos Silva Affiliationids : Aff6

Ezequiel M. Gonçalves Affiliationids : Aff7

Raquel D. Langer Affiliationids : Aff7

Gil Guerra-Júnior Affiliationids : Aff7

Dalmo R. L. Machado Affiliationids : Aff8

Emi Kondo Affiliationids : Aff9

Hiroyuki Sagayama Affiliationids : Aff9

Naomi Omi Affiliationids : Aff9

Yosuke Yamada Affiliationids : Aff10

Tsukasa Yoshida Affiliationids : Aff10

Wataru Fukuda Affiliationids : Aff11

~~Cristina~~Maria Cristina Gonzalez Affiliationids : Aff12

Silvana P. Orlandi Affiliationids : Aff13

Josely C. Koury Affiliationids : Aff14

Tatiana Moro Affiliationids : Aff2

Antonio Paoli Affiliationids : Aff2

Salome Kruger Affiliationids : Aff15

Aletta E. Schutte Affiliationids : Aff16

Angela Andreolli Affiliationids : Aff17

Carrie P. Earthman Affiliationids : Aff18

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Jeanette Bailey Affiliationids : Aff25

Zachary Tausanovitch Affiliationids : Aff25

Natasha Lelijveld Affiliationids : Aff26

Hadeel Ali Ghazzawi Affiliationids : Aff27

Adam Tawfiq Amawi Affiliationids : Aff28

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Suvi T. Kangas Affiliationids : Aff25

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Adriana Vázquez-Vázquez Affiliationids : Aff24

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Chiara Ceolin Affiliationids : Aff31

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Wiebke Braun Affiliationids : Aff41

José M. García-Almeida Affiliationids : Aff42
António L. Palmeira Affiliationids : Aff43
Inês Santos Affiliationids : Aff44
Sofus C. Larsen Affiliationids : Aff45 Aff46
Xueying Zhang Affiliationids : Aff47
John R. Speakman Affiliationids : Aff47 Aff48
Lindsay D. Plank Affiliationids : Aff49
Boyd A. Swinburn Affiliationids : Aff50
Jude Thaddeus Ssensamba Affiliationids : Aff51 Aff52
Keisuke Shiose Affiliationids : Aff53
Edilson S. Cyrino Affiliationids : Aff54
Anja Bosy-Westphal Affiliationids : Aff41
Steven B. Heymsfield Affiliationids : Aff55
Henry Lukaski Affiliationids : Aff56
Luís B. Sardinha Affiliationids : Aff1
Jonathan C. Wells Affiliationids : Aff24
Elisabetta Marini Affiliationids : Aff3

Aff1 Exercise and Health Laboratory, CIPER, Faculdade de Motricidade Humana, Universidade de Lisboa, ~~Lisbon~~1499-002, Lisbon, Portugal

Aff2 Department of Biomedical Science, University of Padova, 35100, Padova, Italy

Aff3 Department of Life and Environmental Sciences, University of Cagliari, Cittadella Universitaria, Monserrato, 09042, Cagliari, Italy

Aff4 Skeletal Muscle Assessment Laboratory, Physical Education Department, School of Technology and Science, São Paulo State University, Presidente Prudente, 19060-900, Brazil

Aff5 Department for Life Quality Studies, University of Bologna, 47921, Rimini, Italy

Aff6 Research Center of Kinanthropometry and Human Performance, Sports Center, Universidade Federal de Santa Catarina, Florianópolis, Brazil

Aff7 Growth and Development Laboratory, Center for Investigation in Pediatrics (CIPED), School of Medical Sciences, University of Campinas (UNICAMP), Campinas, 13083-887, Brazil

Aff8 Laboratory of Kinanthropometry and Human Performance, School of Physical Education and Sport of Ribeirão Preto, University of São Paulo, 05508-030, São Paulo, Brazil

Aff9 Faculty of Health and Sport Sciences, University of Tsukuba, Ibaraki, 305-8574, Japan

Aff10 National Institute of Health and Nutrition, National Institutes of Biomedical Innovation, Health and Nutrition, Osaka, 566-0002, Japan

Aff11 Yokohama Sports Medical Center, Yokohama Sport Association, Kanagawa, 222-0036, Japan

Aff12 Postgraduate Program in Nutrition and Food, Federal University of Pelotas, ~~Pelotas~~96010-610 Pelotas, Brazil

Aff13 Nutrition Department, Federal University of Pelotas, 96010-610, Pelotas, Brazil

