Hazim Hussein

Age- and gender-specific reference data of objectively assessed body composition measures from the HUNT4 study

Master's thesis in Physical Activity and Health
Supervisor: Marius Steiro Fimland
Co-supervisor: Tom Ivar Lund Nilsen
May 2023

Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Medicine and Health Sciences
Department of Neuromedicine and Movement Science

NTNU
Norwegian University of
Science and Technology

Hazim Hussein

Age- and gender-specific reference data of objectively assessed body composition measures from the HUNT4 study

Master's thesis in Physical Activity and Health
Supervisor: Marius Steiro Fimland
Co-supervisor: Tom Ivar Lund Nilsen
May 2023

Norwegian University of Science and Technology
Faculty of Medicine and Health Sciences
Department of Neuromedicine and Movement Science

NTNU
Norwegian University of
Science and Technology

Table of contents

Acknowledgements

In this section, I would like to express my appreciation for the Norwegian society and the Norwegian University of Science and Technology, Norges Teknisk-Naturvitenskapelige Universitet (NTNU), for providing me with this opportunity and offering me the possibility of free higher education, which allowed me to pursue my interests in further studies in the field of health and subsequently allowed me to commence this study.

I would also like to acknowledge the efforts of the study that was the source of the data for this study, which is the Trøndelag Health Study (HUNT), which is a collaboration between HUNT Research Centre (Faculty of Medicine and Health Sciences, NTNU), Trøndelag County Council, Central Norway Regional Health Authority, and the Norwegian Institute of Public Health.

Special thanks also go to my supervisors Marius Steiro Fimland and Tom Ivar Lund Nilsen for their valuable support and guidance through the work with my master´s thesis and for giving me lifelong useful tips and skills. Finally, big thanks to my family and friends for their appreciated support during my stay in a foreign country.

Abbreviations

HUNT: The Trøndelag Health Study

HUNT4: The fourth wave of the Trøndelag Health Study

HUNT4-N: The part of the HUNT4 which is conducted in Nord-Trøndelag

HUNT4-S: The part of the HUNT4 which is conducted in Sør-Trøndelag

WHO: World Health Organization

CDC: The Centers for Disease Control and Prevention

IOTF: The International Obesity TaskForce

CVD: Cardio-Vascular Disease

BIA: Bioelectrical impedance analysis

DEXA: Dual-Energy X-ray Absorptiometry scan

BMI : Body Mass Index

WC: Waist Circumference

WHtR: Waist to Height Ratio

PBF: Percent Body Fat

SMM: Skeletal Muscle Mass

FM: Fat Mass

FFM: Fat Free Mass

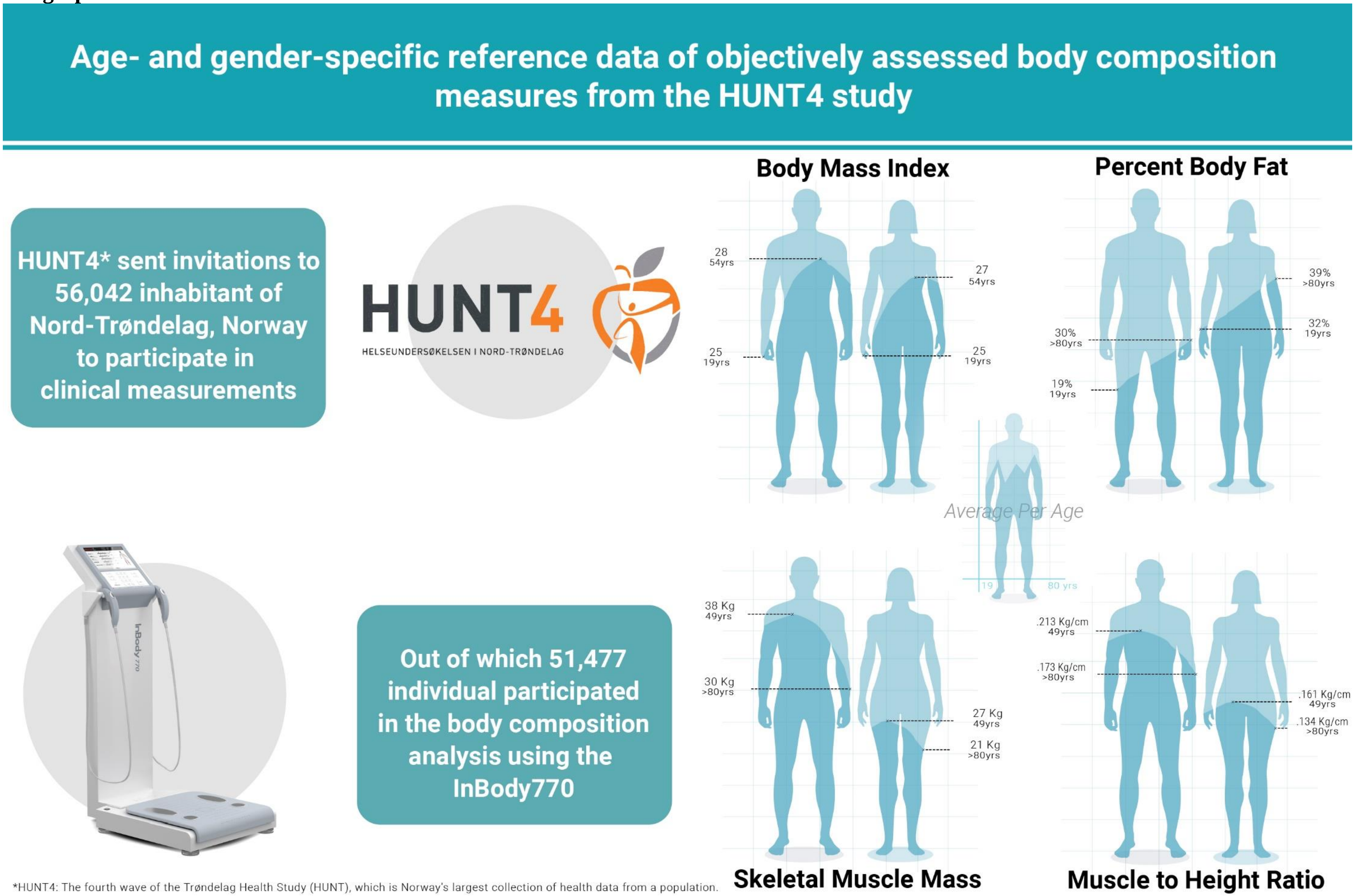
SLM: Soft Lean Mass

VFA: Visceral Fat Area

SMtHR: Skeletal Muscle to Height Ratio

SD: Standard Deviation

Infographic



Abstract

Background The human body composition parameters have been associated with morbidity and all-cause mortality. Therefore, several measures to assess body composition have been investigated and reference values for them were established such as body mass index and waist to height ratio. However, direct reference values for different body composition parameters would provide a better health indicator but currently there are no established reference values for these parameters.

Aims To provide age- and gender- specific body composition reference values for the Norwegian population.

Methods Data collected from the fourth wave of the Trøndelag Health Study (HUNT4), a population-based cohort study, using the InBody 770 Body Composition Analyzer with 51,477 participants, aged 19-102, during the period 2017-2019. The current study is a descriptive study that assessed the variables: Height, Weight, Waist Circumference, Waist to Height Ratio (WHtR), Body Mass Index (BMI), Percent Body Fat (PBF), Body Fat Mass (BFM), Skeletal Muscle Mass (SMM), Skeletal Muscle to Height Ratio (SMtHR), Fat Free Mass (Fat Free Mass), Soft Lean Mass (SLM), and Visceral Fat Area (VFA). In addition, the parameters: BMI, PBF, SMM, and SMtHR were used to create reference curves.

