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Original Study

Age-Related Variations of Muscle Mass, Strength, and Physical Performance in Community-Dwellers: Results From the Milan EXPO Survey

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A B S T R A C T

Objectives: Declining muscle mass and function are hallmarks of the aging process. The preservation of muscle trophism may protect against various negative health outcomes. Age- and sex-specific curves of muscle mass, strength, and function, using data from a large sample of community-dwelling people, are necessary.

Material and methods: Two surveys (Longevity Check-up and Very Important Protein [VIP]), conducted during EXPO 2015 in Milan, consisted of a population assessment aimed at evaluating the prevalence of specific health metrics in subjects outside of a research setting (n = 3206), with a special focus on muscle mass, strength, and function. Muscle mass was estimated by using mid-arm muscle circumference (MAMC) and calf circumference of the dominant side. Muscle strength and function were assessed through handgrip strength testing and repeated chair stand test, respectively.

Results: The mean age of 3206 participants in the Longevity Check-up and VIP surveys was 51.9 years (SD 15.6, range 18–98 years), and 1694 (52.8%) were women. Cross-sectional inspection suggests that both calf circumference and MAMC decline nonlinearly with age and the rate of decline varies by gender. These measures are stable until 50 years and then begin to decrease slightly with age, with the effect being more evident in men than in women. The main effect of the age category was observed in muscle strength and physical performance parameters. Muscle strength declined significantly after 45 years of age, both in men and women ($P < .001$). The muscle quality of the upper extremities, defined as handgrip strength divided by MAMC, declined significantly with aging, as well ($P < .001$). The time to complete the chair stand test was similar from 18 years to 40 to 44 years, and then a linear decline in performing the test across age groups was observed, with an increased time of more than 3 seconds, both in men and women ($P < .001$).

Conclusions: Muscle mass and strength curves may be used to extract reference values for subsequent use in research as well as in the clinical setting. In particular, the analyses of trajectories of muscle parameters may help identify cutoffs for the estimation of risk of adverse events.

The demographic transition experienced by developed countries in recent decades poses unprecedented challenges to managing the care of older persons. Although the prolongation of life remains an important public health goal, the preservation of the capacities to live independently is of even greater significance. Disabling conditions are particularly burdensome for individuals as well as to the sustainability of health care systems.[1] In this respect, it is important to highlight that there is growing demand for the identification of effective solutions against the detrimental consequences that specific age-related conditions (in particular, disabilities) exert on our health care systems.[2] Advancing age

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is linked with important changes in body composition, the most important of which, sarcopenia, is a major cause of physical function decline, disability, and mortality.[3] Special attention has been given to sarcopenia because it is (1) highly prevalent in the older population, (2) associated with negative health-related events, (3) potentially reversible, and (4) relatively easy to prevent and to treat in clinical practice.[4]

There are some studies that have assessed the changes in muscle mass and muscle function during the aging process (the Baltimore Longitudinal Study of Aging, the InCHIANTI study, the Health ABC Study),[5–7] but only a limited number examined populations with a broad age range.[8,9] Overall, the results documented a substantial age-related decline in both muscle mass and muscle function. Nevertheless, most of these studies were conducted either in small sample sizes or with a limited observation time.[10–12] It also should be highlighted that study populations frequently involved homogeneous groups of participants, typically older adults, and although this could be an advantage, it prevents a complete interpretation of lifelong changes in these parameters.[13–15]

Recently, Dodds and colleagues,[16] in their systematic review on hand grip strength, found that normative data from developed regions were similar to those described in British cohorts, whereas those from developing regions were clearly lower.

The present study was, therefore, undertaken to provide a better insight into aging-related changes in muscle mass and muscle function (strength and physical performance) throughout an individual's life span (from 18 to 98 years), using an unselected sample of individuals assessed during Milan EXPO 2015.