Aff14 Nutrition Institute, State University of Rio de Janeiro, 20550-013, Rio de Janeiro, Brazil

Aff15 Centre of Excellence for Nutrition, North-West University, Potchefstroom, 2520, South Africa

Aff16 School of Population Health, University of New South Wales, The George Institute for Global Health, Sydney, NSW, Australia

Aff17 University of Rome Tor Vergata, Rome, Italy

Aff18 University of Delaware, Newark, DE, USA

Aff19 Hospital General de México, Dr. Eduardo Liceaga, Ciudad de México, Mexico

Aff20 National Institute of Physical Education of Catalonia (INEFC), University of Barcelona (UB), Barcelona, Spain

Aff21 School of Health Sciences, TecnoCampus, Pompeu Fabra University, Barcelona, Spain

Aff22 Department of Experimental and Clinical Medicine, University of Florence, Firenze, Italy

Aff23 Department of Sports and Computer Science, Section of Physical Education and Sports, Universidad Pablo de Olavide, Seville, Spain

Aff24 Population, Policy & Practice Research and Teaching Department, UCL Great Ormond Street Institute of Child Health, London, UK

Aff25 International Rescue Committee, New York, NY, 10168, USA

Aff26 Emergency Nutrition Network (ENN), OX5 2DN, Kiddlington, UK

Aff27 Department of Nutrition and Food Technology, School of Agriculture, The University of Jordan, Amman, Jordan

Aff28 Department of Physical and Health Education, Faculty of Educational Sciences, Al-Ahliyya Amman University, Al-Salt, Jordan

Aff29 Energy Balance & Body Composition Laboratory, Department of Kinesiology & Sport Management, Texas Tech University, Lubbock, TX, 79409, USA

Aff30 Department of Expertise and Advocacy, Action contre la Faim, 93358, Montreuil, France

Aff31 Department of Medicine (DIMED), Geriatrics Division, University of Padova, Padova, 35128, Italy

Aff32 School of Chemistry and Molecular Biosciences, The University of Queensland, Brisbane, QLD, 4072, Australia

Aff33 Research Unit for Dietary Studies, The Parker Institute, Frederiksberg and Bispebjerg Hospital, Copenhagen, Denmark

Aff34 Section for general Practice, Department of Public Health, University of Copenhagen, Copenhagen, Denmark

Aff35 Department of Physical Education, Research Group in Physical Activity and Health, Federal University of Rio Grande do Norte, Natal, Brazil

Aff36 Faculty of Health and Sport Science FCSD, Department of Physiatry and Nursing, University of Zaragoza, 50009, Zaragoza, Spain

Aff37 Laboratory of Anthropology, Anthropometry and Ergonomics, Department of Life Sciences and Systems Biology, University of Torino, 10123, Torino, Italy

Aff38 University of Hawaii Cancer Center, Honolulu, HI, USA

Aff39 United States Sports Academy, ~~Daphnes~~Daphne, AL, 36526, USA

Aff40 Weight Management, Metabolism & Sports Nutrition Clinic, Metabolic Lab, Tel-Aviv, Tel Aviv-Yafo, Israel

Aff41 Department of Human Nutrition, Institute of Human Nutrition and Food Sciences, Christian-Albrechts University, 24105, Kiel, Germany

Aff42 Department of Endocrinology and Nutrition, Virgen de la Victoria Hospital, Malaga University, 29010, Malaga, Spain

Aff43 CIDEFES, Universidade Lusófona, Lisboa, Portugal

Aff44 Laboratório de Nutrição, Faculdade de Medicina, Centro Académico de Medicina de Lisboa, Universidade de Lisboa, Lisboa, Portugal

Aff45 Research Unit for Dietary Studies at the Parker Institute, Bispebjerg and Frederiksberg Hospital, The Capital Region, Frederiksberg, Denmark

Aff46 The Research Unit for General Practice and Section of General Practice, Department of Public Health, University of Copenhagen, Copenhagen, Denmark

Aff47 Shenzhen Key Laboratory of Metabolic Health, Center for Energy Metabolism and Reproduction, Shenzhen Institute of Advanced Technology, Chinese Academy of Sciences, Shenzhen, China