Results The lean mass parameters (SMM, SMtHR, SLM, and FFM) were higher in males, with a trend of stabilization or slight increase with age until the mid-40s range and a subsequent continuous decline afterwards. Fat parameters (PBF, BFM, and VFA) were higher in females, with an almost linear trend of increasing with age. Furthermore, general anthropometric parameters (Weight, BMI, Waist Circumference, and Waist to height Ratio) increased with age until the mid-50s range and then started dropping with age, and they were higher in males.

Conclusion The current study provides age- and gender- specific body composition reference values for the adult Norwegian population and additionally provides reference curves for the parameters: BMI, PBF, SMM, and SMtHR.

Introduction

The human body is composed of different tissues including skeletal muscle and fat tissues which acquire different distributions around the body in different individuals (Woodard & White, 1986). The absolute and relative amount of these tissues has a well-documented association with morbidity and all-cause mortality (Lee & Giovannucci, 2018). Therefore having good assessment parameters of body composition can be used as evaluation tools for health status (Odegaard & Manson, 2021).

Body Mass Index (BMI) seemed like a good feasible measure for body composition as it adjusts the weight for the height of the individual. Hence, international reference values for BMI were created by many organizations such as the World Health Organization (WHO) (A Healthy Lifestyle - WHO Recommendations, n.d.), the Centers for Disease Control and Prevention (CDC) (About Adult BMI | Healthy Weight, Nutrition, and Physical Activity | CDC, n.d.) and the International Obesity TaskForce (IOTF) (Cole & Lobstein, 2012), as well as some regional reference values for specific populations such as the Finnish reference values for individuals under the age of 20 years (Saari et al., 2011) and similarly the Danish reference values for the same age group (Tinggaard et al., 2014). However, the validity of using BMI as a measure of obesity has been called into question, as it adjusts only for height and fails to account for lean mass (Adab et al., 2018).

Therefore, new measures of body composition have been investigated and compared to BMI as health indicator tools such as Waist Circumference (WC) and Waist to Height Ratio (WHtR), which showed superior sensitivity compared to BMI as an early indicator of cardiovascular disease (CVD) risk factors (Ashwell & Hsieh, 2005). So, similar international reference values were created (Waist Circumference and Waist-Hip Ratio, n.d.) as well as regional population specific reference values such as the reference values for the Norwegian children 4 – 18 years old (Brannsether et al., 2011) and for Asian Indians (Misra et al., 2006).

However, further studies have shown that a more direct measure of body composition would provide a more reliable tool to assess health risks than using only WC or BMI (Heinrich et al., 2008). These include multiple techniques such as Bioelectrical impedance analysis (BIA), Dual-energy X-ray absorptiometry (DEXA) scan, Computed tomography, and Magnetic resonance imaging (Kuriyan, 2018). However, most of these are cumbersome and expensive techniques and as creating reference values requires collecting data from a considerable sample size, the infeasibility of assessing body composition represented a huge challenge in creating reference data and hence there is no standardized reference values for body composition yet (Adab et al., 2018). Regardless, some efforts have been done and probably the most notable one was the reference values created for the northwest and central Europian population, which were collected using Lunar Prodigy DEXA on more than 10,000 individual over a 10 year period in Austria (Ofenheimer et al., 2020).

Meanwhile, the need for body composition reference values for the population have increased in both the clinical and the sports fields (Bosy-Westphal et al., 2018; Buckinx et al., 2018). As having these reference values would provide a beneficial tool to improve the cardiometabolic health, facilitate the diagnosis and treatment of obesity and sarcopenia as well as monitoring the body tissues development in sick or healthy individuals.

Fortunately, the fourth wave of the Trøndelag Health (HUNT4) study, Norway, conducted between 2017 – 2019, which is one of the largest population-based health studies, contained the results of BIA for over 50,000 individuals from the Trøndelag county in Norway (Åsvold et al., 2023). As BIA, among body composition measurement techniques, stands out as a useful tool for large studies and public use as it provides a technique, which is feasible and relatively low cost with minimal participant burden (Kuriyan, 2018). BIA's principle is based on the fact that different body compartments exhibit different electrical impedance. So, alternating electrical currents of low- and high-frequency are sent throughout the body and the impedance is measured to identify different tissues (Kuriyan, 2018). In addition, InBody, which is a device that uses BIA to assess body composition, has showed reliable results compared to the more expensive and infeasible DEXA scan (McLester et al., 2020), which is sometimes referred to as the gold standard tool for measuring body composition (Scafoglieri & Clarys, 2018). Therefore, the current study aims to use data collected using the research-grade InBody 770 during a large population-based cohort study in Norway to provide age- and gender- specific body composition reference values for the Norwegian population .

Materials and Methods

Study Design

The current study is an observational study based on the largest population based cross-sectional study in Norway. The HUNT4 study was conducted between 2017 – 2019 with 56,078 participants and is the fourth wave of the Trøndelag Health (HUNT) study (Åsvold et al., 2023). It was called previously the Nord-Trøndelag Health study as it only included residents from the Nord-Trøndelag county but starting from the HUNT4, the study has expanded to additionally include residents of Sør-Trøndelag. Therefore the HUNT4 was divided into Nord- HUNT4 (HUNT4-N) and Sør- HUNT4 (HUNT4-S). During the HUNT study biological samples as well as data using questionnaires, interviews, laboratory measurements, and clinical examinations were collected from participants. Therefore, the HUNT research center has both the HUNT Biobank, a physical storage for biological samples, and the HUNT Database, a digital storage for data collected during the study.

The current study uses data from the HUNT4-N Database collected during body composition clinical examination. The Regional Ethics Committee South-East Norway (REK 2019/28506) provided its approval for the current study and all participants signed a written informed consent for the participation in the HUNT study and the permission for the usage of their data in future research.

Population

Throughout the HUNT4-N study, participation invitations were sent as surveys to all inhabitants of Nord-Trøndelag county aged 20 years or older through the period between 29 August 2017 and 23 Febraury 2019 (Åsvold et al., 2023). Together with the survey an invitation for screening measurements was included. In addition, some individuals dropped in the screening station without invitation. Individuals from Nord-Trøndelag who answered the HUNT4-N survey, participated in the screening measurements, or both and found eligible to participate in the HUNT4-N study were further invited to the clinical examination phase. Individuals who were not able to participate in a barefoot clinical measurement, or had a pacemaker were excluded from the body composition assessment.

Body composition measurement

HUNT4-N assessed body composition by BIA using the InBody 770 Body Composition Analyzer (InBody 770, Cerritos, CA, USA). During the measurement process, participants held hand electrodes and stood barefoot on foot electrodes, from which alternating currents of low- and high-frequency are sent through the body. The measurement process was performed under supervision for all participants.

For this study, the variables of interest derived from the HUNT4 dataset and measured using the InBody770 are Weight, Height, BMI, WC, Percent Body Fat (PBF), Skeletal Muscle Mass (SMM), Fat Mass (FM), Fat Free Mass (FFM), Soft Lean Mass (SLM), and Visceral Fat Area (VFA). The FFM consists of bone mass, muscle mass, vital organs, and extracellular fluid while the SLM is calculated by subtracting the bone minerals from the FFM. In addition, WHtR and Skeletal Muscle to Height Ratio (SMtHR) were calculated using the formulas WC/Height and SMM/Height. Information about age and gender was collected during the interview phase of the HUNT4-N with the participants. Besides, the parameters: Weight, Height, BMI, and WC, were collected first during the screening measurements and later on the values were updated for the participants of the body composition assessment with the values recorded from the InBody 770.