Materials and Methods

The Longevity Check-up and the Very Important Protein (VIP) projects are 2 initiatives developed by the Geriatric Medicine Department of the Catholic University of the Sacred Heart in Rome, designed with the intent to promote a healthy lifestyle in the general population. A team of medical doctors, researchers, and nutritionists evaluated all visitors in the pavilion of the Marche Region (during June 2015) and the Casa Ferrarini (during the weekends of September and October 2015) who agreed to be screened, using a questionnaire on lifestyle and eating habits and performing a brief check-up. The pavilion of the Marche Region and Casa Ferrarini exhibition center, both close to the Tree of Life (the universal symbol of Milan EXPO 2015), were chosen as the setting for the initiative because of the chance to meet an unselected population of individuals not generally referred to traditional health care services. Study participants were eligible for the study if they were at least 18 years of age and provided written informed consent. Participants were designated as ineligible if they were younger than 18 ($n = 10$), self-reported pregnancy ($n = 4$), declared unwillingness to perform functional tests (hand grip and chair stand test) or anthropometric measures (calf circumference and mid-arm muscle circumference [MAMC]) ($n = 36$), or were unable to give a written informed consent ($n = 4$).

Within the context of the National Campaigns of cardiovascular prevention,[17] the Catholic University of Sacred Heart ethical committee ratified the entire study protocol. A written informed consent was obtained from each participant.

Study Sample

Between June 1, 2015, and June 15, 2015 (pavilion of Marche Region), and between September 1, 2015, and October 31, 2015 (Casa Ferrarini), a sample of 3206 individuals, from different Italian regions, underwent individual assessments that consisted of a brief questionnaire, the measurement of the objective health metrics of interest, and the evaluation of specific anthropometric parameters (MAMC and calf circumference) and functional performance (hand grip and limb strength). Finally, a chart indicating the main assessment results and recommendations about future prevention measures were given.

Data Collection

The age and gender of all participants were recorded. Seven parameters highlighting the most important cardiovascular risk factors (CV health metrics)[17,18] were assessed through closed questions and direct measurement. Smoking habit was categorized as current or never/former smoker. Regular participation in physical activity was considered as involvement in exercise training at least twice a week. Body weight was measured through an analogue medical scale. Body height was measured using a standard stadiometer. Body mass index (BMI) was defined as weight (kilograms) divided by the square of height (meters). Healthy diet was considered as the consumption of at least 3 portions of fruit and/or vegetables per day. Cholesterol was measured from capillary blood samples using disposable reagent strips based on a reflectometric system with the portable device MultiCare-In (Biomedical Systems Internation srl, Florence, Italy).[19] Random blood glucose was measured from capillary blood samples using disposable reagent strips based on an amperometric system with the portable device MultiCare-In.[19] Those who declared being diabetic and, according to international guidelines,[20] those who presented with a random blood glucose level of more than 200 mg/dL were considered to be suffering from diabetes. Blood pressure was measured with an electronic sphygmomanometer according to recommendations from international guidelines.[21]

Assessment of Muscle Mass and Function

During the assessment visit, all participants underwent direct evaluation of muscle mass, by using anthropometric measures (calf circumference and MAMC), muscle strength (hand grip test), and muscle power (chair stand test).[22]

Calf circumference

Anthropometric measures were performed using a nonelastic but flexible plastic tape.[23,24] Calf circumference was measured on the left leg (or the right leg for left-handed persons) in a sitting position with the knee and ankle at a right angle and feet resting on the floor. The calf circumference was measured at the point of greatest circumference. Subcutaneous tissues were not compressed.

MAMC

MAMC was calculated by using a standard formula: MAMC = mid-arm circumference − (3.14 × triceps skin fold thickness). The mid-arm circumference was determined with a standard flexible measuring tape. All measurements were taken at the right arm, unless affected by disability or diseases. The measurement of triceps skin fold thickness was obtained by using a Harpenden skin fold caliper (Baty International, Burgess Hill, UK). In previous studies, both these anthropometric measures (calf circumference and MAMC) have shown excellent reliability when performed by expert and trained personnel.[25–27]

Muscle strength measure

Muscle strength was assessed by hand grip strength, which was measured by using a dynamometer (North Coast Hydraulic Hand Dynamometer; North Coast Medical, Inc, Morgan Hill, CA). Participants performed one familiarization trial and one measurement trial with each hand, and the result from the stronger side was used for the analyses.[14,28]

Chair stand test

This test is part of the Short Physical Performance Battery (SPPB).[29] Participants were asked to stand up from a chair with their arms