Aff48 School of Biological Sciences, University of Aberdeen, Aberdeen, UK

Aff49 Department of Surgery, University of Auckland, Auckland, New Zealand

Aff50 School of Population Health, University of Auckland, Auckland, New Zealand

Aff51 Center for Innovations in Health Africa (CIHA Uganda), Kampala, Uganda

Aff52 Makerere University Walter Reed Project, Kampala, Uganda

Aff53 Faculty of Education, University of Miyazaki, Miyazaki, Japan

Aff54 Metabolism, Nutrition, and Exercise Laboratory. Physical Education and Sport Center, State University of Londrina, Rod. Celso Garcia Cid, Km 380, ~~Zip code: 86057-970~~86057-970, ~~Londrina, PR~~Londrina-PR, Brazil

Aff55 Pennington Biomedical Research Center, Baton Rouge, LA, 70808, USA

Aff56 Department of Kinesiology and Public Health Education, Hyslop Sports Center, University of North Dakota Grand Forks, Grand Forks, ND, 58202, USA

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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, race and ethnicity, geographic ancestry, lifestyle, and health status. To advance understanding of this variability, we propose to develop a large and diverse 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.

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, 3, 4, 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. **AQ1** **AQ2** **AQ3** **AQ4** **AQ5**

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, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34]. 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 [35, 36]. At the cellular level, BIA-derived body cell mass [19, 37, 38], and at the tissue level, skeletal muscle (SM) mass, can be accurately predicted in healthy populations, as compared to magnetic resonance imaging or computerized tomography [39]. These components have a recognized implication in health and performance, specifically intracellular water [40, 41, 42, 43], but also in disease susceptibility due to increased levels of fatness and loss of SM [44, 45, 46, 47]. The latter is also a key characteristic of sarcopenia, a SM disease rooted in adverse muscle changes that accrue across a lifetime [48]. Indeed, for sarcopenia diagnosis, BIA has been recognized as a useful tool to estimate SM quantity (mass) and quality (amount of strength and/or power per unit of SM mass) [48].

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, ageing, morbidity and mortality in several populations [49, 50, 51, 52, 53, 54, 55, 56, 57, 58]. 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, 56]. There has been growing interest in the use of such raw BIA parameters as proxy markers of health, physical fitness and function, disease status, and mortality avoiding the need for prediction equations [59, 60, 61, 62, 63, 64, 65, 66, 67, 68]. 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 [69, 70], German [71] and Swiss [72] adult populations, as well as athletes [73] and UK children [74], 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) [75], which in turn has been developed in different ways. BIVA [75, 76] 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 HT 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 [75], whereas in specific BIVA it indicates different levels of FM% [76, 77, 78]. Hence, both classic and specific BIVA can be used simultaneously [79]. 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 [76, 77, 78, 80, 81, 82, 83], but factors such as race and ethnicity, geographic ancestry, lifestyle, socio-economic status have not yet been considered in depth.

Body composition shows profound variability in association with age, sex, race and ethnicity, geographic ancestry, lifestyle and health status [84, 85]. In turn, this incorporates variability both in bio-conducting tissues, and also in total and regional body composition [55, 86, 87, 88]. 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, race and ethnicity, geographic 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 health clubs, in order to help them maintain healthy weight and body composition.
- To contribute to academic training and teaching by enabling the use of a large and unique dataset adequately managed.

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 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, race and ethnicity, geographic ancestry, 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.