Statistics

Age grouping (19 – 24, 25 – 29, 30 -34, 35 – 39, 40 – 44, 45 – 49, 50 – 54, 55 – 59, 60 – 64, 65 - 69, 70 – 74, 75 – 79, and >80 years) with five years intervals was chosen as we have large enough sample size as well as to be consistent with previous age related reference values studies where they usually use 5- or 10- years interval age grouping. However, while analysing the data, there still seemed to be age related significant differences in most individual groups if a 10 years interval was chosen. Therefore, we chose to use a five years interval grouping. In addition, sex stratification was applied on the dataset. As the dataset is large, normality was assumed and confirmed visually using histograms for each variable. After that, significant differences between age groups and genders for each parameter were tested. For age groups, the testing was performed for each gender at a time using one-way ANOVA with post-hoc Scheffe test. On the other hand for gender groups, the testing was performed for each age group at a time. Bartlett's test for equal variance was performed, and if there was equal variance, standard t-test was used, otherwise t-test with unequal variance assumption was used.

The 10^{th}, 25^{th}, 50^{th}, 75^{th} and 90^{th} centile curves for the parameters: BMI, PBF, SMM, and SMtHR were created by calculating the centiles for each age separately and running a locally weighted smoothing function on these values to get the corresponding smooth curves. Furthermore, gender comparative graphs were created for these parameters using age-specific mean values. Both real values and predicted values calculated using non-linear regression were used. Statistical significance was assumed at $p < 0.01$. All analyses were performed using STATA SE version 17 (Statistical Software for Data Science | Stata, n.d.) utilized by Jupyter Notebooks on top of a Python environment with the use of pystata package.

Results

Subjects' characteristics

103,800 individuals were invited to the HUNT4-N study either by receiving the survey or after dropping in the screening measurements center (Åsvold et al., 2023; *HUNT Databank*, n.d.). Out of those, 56,042 (54%), of which 25,468 males aged 19-101 years old and 30,574 females aged 19-102 years old accepted the invitation. Out of the 56,042 individuals who accepted the HUNT4-N invitation, 53,816 individuals participated in the clinical measurements phase, during which 51,477 individuals were able to participate in the barefoot body composition analysis. However, abnormal values were deleted due to measurement errors, reducing the sample size to 51,241 individual, of which 23,324 males and 27,917 females. Additionally, two extra PBF abnormal values were removed, both are in the male groups, one in the age group 40-44, and the other is in the age group 65-69. Nevertheless, for the parameters weight, height, BMI, and WC, after merging the values recorded from the InBody 770 with the values collected during the screening measurements the total number of collected values became 53,560, 53,550, 54,146, and 52,555, respectively. Therefore, the number of generated values for the calculated parameters, WHtR and SMtHR, equals the number of values of the parameter with the least values of the parameters used in the corresponding calculation, WC and SMM, respectively. Table 1 shows the distribution of the participants for the different parameters.

Table 1 Sample distribution

Parameter	Age group	19-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	≥80	Total
Weight															
	Males	1,365	1,239	1,306	1,430	1,603	2,146	2,380	2,382	2,617	2,709	2,377	1,457	1,279	24,290
	Females	1,776	1,645	1,838	1,921	2,184	2,760	2,866	2,837	2,890	2,779	2,560	1,631	1,583	29,270
Height															
	Males	1,365	1,239	1,305	1,430	1,601	2,147	2,379	2,381	2,615	2,707	2,375	1,454	1,277	24,275
	Females	1,779	1,645	1,839	1,923	2,185	2,759	2,865	2,836	2,889	2,781	2,564	1,631	1,579	29,275
Body Mass Index															
	Males	1,365	1,239	1,305	1,430	1,601	2,146	2,379	2,381	2,615	2,706	2,391	1,487	1,419	24,464
	Females	1,776	1,645	1,838	1,920	2,184	2,759	2,864	2,836	2,888	2,778	2,588	1,674	1,932	29,682
Waist Circumference*															
	Males	1,354	1,227	1,288	1,408	1,590	2,116	2,351	2,350	2,586	2,657	2,315	1,412	1,189	23,843
	Females	1,762	1,628	1,804	1,907	2,157	2,736	2,829	2,797	2,855	2,724	2,493	1,564	1,456	28,712
InBody 770 variables**															
	Males	1,347	1,215	1,276	1,399	1,572***	2,095	2,325	2,327	2,548	2,584***	2,237	1,323	1,076	23,324
	Females	1,754	1,612	1,796	1,895	2,133	2,713	2,796	2,762	2,788	2,663	2,373	1,444	1,188	27,917

Shows the number of collected values for different body composition parameters in different age groups divided by gender collected during the HUNT4-N study.
** The Waist to Height ratio parameter uses the same distribution*
*** These include Percent Body Fat, Body Fat Mass, Visceral Fat Area, Skeletal Muscle Mass, Fat Free Mass, and Soft Lean Mass. In addition, the Skeletal Muscle to Height Ratio parameter uses the same distribution.*
**** The Percent Body Fat parameter has one less value in these age groups (1,571 in 40-44) and (2,583 in 65-69).*

Body Composition Measurements with age

Table 2 shows the descriptive statistics for the body composition measurements of both genders across all age groups. In males, the mean height was 180.6 cm (SD = 6.9) in the age group 19 – 24 years and plateaued to age group 45-49 years when it started showing incremental declines with age to 173.3 cm (SD = 6) in age group 80 and above years. Similarly, in females, the mean height started from 167 cm (SD = 6.2), plateaued to age group 50-54 years and then declined to 158.9 cm (SD = 5.9) at age group 80 or above years.

The mean weight in males started from 82.1 kg (SD = 16.9) and then kept increasing to 92 kg (SD = 14.5) at age group 50-54 years and then started decreasing to 80.1 kg (SD = 11.9) at age group 80 and above years. While in females, the mean weight started from 68.4 kg (SD = 15.8) and kept increasing to 75.3 kg (SD = 15.2) at age group 45-49 years and then started decreasing to 66.9 kg (SD = 12.6) at age group 80 and above years.

The mean BMI showed a similar trend to weight as it started in males from 25.1 kg/m2 (SD = 4.7) and then kept increasing to 28.4 kg/m2 (SD = 4.1) at age group 50-54 years and then started decreasing to 26.6 kg/m2 (SD = 3.8) at age group 80 and above years. While the mean BMI in females started from 25.2 kg/m2 (SD = 5.4) and kept increasing to 27.5 kg/m2 (SD = 5) at age group 50-54 years, plateaued to age group 75-79 years, and then decreased to 26.6 kg/m2 (SD = 3.8) at age group 80 and above years.

The mean WC in males started from 91.3 cm (SD = 15.5) then kept increasing to 102.7 cm (SD = 13.9) at age group 50-54 years and then started decreasing to 97.3 cm (SD = 12.5) at age group 80 and above years. The mean WC in females as well started from 90.5 cm (SD = 14.8) and kept increasing to 97 cm (SD = 13.2) at age group 65-69 years, and then started decreasing to 91.1 cm (SD = 12.3) at age group 80 and above years.

The mean WHtR in males started from 0.51 (SD = 0.08) then kept increasing to 0.58 (SD = 0.07) at age group 70-74 years, and then decreased to 0.56 (SD = 0.07) at age group 80 and above years. In comparison the mean WHtR in females started from 0.54 (SD = 0.09) and kept increasing to 0.59 (SD = 0.08) at age group 70-74 years, and then decreased to 0.57 (SD = 0.08) at age group 80 and above years.

In an almost linear trend the mean PBF in males started from 19.3 % (SD = 8.5) then kept increasing to 30.1 % (SD = 7) at age group 80 and above years. Similarly in females, the mean PBF started from 31.8 % (SD = 9.2) and kept increasing to 38.6 % (SD = 7.4) at age group 80 and above years.