Table 1
Characteristics of Study Population According to Age Group

Age Group	Gender Female	Physical Activity	Healthy Diet	Smoking Habit	BMI, Kg/m^2	SBP, mm Hg	DBP, mm Hg	Diabetes
Whole Sample, n = 3206	1694 (52)	2103 (65)	2604 (81)	537 (17)	25.2 ± 4.2	129.3 ± 17.3	78.9 ± 9.6	110 (3)
18–19, n = 48	24 (50)	36 (75)	33 (69)	9 (19)	21.7 ± 2.9	120.5 ± 10.0	70.9 ± 7.9	0 (0)
20–24, n = 137	67 (49)	100 (72)	97 (70)	40 (30)	22.4 ± 3.5	122.8 ± 12.8	72.6 ± 8.5	2 (1)
25–29, n = 191	110 (57)	128 (67)	134 (70)	54 (28)	22.2 ± 3.3	119.9 ± 14.4	74.3 ± 8.7	0 (0)
30–34, n = 170	75 (44)	117 (69)	116 (68)	41 (24)	23.3 ± 3.9	120.8 ± 13.5	74.8 ± 7.8	2 (1)
35–39, n = 193	100 (51)	114 (59)	139 (72)	55 (28)	24.1 ± 4.1	121.7 ± 13.5	76.8 ± 8.8	0 (0)
40–44, n = 294	112 (48)	150 (64)	176 (75)	47 (20)	24.3 ± 3.6	122.7 ± 14.1	77.8 ± 9.3	2 (1)
45–49, n = 309	175 (57)	177 (57)	237 (77)	56 (18)	25.2 ± 4.3	125.9 ± 16.2	79.5 ± 9.5	7 (2)
50–54, n = 388	227 (58)	231 (59)	311 (80)	66 (17)	25.2 ± 3.8	127.3 ± 15.8	80.3 ± 9.1	9 (2)
55–59, n = 414	229 (55)	263 (63)	348 (84)	58 (14)	25.9 ± 4.2	130.4 ± 16.8	81.3 ± 9.2	13 (3)
60–64, n = 360	205 (56)	238 (63)	313 (86)	45 (12)	26.2 ± 4.0	132.3 ± 17.3	80.6 ± 9.9	17 (5)
65–69, n = 349	177 (51)	242 (69)	320 (91)	39 (11)	26.8 ± 4.1	137.0 ± 17.3	80.6 ± 9.3	26 (7)
70–74, n = 233	112 (48)	164 (70)	216 (93)	17 (7)	27.0 ± 3.8	141.0 ± 17.8	80.3 ± 9.6	17 (7)
75–79, n = 132	63 (48)	107 (81)	121 (92)	7 (5)	26.5 ± 3.8	140.9 ± 16.6	79.3 ± 9.5	11 (8)
80+, n = 48	18 (38)	36 (75)	43 (90)	3 (6)	25.6 ± 3.0	140.6 ± 16.8	77.7 ± 9.6	4 (7)

DBP, diastolic blood pressure; SBP, systolic blood pressure.
Data are given as n (%) for gender, smoking, regular physical activity, healthy diet, and diabetes; for all the other variables, means ± SD are reported. Regular physical activity is physical exercise at least twice a week. Healthy diet indicates consumption of at least 3 portions of fruit and/or vegetables per day.

folded across the chest 5 times in a row as quickly as possible. The time needed to complete the task was recorded.

Statistical Analyses

Descriptive statistics were used to describe demographic and key clinical characteristics of the study population according to age group. The primary focus of the analytic plan was to explore the age-related and gender trends across muscle mass measurements and performance variables. For this reason, the study sample was divided into the following age groups: 18–19, 20–24, 25–29, 30–34, 35–39, 40–44, 45–49, 50–54, 55–59, 60–64, 65–69, 70–74, 75–79, 80 and more years.

The differences in proportions and the means of covariates between age groups were assessed by using the Fisher Exact Test and *t* test statistics, respectively. Analysis of covariance (ANCOVA) also was used to examine the effect of age on muscle mass (calf circumference and MAMC), and muscle strength and function (hand grip and chair stand tests, respectively). Variables considered for adjustment were those thought to be clinically significant, such as BMI, diet, and physical activity. Furthermore, the Spearman correlation (*r* value) test was used to assess the correlation between age and the variables of interest.