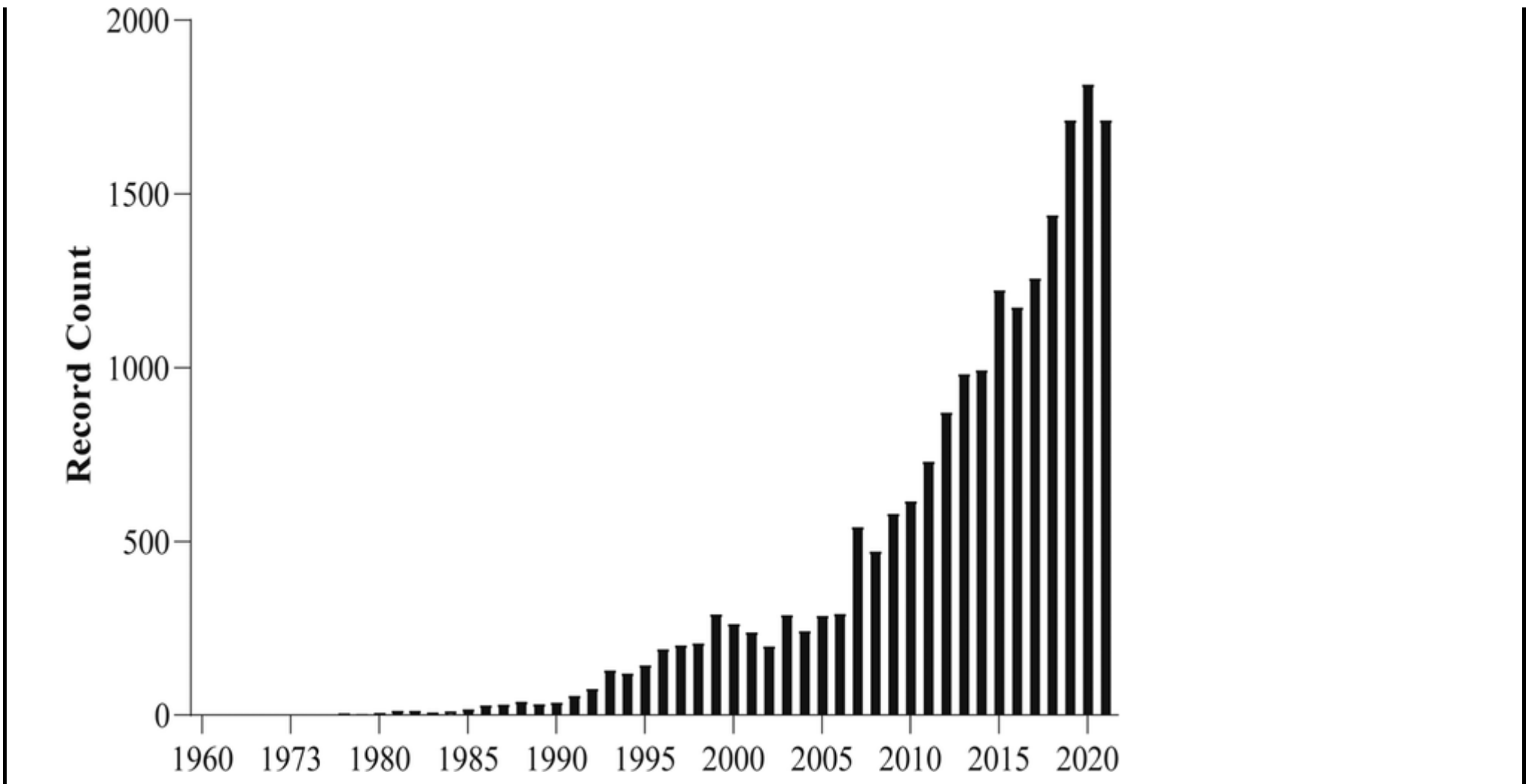
Call for data

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 [89], 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 Fig. 1.

Fig. 1

ISI-indexed publications using bioelectrical **AQ6** impedance analysis.



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://labes.fmh.ulisboa.pt/projetos/a-decorrer/item/101-bia-international-database.

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), and health status.

2. ***Additional data***: segmental raw BIA measures (R, Xc, PhA, Z), for specific BIVA, arm, waist and calf circumferences, race and ethnicity (White, Black, Hispanic, Asian, Other), and geographic ancestry (Africa, America, Central South Asia, East Asia, Europe, Middle East, Oceania).

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://labes.fmh.ulisboa.pt/projetos/a-decorrer/item/101-bia-international-database.

All data are de-identified, 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 **AQ7** 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 General Data Protection Regulation

(GDPR) key requirements. Furthermore, all received data will be converted into password **AQ8** protected files and stored at FMH server, with access limited to the chairman of the management group, AMS, or designated members.