The mean BFM in males started from 16.9 kg (SD = 11.4) and then kept increasing to 25.2 kg (SD = 8.9) at age group 70-74 years and then started decreasing to 24.6 kg (SD = 8.5) at age group 80 and above years. While in females, the mean BFM started from 23.4 kg (SD = 12) and kept increasing to 28.7 kg (SD = 10) at age group 65-69 years and then started decreasing to 26.7 kg (SD = 9.1) at age group 80 and above years.

In males the mean SMM started from 37.1 kg (SD = 5.3) then kept increasing to 38.5 kg (SD = 4.7) at age group 45-49 years and then started decreasing to 30 kg (SD = 3.6) at age group 80 and above years. Similarly, the mean SMM in females, which started from 25.7 kg (SD = 3.5) and kept increasing to 26.9 kg (SD = 3.5) at age group 45-49 years and then started decreasing to 21.4 kg (SD = 2.8) at age group 80 and above years.

The mean SMtHR in males started from 0.205 kg/cm (SD = 0.025) then kept increasing to 0.213 kg/cm (SD = 0.021) at age group 45-49 years and then started decreasing to 0.173 kg/cm (SD = 0.018) at age group 80 and above years. As with females, the mean SMtHR started from 0.154 kg/cm (SD = 0.018) and kept increasing to 0.161 kg/cm (SD = 0.018) at age group 45-49 years and then started decreasing to 0.134 kg/cm (SD = 0.015) at age group 80 and above years.

Starting from 65.2 kg (SD = 8.9), the mean FFM in males then kept increasing to 67.9 kg (SD = 8) at age group 45-49 years and then started decreasing to 55.3 kg (SD = 6.3) at age group 80 and above years. Comparably, the mean FFM in females started from 46.8 kg (SD = 5.9) and kept increasing to 48.9 kg (SD = 6) at age group 45-49 years and then started decreasing to 40.6 kg (SD = 4.8) at age group 80 and above years.

In a similar fashion to most lean mass parameters, the mean SLM in males started from 61.4 kg (SD = 8.3) and then kept increasing to 64.1 kg (SD = 7.5) at age group 45-49 years and then started decreasing to 52.1 kg (SD = 5.9) at age group 80 and above years. Meanwhile the mean SLM in females started from

44 kg (SD = 5.6) and kept increasing to 46 kg (SD = 5.7) at age group 45-49 years and then started decreasing to 38.1 kg (SD = 4.6) at age group 80 and above years.

Finally, the mean VFA in males started from 73.2 cm^2 (SD = 53.1) and then kept increasing to 127 cm^2 (SD = 45.8) at age group 80 and above years. On the other hand, the mean VFA in females started from 109.4 cm^2 (SD = 60.3) and kept increasing to 148.9 cm^2 (SD = 51.9) at age group 75-79 years and then decreased to 145.2 cm^2 (SD = 50.3) at age group 80 and above years.

Table 2 Body composition reference values for the study population

Variables	Height, cm		Weight, kg		BMI, kg/m^2		WC, cm	
Age groups	Males	Females	Males	Females	Males	Females	Males	Females
Total	178.5 ±6.7	165.1 ±6.4	88.1 ±14.9	72.5 ±14.6	27.6 ±4.2	26.9 ±5.1	100.4 ±14.3	94.6 ±13.9
19-24	180.6 ±6.9	167.0 ±6.2	82.1 ±16.9	68.4 ±15.8	25.1 ±4.7	25.2 ±5.4	91.3 ±15.5	90.5 ±14.8
25-29	180.3 ±6.8	166.5 ±6.4	85.9 ±16.7	69.3 ±15.3	26.3 ±4.6	25.5 ±5.2	95.7 ±15.5	90.6 ±14.5
30-34	179.9 ±6.7	166.5 ±6.4	87.5 ±16.6	70.3 ±15.6	27.0 ±4.6	25.9 ±5.3	97.7 ±15.1	91.7 ±14.6
35-39	180.5 ±6.7	166.5 ±6.5	88.4 ±15.5	72.3 ±15.3	27.1 ±4.4	26.4 ±5.3	98.0 ±14.7	92.9 ±14.8
40-44	180.3 ±7.0	166.6 ±6.5	90.6 ±15.2	73.9 ±15.3	27.9 ±4.3	27.0 ±5.3	100.7 ±14.4	94.5 ±14.5
45-49	180.0 ±6.6	166.7 ±6.2	91.9 ±15.1	75.3 ±15.2	28.4 ±4.3	27.4 ±5.3	102.2 ±14.4	95.8 ±14.6
50-54	179.8 ±6.3	166.2 ±6.1	92.0 ±14.5	75.2 ±14.4	28.4 ±4.1	27.5 ±5.0	102.7 ±13.9	96.2 ±13.7
55-59	179.1 ±6.4	165.7 ±5.9	90.7 ±13.7	74.5 ±13.9	28.3 ±3.9	27.4 ±4.9	102.2 ±13.4	96.4 ±13.5
60-64	178.3 ±6.2	164.8 ±5.8	89.4 ±14.1	73.4 ±13.5	28.1 ±4.2	27.3 ±4.8	102.3 ±13.4	96.3 ±13.0
65-69	177.3 ±6.2	164.1 ±5.7	88.0 ±13.6	73.4 ±13.5	28.0 ±4.0	27.5 ±4.8	102.4 ±13.6	97 .0 ±13.2
70-74	176.7 ±6.4	163.0 ±5.7	86.8 ±13.4	71.8 ±13.6	27.8 ±3.9	27.4 ±5.0	102.0 ±13.0	95.5 ±12.9
75-79	175.2 ±6.0	161.6 ±5.5	83.7 ±12.8	70.4 ±12.8	27.3 ±3.9	27.2 ±4.8	100.0 ±12.9	94.1 ±12.6
80 or above	173.3 ±6.0	158.9 ±5.9	80.1 ±11.9	66.9 ±12.6	26.6 ±3.8	26.6 ±4.7	97.3 ±12.5	91.1 ±12.3
	WHtR		**PBF, %**		**BFM, kg**		**SMM, kg**	
Total	.56 ±.08	.57 ±.08	25.7 ±7.7	35.5 ±8.4	23.4 ±10.1	26.9 ±10.9	36.4 ±5.0	25.4 ±3.6
19-24	.51 ±.08	.54 ±.09	19.3 ±8.5	31.8 ±9.2	16.9 ±11.4	23.4 ±12.0	37.1 ±5.3	25.7 ±3.5
25-29	.53 ±.08	.54 ±.09	21.6 ±8.1	32.2 ±8.9	19.5 ±11.0	23.7 ±11.3	37.7 ±5.3	25.8 ±3.6
30-34	.54 ±.08	.55 ±.09	23.0 ±7.8	32.4 ±8.9	21.0 ±10.9	24.3 ±11.6	37.8 ±5.2	26.2 ±3.7
35-39	.54 ±.08	.56 ±.09	23.0 ±7.7	33.1 ±8.8	21.2 ±10.5	25.3 ±11.5	38.2 ±4.9	26.4 ±3.6
40-44	.56 ±.08	.57 ±.09	24.6 ±7.4	33.9 ±8.3	23.0 ±10.2	26.4 ±11.4	38.3 ±4.9	26.8 ±3.7
45-49	.57 ±.08	.57 ±.09	25.4 ±7.3	34.6 ±8.5	24.1 ±10.4	27.3 ±11.5	38.5 ±4.7	26.9 ±3.5
50-54	.57 ±.08	.58 ±.08	25.8 ±6.9	35.7 ±8.1	24.4 ±9.7	28.0 ±10.8	38.2 ±4.5	26.3 ±3.4
55-59	.57 ±.07	.58 ±.08	26.1 ±6.8	36.4 ±7.6	24.3 ±9.2	28.2 ±10.4	37.4 ±4.3	25.7 ±3.2
60-64	.57 ±.07	.58 ±.08	26.8 ±6.9	36.9 ±7.5	24.6 ±9.5	28.1 ±10.0	36.3 ±4.3	25.1 ±3.1
65-69	.58 ±.08	.59 ±.08	27.6 ±6.9	37.8 ±7.3	24.9 ±9.4	28.7 ±10.0	35.1 ±4.0	24.6 ±3.1
70-74	.58 ±.07	.59 ±.08	28.4 ±6.7	38.0 ±7.4	25.2 ±8.9	28.4 ±10.1	34.0 ±4.1	23.9 ±3.0
75-79	.57 ±.07	.58 ±.08	28.9 ±6.9	38.5 ±7.3	24.7 ±8.8	28.0 ±9.4	32.3 ±3.9	23.0 ±2.9
80 or above	.56 ±.07	.57 ±.08	30.1 ±7.0	38.6 ±7.4	24.6 ±8.5	26.7 ±9.1	30.0 ±3.6	21.4 ±2.8
	SMtHR, kg/cm		**FFM, kg**		**SLM, kg**		**VFA, cm2**	
Total	.203 ±.023	.153 ±.018	64.7 ±8.4	46.5 ±6.0	61.1 ±7.9	43.8 ±5.7	110.4 ±50.1	133.4 ±57.5