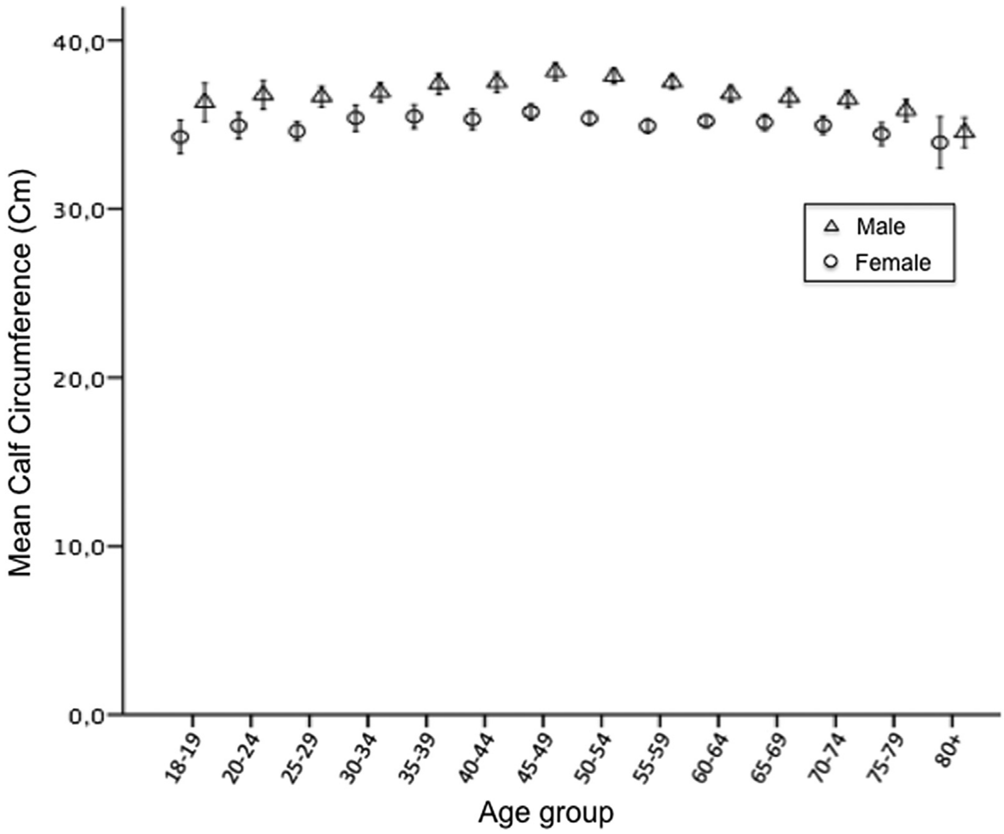

Fig. 1. Calf circumference (mean and SD) according to age group and gender (*triangle* for men, *circle* for women).