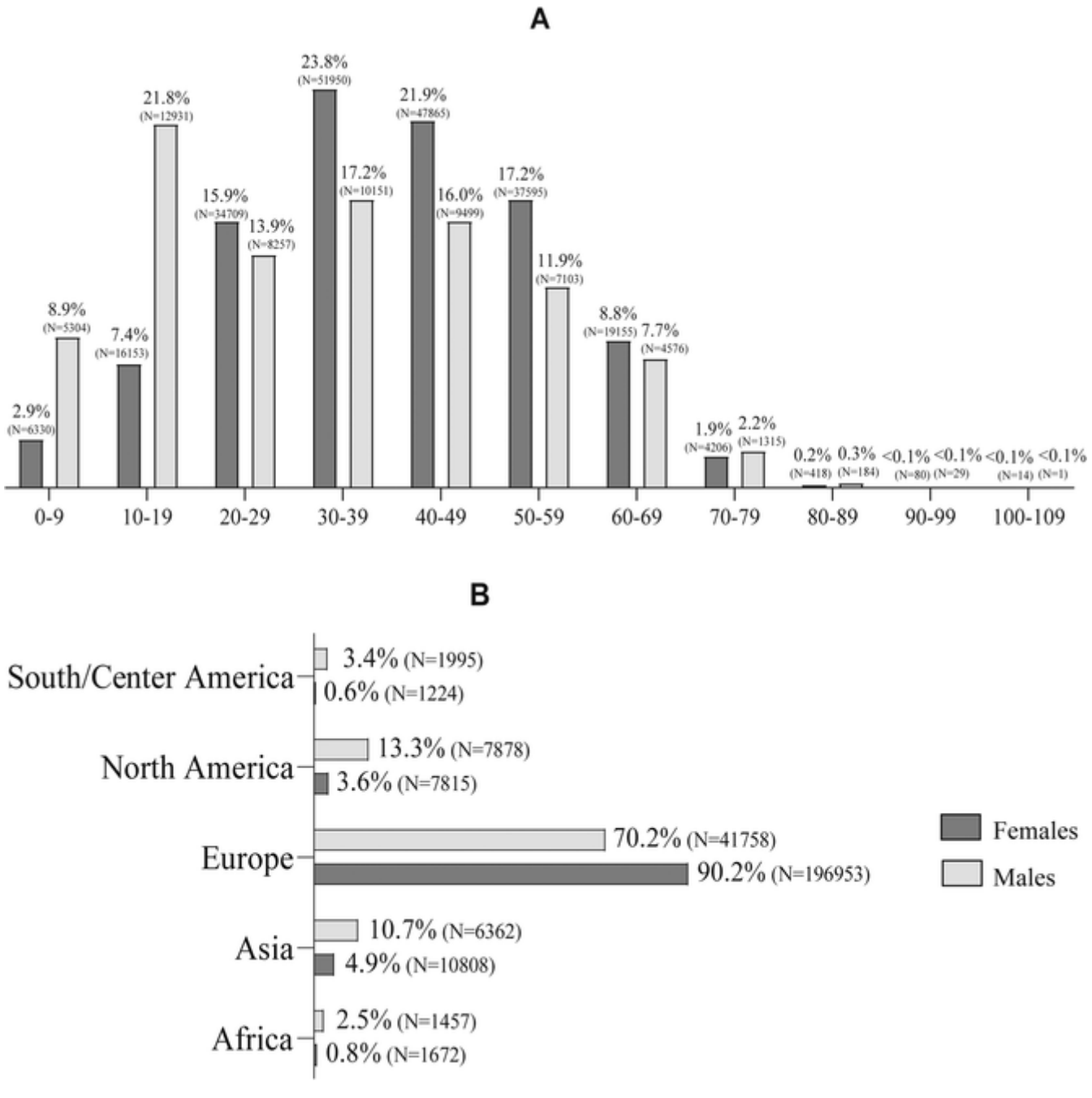
Access to the whole or part of the database will be supervised, as authors aiming to use the database must first obtain the approval by the management group, providing their intended analysis (i.e., scope and aim of the analysis, the intended variables and sample characteristics, as well a list of authors 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 Fig. 2, including the geographical distribution of where the data was collected, the sex and age distribution of the sample.