19-24	.205 ±.025	.154 ±.018	65.2 ±8.9	46.8 ±5.9	61.4 ±8.3	44.0 ±5.6	73.2 ±53.1	109.4 ±60.3
25-29	.209 ±.025	.154 ±.019	66.3 ±9.0	46.9 ±6.1	62.5 ±8.4	44.1 ±5.8	86.7 ±51.9	111.3 ±57.9
30-34	.209 ±.024	.157 ±.019	66.5 ±8.7	47.6 ±6.2	62.7 ±8.2	44.8 ±5.8	94.1 ±51.2	114.4 ±58.3
35-39	.211 ±.023	.158 ±.018	67.3 ±8.3	48.0 ±6.1	63.4 ±7.8	45.1 ±5.7	95.5 ±49.5	119.6 ±59.3
40-44	.212 ±.022	.160 ±.019	67.6 ±8.3	48.6 ±6.2	63.7 ±7.7	45.8 ±5.9	104.9 ±48.8	125.5 ±57.5
45-49	.213 ±.021	.161 ±.018	67.9 ±8.0	48.9 ±6.0	64.1 ±7.5	46.0 ±5.7	110.8 ±49.6	131.2 ±58.6
50-54	.212 ±.021	.158 ±.017	67.5 ±7.7	48.0 ±5.7	63.7 ±7.3	45.2 ±5.4	113.4 ±47.0	136.7 ±56.1
55-59	.209 ±.020	.155 ±.016	66.5 ±7.4	47.0 ±5.4	62.7 ±6.9	44.2 ±5.1	114.1 ±45.4	139.9 ±54.9
60-64	.203 ±.020	.152 ±.016	64.7 ±7.3	46.0 ±5.3	61.1 ±6.9	43.3 ±5.0	117.1 ±46.4	141.9 ±53.6
65-69	.198 ±.019	.150 ±.016	63.0 ±6.9	45.3 ±5.3	59.4 ±6.5	42.6 ±5.0	120.9 ±47.9	148.1 ±54.1
70-74	.192 ±.019	.146 ±.016	61.4 ±7.1	44.3 ±5.2	57.9 ±6.7	41.7 ±4.9	124.4 ±45.9	148.1 ±53.3
75-79	.184 ±.019	.142 ±.015	58.8 ±6.8	42.9 ±4.9	55.4 ±6.4	40.3 ±4.6	124.4 ±46.3	148.9 ±51.9
80 or above	.173 ±.018	.134 ±.015	55.3 ±6.3	40.6 ±4.8	52.1 ±5.9	38.1 ±4.6	127.0 ±45.8	145.2 ±50.3

Shows the descriptive statistics comprised of the mean ± the standard deviation adjusted by gender and age for some of the body composition variables collected using the InBody770 during the HUNT4-N study. The included variables are height, weight, Body Mass Index (BMI), Waist Circumference (WC), Percent Body Fat (PBF), Body Fat Mass (BFM), Skeletal Muscle Mass (SMM), Fat Free Mass (FFM), Soft Lean Mass (SLM), and Visceral Fat Area (VFA). In addition to Waist to Height Ratio (WHtR) calculated using WC/Height, and Skeletal Muscle to Height Ratio (SMtHR) calculated using SMM/Height.

Gender differences

All parameters showed significant difference between genders in all age groups except BMI in the youngest (19-24) and the two oldest (75-79, 80 and above) age groups and Wc in the youngest (19-24) age group, where no significant differences were found. Males had greater values in height, weight, BMI, Wc, SMM, FFM, and SLM parameters. While females had greater values in WHtR, PBF, BFM, and VFA parameters. Figure 1 shows the gender comperative graphs for BMI, PBF, SMM, and SMtHR.