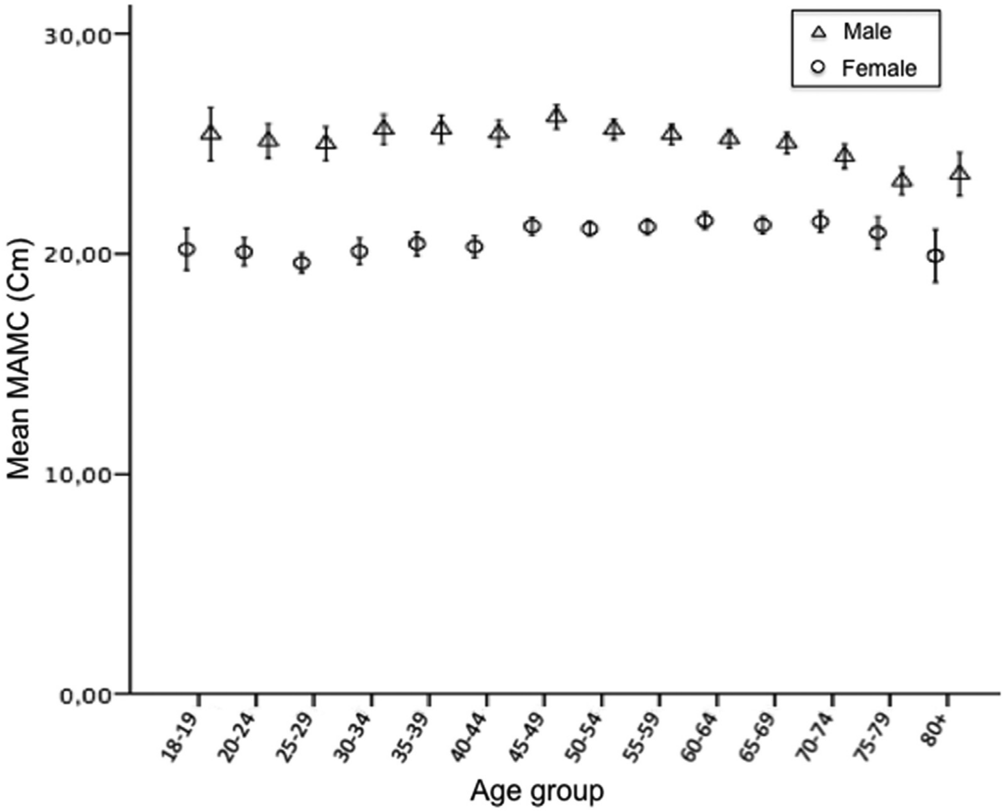

Fig. 2. MAMC (mean and SD) according to age group and gender (*triangle* for men, *circle* for women).

All analyses were performed using SPSS software (version 11.0; SPSS, Inc, Chicago, IL).

Results

The mean age of 3206 participants in the Longevity Check-up and VIP surveys was 51.9 years (SD 15.6, range 18–98 years), and 1694 (52.8%) were women. Characteristics of the study population according to the different age groups are summarized in Table 1. As compared with the participants in the youngest age groups, those in the oldest age groups had a slightly higher prevalence of physical activity and healthy diet and a significantly higher BMI. As expected, the mean systolic blood pressure increased from the youngest to the oldest age groups; similarly, the prevalence of diabetes was significantly higher in the oldest groups, compared with other participants. On the other hand, those in the youngest groups had a higher prevalence of smoking habits (30% among those aged 20–24 years and 6% among those aged 80 years and older; $P < .001$).

Means and SDs for muscle mass across age groups are presented in Figures 1 and 2. Overall, cross-sectional observations suggest that both calf circumference (Figure 1) and MAMC (Figure 2) marginally decline with age, and the rates of decline differ by gender. These measures are stable until 50 years and then begin to slightly decrease with age, with more of an effect evident in men than in women. In men, the maximum difference for the calf circumference between the oldest (80 years and older group), and the youngest group (18–19 years) is approximately 2 cm (34.5 vs 36.3 cm, respectively; $P < .001$). The difference among women is less than 1 cm (33.9 vs 34.2, respectively; P = nonsignificant [ns]). This trend is similar for MAMC. In men, there is a loss of 2 cm (25.4 vs 23.6, in younger and older individuals, respectively; $P < .001$), whereas in women the MAMC value is more stable across age groups (20.2 vs 19.9, respectively; P = ns).

The main effect of age was observed for muscle strength and physical performance parameters. Figures 3 and 4 show the mean and SD of muscle strength and physical performance across age groups. Muscle strength (as measured by the hand grip strength test) declined significantly after 45 years of age, both in men and women (Figure 3). In particular, among men, muscle strength increased slightly from 18 years (43.5 kg) to 40 to 44 years (48.3 kg); after 45 years a significant decline is observed with a loss of more than 16 kg in the group of oldest individuals (48.3 vs 31.5 kg, respectively; $P < .001$). In women, muscle strength was more stable between 18 years and 40 to 44 years, and then, as observed in men, a linear decline was detected, with an approximately 10-kg difference between the youngest group and the oldest group (27.5 vs 17.2 kg, respectively; $P < .001$).

The time to complete the chair stand test (a measure of physical performance) was similar between 18 years and 40 to 44 years, and then a linear decline in performing the test across age groups was observed (Figure 4). The time to complete the test increased by approximately more than 3 seconds between the youngest (18–19 years) and the oldest group (80 years and older) (6.2 vs 9.4 seconds, respectively; $P < .001$), in both men and women.