Fig. 2

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

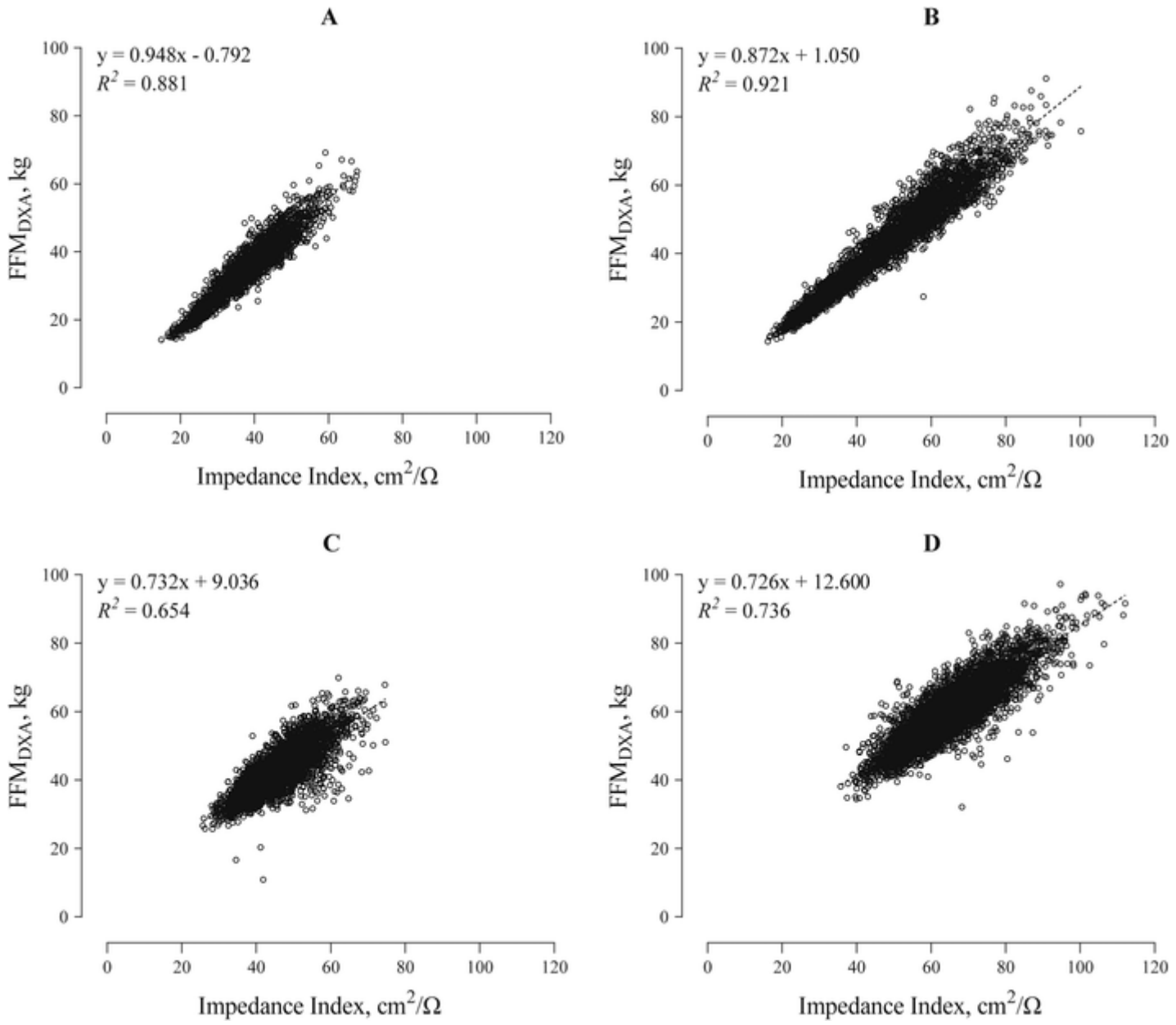


An overall description of the types of data available in the database can be also found on the website under the “data overview tab”. A more comprehensive understanding of the database contents can be obtained by downloading the excel file example including details on the variables included in the main database.

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

Fig. 3

Graphical representation of the relationship between impedance index ($cm^2/\ \Omega$) and FFM (assessed by DXA), stratified by age and sex, in **A** female children and adolescents (<18 years, $N = 2190$), **B** male children and adolescents (<18 years, $N = 3574$), **C** female adults (≥18 years, $N = 4741$), and **D** male adults (≥18 years, $N = 5205$).



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

Step 4. Data access

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

Step 5. Publication policy

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

Individuals submitting data will be acknowledged as authors on publications from the 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 Fig. 3 plots. Evidence has been accumulating underlining the influence of the life cycle, sexual dimorphism, race and ethnicity, geographic ancestry, athletic and disease status [49, 51, 53, 54, 58, 63, 64, 90, 91] 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 [92]. 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 [93]. 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 [94]. More generally, the project provides a new basis for personalized medicine, addressing age, race and ethnicity, geographic ancestry, 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. Nevertheless, we anticipate some limitations in the process of building the dataset, as it is likely that the repository will lack representation from ethnic minorities given the principles for indigenous data sovereignty and governance (https://www.gida-global.org/history-of-indigenous-data-sovereignty), as there are population groups for whom the sharing of biometric data with overseas entities is difficult.

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.

Data availability

The data sets generated and/or analyzed during the current project are not publicly available due to the data confidentiality requirements of the ethics committee for each study but are available from the corresponding author on reasonable request and approval from the ethics committee.

Competing interests The authors declare no competing interests.

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