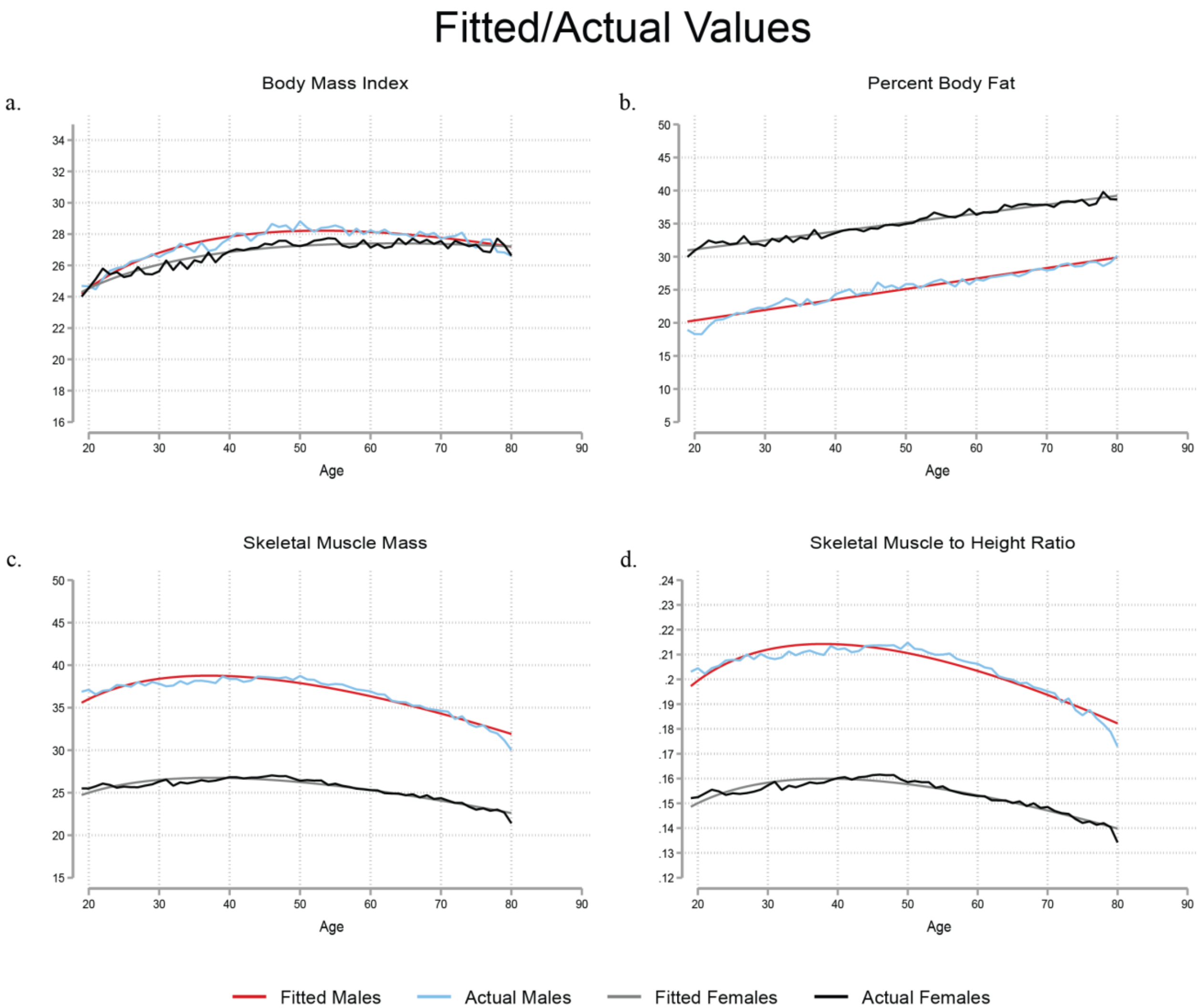


Figure 1 shows gender comparative graphs using both the actual mean values and the predicted mean values calculated using non-linear regression for each age after aggregating age to a one-year interval value 19-≥80. The graphs are: a. Body Mass Index (BMI), b. Percent Body Fat (PBF), c. Skeletal Muscle Mass (SMM), and d. Skeletal Muscle to Height Ratio (SMtHR).

Visualized Data

Figure 2 shows the centile curves for BMI, PBF, SMM, and SMtHR for both males and females.

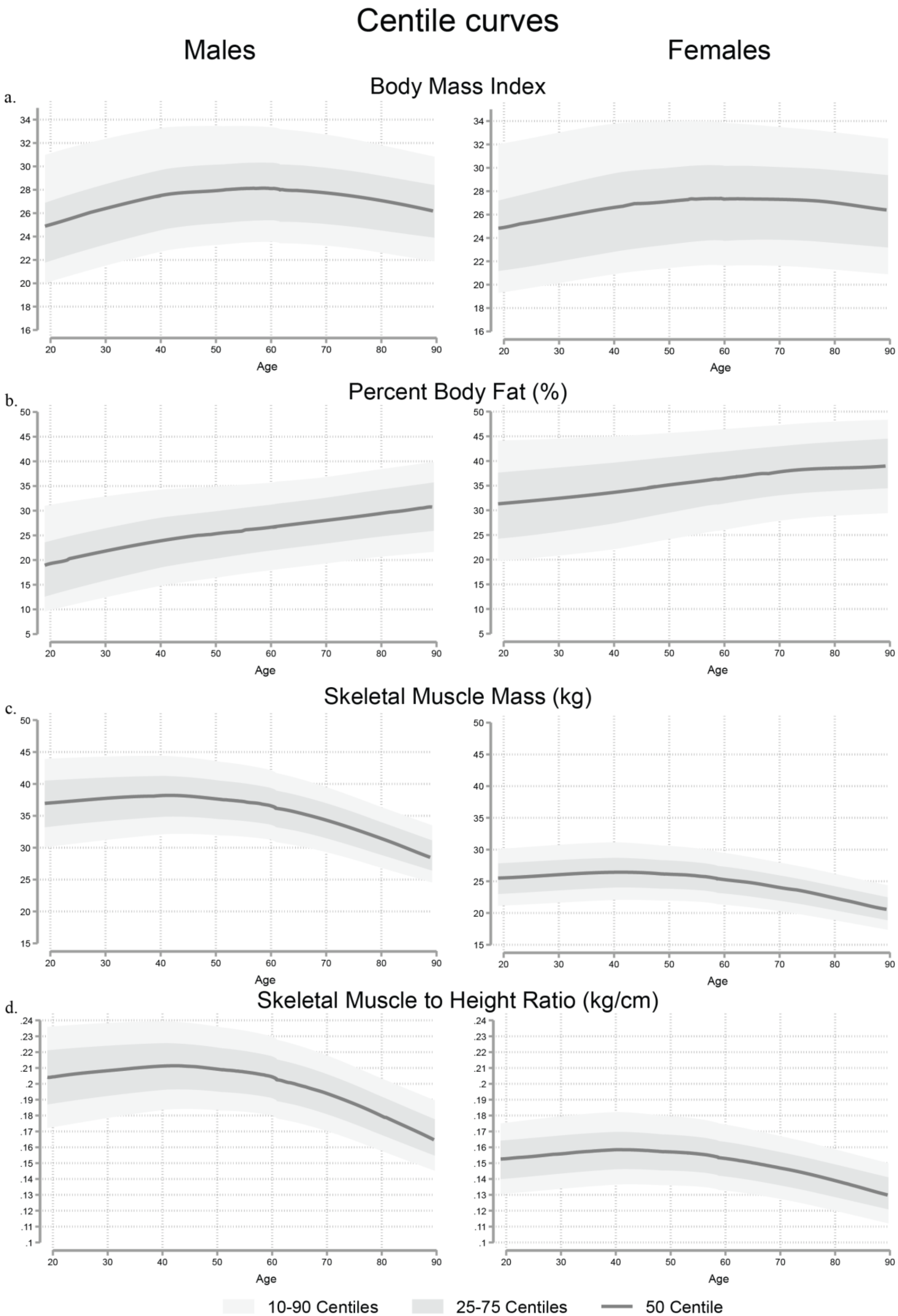

Centile curves
Males
Females
a.
Body Mass Index
Age
b.
Percent Body Fat (%)
Age
c.
Skeletal Muscle Mass (kg)
Age
d.
Skeletal Muscle to Height Ratio (kg/cm)
Age
10-90 Centiles
25-75 Centiles
50 Centile

Figure 2 shows, by using weighted average smoothing, the area between the smoothed 10th and 90th centiles and between the smoothed 25th and 75th centiles, while highlighting the mean for each age in each gender separately for the parameters a. Body Mass Index (BMI), b. Percent Body Fat (PBF), c. Skeletal Muscle Mass (SMM), and d. Skeletal Muscle to Height Ratio (SMtHR).

Discussion

To our Knowledge, the HUNT4 study, which is the largest population-based cross-sectional study in Norway, currently provides the largest and most recent database for body composition values in the world, measured through BIA using InBody 770 based on a 51,477 large Norwegian population cohort aged 19-102 years old. The present study used these data to provide age- and gender- specific body composition reference values for the Norwegian population.

At the moment, there are no established international body composition reference values. Regardless, multiple population specific body composition reference values were investigated, of which the closest to the Norwegian population are the body composition reference values for the northwest and central Europian population that were collected using Lunar Prodigy DEXA (Ofenheimer et al., 2020). However, these values were based on a smaller sample than the current study and it is unclear how representative these are to the Norwegian population. Our findings provide better representative reference values for the Norwegian population as our data shows difference to Ofenheimer et al. (2020) results, with a bit higher lean mass values and lower fat mass values. In addition, body composition reference values need to be specific to the measuring technique as value differences were found between different measuring techniques (Kuriyan, 2018). Although, DEXA has shown to be an accurate and valid, arguably even more than BIA as a body composition measuring technique, the current study used BIA, which can be justified by multiple reasons. Firstly, BIA has shown to provide DEXA comperable accuracy and validity (McLester et al., 2020). Additionally, BIA devices use has been widely increased as they provide an inexpensive, portable, fast and safe tool to assess body composition (Buckinx et al., 2018). Therefore, BIA presents a suitable tool for screening purposes and for clinical use.