The results from ANCOVA models, adjusted for BMI, diet, and physical activity, were similar to those observed from the unadjusted analyses. The same trend across aging was observed for all the variables of interest (calf circumference and MAMC, hand grip strength, and chair stand test). Furthermore, to better address these correlations, we tested the linear regression starting from the age category of 40 to 44 years. The correlation values between age and hand grip strength were $r = 0.447$ ($P < .001$) and $r = 0.484$ ($P < .001$) for men and women, respectively. Similarly, the correlation values between age

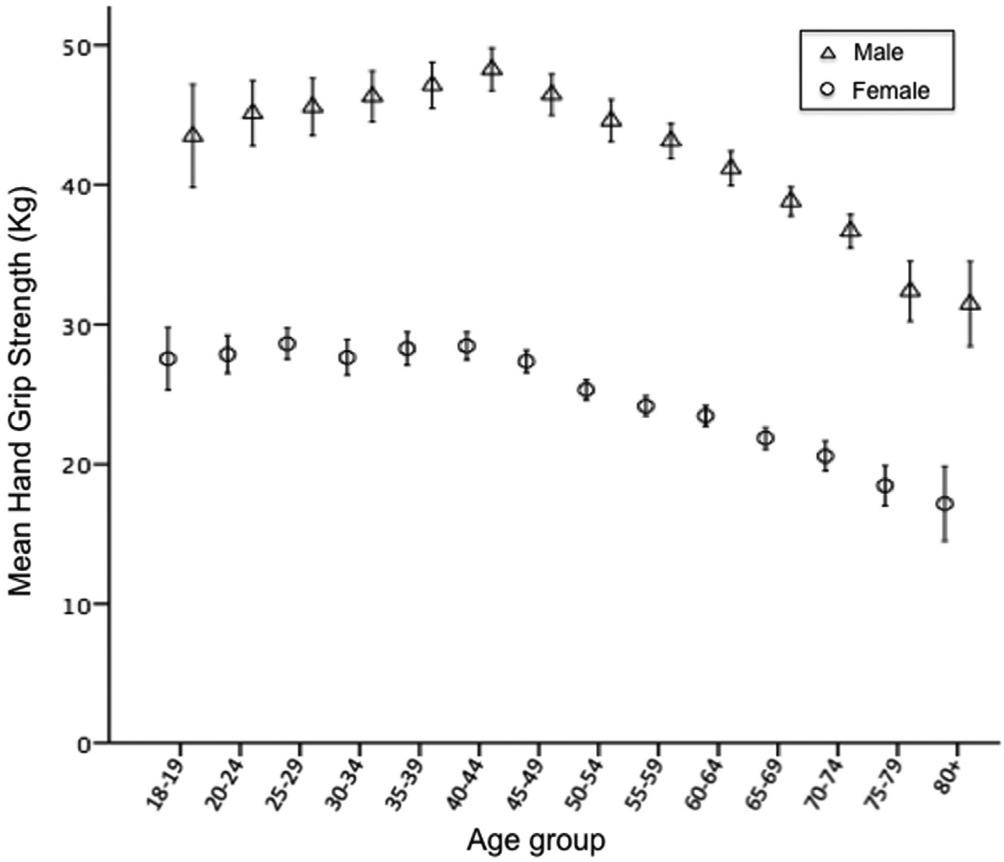

Fig. 3. Hand grip strength (mean and SD) according to age group and gender (*triangle* for men, *circle* for women).

and chair stand test were $r = 0.426$ ($P < .001$) and $r = 0.448$ ($P < .001$) for men and women, respectively.

Finally, Figure 5 shows the percent changes between the various age groups compared with the youngest group (18–19 years). The percent change in muscle mass was significantly less than the change observed for muscle strength and physical performance. After 75 years of age, there is a reduction of approximately 6% to 7% of muscle mass (with no difference between calf circumference and MAMC), approximately 60% of muscle strength, and 30% of physical performance.

Discussion

The patterns of age-related decline, and the age at which decreases in muscle mass, muscle strength, and physical performance can first be identified, have not been extensively studied.[30] In the present study, we explored the change of muscle mass, strength, and physical performance across age in a large and unselected sample of community-dwelling individuals. Our findings show that different patterns of muscle mass and physical decline with age were observed for different ages. In general, muscle mass (as measured by calf circumference and MAMC) marginally decreased with advancing age. Interestingly, for muscle strength (as measured by hand grip test) and physical performance (as measured by chair stand test) there was stability in the first decades of adulthood, and decrements in the middle years (45+) and late adulthood. In particular, individuals older than 75 years lose approximately 60% of their muscle strength and 30% of their physical function. We observed a linear pattern of age-decline that was surprisingly similar in men and women across the entire course of life.