Our findings show that lean mass parameters (SMM, FFM, SLM and SMtHR) increase slightlty or plateue in younger ages and then they start declining incrementally in old ages, which is shown in the centile graphs for SMM and SMtHR (Figure 2), where the graphs shows a relatively inverted J-shaped curves. In contrast, fat parameters (PBF, BFM, and VFA) keep increasing almost linearly with age as shown in figure 2. This shows that the body composition of the total mass shifts with age to having less lean mass and more fat mass even though the total Weight decreases in old age. Therefore, the BMI values, which only takes into consideration the Weight and Height parameters and not body composition, becomes biased as it increases with weight increase in the young ages and decreases with weight decline in the old ages, which is represented by an inverted U-shaped curve of mean BMI values over age (Figure 2). This shows that two different age groups, young and old, can have the same BMI value but with different body composition, with more lean mass and less fat mass in the younger group. This finding questions the reliabilty of BMI as a tool for evaluating health status as it was shown that body fat especially visceral fat has a stronger correlation with metabloic risk factors than total mass (Fox et al., 2007; Liu et al., 2013). Hence, strengthening the notion of using body composition values as health assessment tools.

As expected, our findings suggest that there are significant differences between genders in almost all age groups in all parameters, which is in line with Bosy-Westphal & Müller (2015) where they pointed out that reference values should be sex and age specific. Furthermore, in agreement with Ofenheimer et al. (2020), these differences are represented by higher fat parameters (PBF, BFM, and VFA) in females than males. The explanation for that can be attributed to the effect of genes and sex hormones on total adipose tissues and fat distribution (Karastergiou et al., 2012). In contrast, males had higher lean mass parameters (Height, SMM, FFM, SLM, and SMtHR) than females, which is in line with the findings of Janssen et al. (2000). This can also be attributed to genes and sex hormones, which becomes more prominent during puberty (Kanehisa et al., 1994).

Additionally and consistent with previous studies (Janssen et al., 2000; Ofenheimer et al., 2020), we generally found an increase or persistance in lean mass parameters (Height, SMM, FFM, SLM, and SMtHR) to an age in the mid 40s range as well as total Weight values, which supports the notion that people with higher weights tend to have more lean mass values as total weight is comprised of both fat and muscle tissues (Bosy-Westphal & Müller, 2015). This can be confirmed by the observed concurrent increase in Weight and BMI, which is probably due to a higher caloric surplus, and subsequently an increase in lean mass.

The decline in lean mass after the mid 40s can be attributed to skeletal muscle loss as well as decline in other lean mass tissues as our data shows declines in both SMM and Height with age. Nevertheless, when adjusting skeletal muscle to height, the SMtHR still showed significant declines with age which suggests that the main contributor to the decline in lean mass is the skeletal muscle loss. The potential causes of age-related muscle loss include a range of cellular, biochemical, and metabolic changes, neuromascular alterations, hormonal stimuli as well as nutrition related causes (Volpi et al., 2004).

Conversely, fat parameters (PBF, BFM, and VFA) generally showed, in an almost linear trend, an increase with age with no decline in older ages, which agrees with Ofenheimer et al. (2020) results, with the exception of BFM which showed a plateau or a slight decrease in the last three age groups but this can be explained by the decline in total Weight values.

As fat increments specially visceral fat propses increases in various health risks such as cardiovascular diseases (Bosy-Westphal et al., 2018), these findings as well as Jura & Kozak (2016) raises awareness to a vicious cycle, in which age contributes to increased health risks and fat parameters which in turn contribute to aging and increased health risks. Jura & Kozak, (2016) explains the potential causes of age-related fat increase, which include hormonal causes mediated by growth hormone, leptin, and adiponectin activity, reduction in the metabolically active lean tissues, as well as genetic and inflammatory causes hence the observed increase of fat parameters with age in our findings.

The large sample size, with more than 50,000 participant, represents the major strength of the current study, by enabling narrower age grouping than previous studies and giving a more accurate representation of the Norwegian population. Although the sample of the HUNT4 study was collected from a restricted area in Norway, the Trøndelag county, and as this study only uses the body composition values which were collected only during the HUNT4-N, making the population of the study the inhabitants of the Nord-Trøndelag region, it was still proved that the Nord-Trøndelag region is fairly representative of Norway but with the exception of immigrants and large cities (Åsvold et al., 2023). Secondly, the HUNT4-N database provides recently collected body composition values measured in a relatively short period between 2017-2019 limiting the changes of population reference values across time. Finally, the values were measured through BIA using InBody770 which showed high validity and accuracy in measuring different body composition values as well as representing a safe and feasible tool for public use (Buckinx et al., 2018; McLester et al., 2020). Nonetheless, this study had some limitations. It is still unclear how representative these results to the Europian population, and it is probably not applicable to other ethnicities, which is an important aspect in addition to age and gender when considering reference values (Bosy-Westphal & Müller, 2015). Moreover, although BIA is relatively valid tool to assess body composition, it may have limitations compared to the more infeasible or accurate methods such as DEXA or magnetic resonance imaging.

Our data can provide a useful tool in clinical settings to help identify people with sub-optimal body composition which could be at risk of developing various disorders. For example, the lean mass parameter data can be used to diagnose or predict early onset or rapid sarcopenia in the Norwegian population. Additionally, the fat parameters can be used to diagnose and treat obesity as well as an assessment for cardiometabloic health. Our data specially the centile curves can also be used to raise public awareness and provide a self assessment screening tool. In addition, it provides insights for future measures directed towards improving the population health, which can be assessed in future waves of the HUNT-study or by linking to health registers.

In conclusion, our study provides age- and gender- specific body composition reference values for the adult Norwegian population aged 19->80 based on measurements collected from the largest population-based cohort study in Norway, the HUNT4 study. Represeneted mainly as an increase in lean mass parameters, which are higher in males, to the mid 40s range then they start declining afterwards. Additionally, the fat parameters, which are higher in females, increase almost linearly with age. Our findings can provide basis for future research aimed at preventing and managing obesity and sarcopenia in middle-aged and older adults or highlighting the importance of sex-specific health strategies in promoting optimal health outcomes. Further research is needed to better understand the mechanisms underlying these age- and gender-related changes and to develop effective interventions to improve them.

References

A healthy lifestyle—WHO recommendations. (n.d.). Retrieved January 30, 2023, from https://www.who.int/europe/news-room/fact-sheets/item/a-healthy-lifestyle---who-recommendations

About Adult BMI | Healthy Weight, Nutrition, and Physical Activity | CDC. (n.d.). Retrieved January 30, 2023, from https://www.cdc.gov/healthyweight/assessing/bmi/adult_bmi/index.html#InterpretedAdults

Adab, P., Pallan, M., & Whincup, P. H. (2018). Is BMI the best measure of obesity? *BMJ*, *360*, k1274. https://doi.org/10.1136/bmj.k1274

Ashwell, M., & Hsieh, S. D. (2005). Six reasons why the waist-to-height ratio is a rapid and effective global indicator for health risks of obesity and how its use could simplify the international public health message on obesity. *International Journal of Food Sciences and Nutrition*, *56*(5), 303–307. https://doi.org/10.1080/09637480500195066

Åsvold, B. O., Langhammer, A., Rehn, T. A., Kjelvik, G., Grøntvedt, T. V., Sørgjerd, E. P., Fenstad, J. S., Heggland, J., Holmen, O., Stuifbergen, M. C., Vikjord, S. A. A., Brumpton, B. M., Skjellegrind, H. K., Thingstad, P., Sund, E. R., Selbæk, G., Mork, P. J., Rangul, V., Hveem, K., … Krokstad, S. (2023). Cohort Profile Update: The HUNT Study, Norway. *International Journal of Epidemiology*, *52*(1), e80–e91. https://doi.org/10.1093/ije/dyac095

Bosy-Westphal, A., Braun, W., Geisler, C., Norman, K., & Müller, M. J. (2018). Body composition and cardiometabolic health: The need for novel concepts. *European Journal of Clinical Nutrition*, *72*(5), Article 5. https://doi.org/10.1038/s41430-018-0158-2

Bosy-Westphal, A., & Müller, M. J. (2015). Identification of skeletal muscle mass depletion across age and BMI groups in health and disease—There is need for a unified definition. *International Journal of Obesity (2005)*, *39*(3), 379–386. https://doi.org/10.1038/ijo.2014.161

Brannsether, B., Roelants, M., Bjerknes, R., & Júlíusson, P. (2011). Waist circumference and waist-to-height ratio in Norwegian children 4–18 years of age: Reference values and cut-off levels. *Acta Paediatrica*, *100*(12), 1576–1582. https://doi.org/10.1111/j.1651-2227.2011.02370.x

Buckinx, F., Landi, F., Cesari, M., Fielding, R. A., Visser, M., Engelke, K., Maggi, S., Dennison, E., Al-Daghri, N. M., Allepaerts, S., Bauer, J., Bautmans, I., Brandi, M. L., Bruyère, O., Cederholm, T., Cerreta, F., Cherubini, A., Cooper, C., Cruz-Jentoft, A., … Kanis, J. A. (2018). Pitfalls in the measurement of muscle mass: A need for a reference standard. *Journal of Cachexia, Sarcopenia and Muscle*, *9*(2), 269–278. https://doi.org/10.1002/jcsm.12268

Cole, T. J., & Lobstein, T. (2012). Extended international (IOTF) body mass index cut-offs for thinness, overweight and obesity. *Pediatric Obesity*, *7*(4), 284–294. https://doi.org/10.1111/j.2047-6310.2012.00064.x

Fox, C. S., Massaro, J. M., Hoffmann, U., Pou, K. M., Maurovich-Horvat, P., Liu, C.-Y., Vasan, R. S., Murabito, J. M., Meigs, J. B., Cupples, L. A., D'Agostino, R. B., & O'Donnell, C. J. (2007). Abdominal Visceral and Subcutaneous Adipose Tissue Compartments. *Circulation*, *116*(1), 39–48. https://doi.org/10.1161/CIRCULATIONAHA.106.675355

Heinrich, K. M., Jitnarin, N., Suminski, R. R., Berkel, L., Hunter, C. M., Alvarez, L., Brundige, A. R., Peterson, A. L., Foreyt, J. P., Haddock, C. K., & Poston, W. S. C. (2008). Obesity classification in military personnel: A comparison of body fat, waist circumference, and body mass index measurements. *Military Medicine*, *173*(1), 67–73. https://doi.org/10.7205/milmed.173.1.67

HUNT Databank. (n.d.). Retrieved January 30, 2023, from https://hunt-db.medisin.ntnu.no/hunt-db/instrument/InBody770

Janssen, I., Heymsfield, S. B., Wang, Z. M., & Ross, R. (2000). Skeletal muscle mass and distribution in 468 men and women aged 18-88 yr. *Journal of Applied Physiology (Bethesda, Md.: 1985)*, *89*(1), 81–88. https://doi.org/10.1152/jappl.2000.89.1.81

Jura, M., & Kozak, Leslie. P. (2016). Obesity and related consequences to ageing. *Age*, *38*(1), 23. https://doi.org/10.1007/s11357-016-9884-3

Kanehisa, H., Ikegawa, S., Tsunoda, N., & Fukunaga, T. (1994). Cross-sectional areas of fat and muscle in limbs during growth and middle age. *International Journal of Sports Medicine*, *15*(7), 420–425. https://doi.org/10.1055/s-2007-1021081

Karastergiou, K., Smith, S. R., Greenberg, A. S., & Fried, S. K. (2012). Sex differences in human adipose tissues – the biology of pear shape. *Biology of Sex Differences*, *3*, 13. https://doi.org/10.1186/2042-6410-3-13

Kuriyan, R. (2018). Body composition techniques. *The Indian Journal of Medical Research*, *148*(5), 648–658. https://doi.org/10.4103/ijmr.IJMR_1777_18

Lee, D. H., & Giovannucci, E. L. (2018). Body composition and mortality in the general population: A review of epidemiologic studies. *Experimental Biology and Medicine*, *243*(17–18), 1275–1285. https://doi.org/10.1177/1535370218818161

Liu, P., Ma, F., Lou, H., & Liu, Y. (2013). The utility of fat mass index vs. Body mass index and percentage of body fat in the screening of metabolic syndrome. *BMC Public Health*, *13*, 629. https://doi.org/10.1186/1471-2458-13-629

McLester, C. N., Nickerson, B. S., Kliszczewicz, B. M., & McLester, J. R. (2020). Reliability and Agreement of Various InBody Body Composition Analyzers as Compared to Dual-Energy X-Ray Absorptiometry in Healthy Men and Women. *Journal of Clinical Densitometry: The Official Journal of the International Society for Clinical Densitometry*, *23*(3), 443–450. https://doi.org/10.1016/j.jocd.2018.10.008

Misra, A., Vikram, N. K., Gupta, R., Pandey, R. M., Wasir, J. S., & Gupta, V. P. (2006). Waist circumference cutoff points and action levels for Asian Indians for identification of abdominal obesity. *International Journal of Obesity*, *30*(1), Article 1. https://doi.org/10.1038/sj.ijo.0803111

Odegaard, A. O., & Manson, J. E. (2021). Weight and mortality: Why body composition matters. *The American Journal of Clinical Nutrition*, *113*(3), 493–494. https://doi.org/10.1093/ajcn/nqaa409

Ofenheimer, A., Breyer-Kohansal, R., Hartl, S., Burghuber, O. C., Krach, F., Schrott, A., Wouters, E. F. M., Franssen, F. M. E., & Breyer, M.-K. (2020). Reference values of body composition parameters and visceral adipose tissue (VAT) by DXA in adults aged 18–81 years—Results from the LEAD cohort. *European Journal of Clinical Nutrition*, *74*(8), Article 8. https://doi.org/10.1038/s41430-020-0596-5

Saari, A., Sankilampi, U., Hannila, M.-L., Kiviniemi, V., Kesseli, K., & Dunkel, L. (2011). New Finnish growth references for children and adolescents aged 0 to 20 years: Length/height-for-age, weight-for-length/height, and body mass index-for-age. *Annals of Medicine*, *43*(3), 235–248. https://doi.org/10.3109/07853890.2010.515603

Scafoglieri, A., & Clarys, J. P. (2018). Dual energy X-ray absorptiometry: Gold standard for muscle mass? *Journal of Cachexia, Sarcopenia and Muscle*, *9*(4), 786–787. https://doi.org/10.1002/jcsm.12308

Statistical software for data science | Stata. (n.d.). Retrieved January 31, 2023, from https://www.stata.com/

Tinggaard, J., Aksglaede, L., Sørensen, K., Mouritsen, A., Wohlfahrt-Veje, C., Hagen, C. P., Mieritz, M. G., Jørgensen, N., Wolthers, O. D., Heuck, C., Petersen, J. H., Main, K. M., & Juul, A. (2014). The 2014 Danish references from birth to 20 years for height, weight and body mass index. *Acta Paediatrica*, *103*(2), 214–224. https://doi.org/10.1111/apa.12468

Volpi, E., Nazemi, R., & Fujita, S. (2004). Muscle tissue changes with aging. *Current Opinion in Clinical Nutrition and Metabolic Care*, *7*(4), 405–410.

Waist circumference and waist-hip ratio: Report of a WHO expert consultation. (n.d.). Retrieved January 30, 2023, from https://www.who.int/publications-detail-redirect/9789241501491

Woodard, H. Q., & White, D. R. (1986). The composition of body tissues. *The British Journal of Radiology*, *59*(708), 1209–1218. https://doi.org/10.1259/0007-1285-59-708-1209

Norwegian University of
Science and Technology