These findings corroborate the evidence that physical performance, more than muscle mass, decreases with age, and that the onset of decline by age group is observed as early as the fourth and fifth decades.[31,32] The results in the present investigation extend the knowledge in this field and also show that the decline in strength is significantly greater than the decline in muscle mass.[9,33] Nevertheless, it is important to highlight that most of the evidence derives from selected population, such as athletes, frail older people, or selected clinical settings, such as outpatient clinics.[3,34] Our survey is the first assessing the age-related change of muscle mass and function in a general and nonselected population. In this respect, the Milan EXPO 2015 provided a unique opportunity to assess this change among individuals of any age and gender that entered the Universal Exposition to visit stands and not to do a lifestyle evaluation and health assessment.

For many years, it has been hypothesized that the loss of mobility and the onset of physical disability with aging were correlated, at least in part, with age-associated modifications in body composition, namely the decline of muscle mass and increase in other less metabolically active tissues, mostly fat and connective tissue.[35,36] However, studies in the past decade found independent associations between muscle strength and not muscle mass with physical function, mobility, and mortality.[37,38] Hence, it emerges that modification in characteristics of muscle tissue have functional effects of greater importance than those caused by the decline in muscle mass alone.[15,39]

Understanding whether the decline of muscle function appears early in adulthood and recognizing the potential causes of muscle quality impairment may help develop new preventive strategies.[40,41]

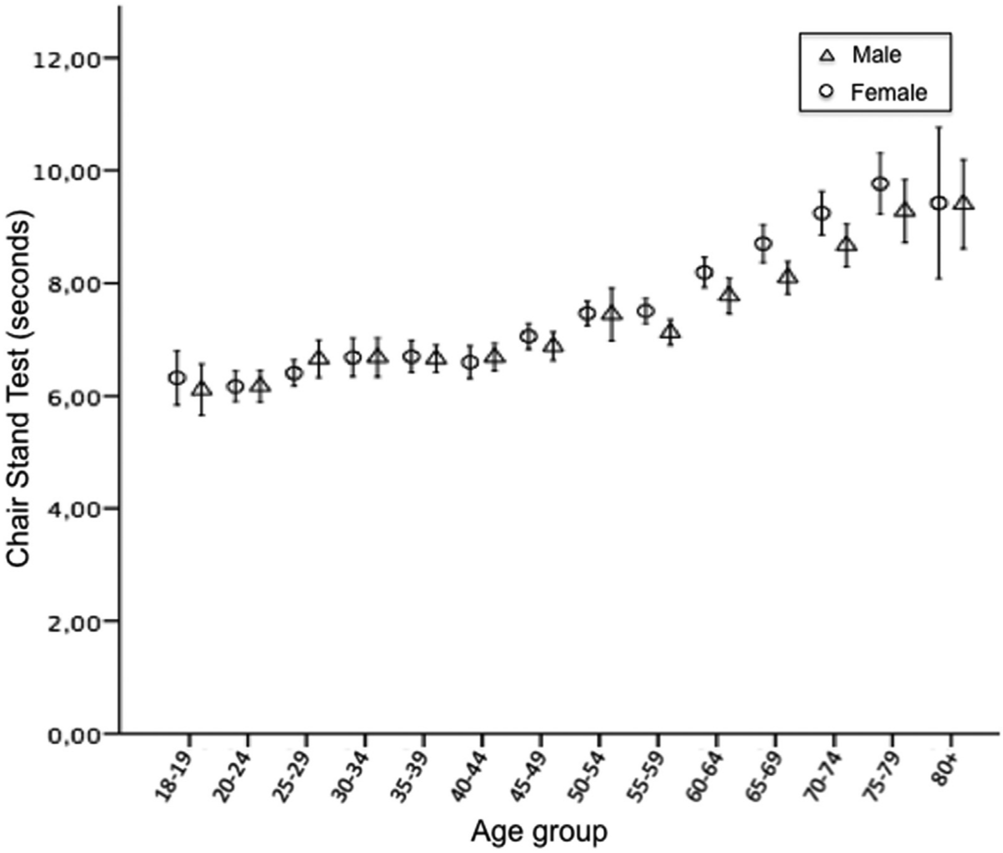

Fig. 4. Chair stand test (mean and SD) according to age group and gender (*triangle* for men, *circle* for women).

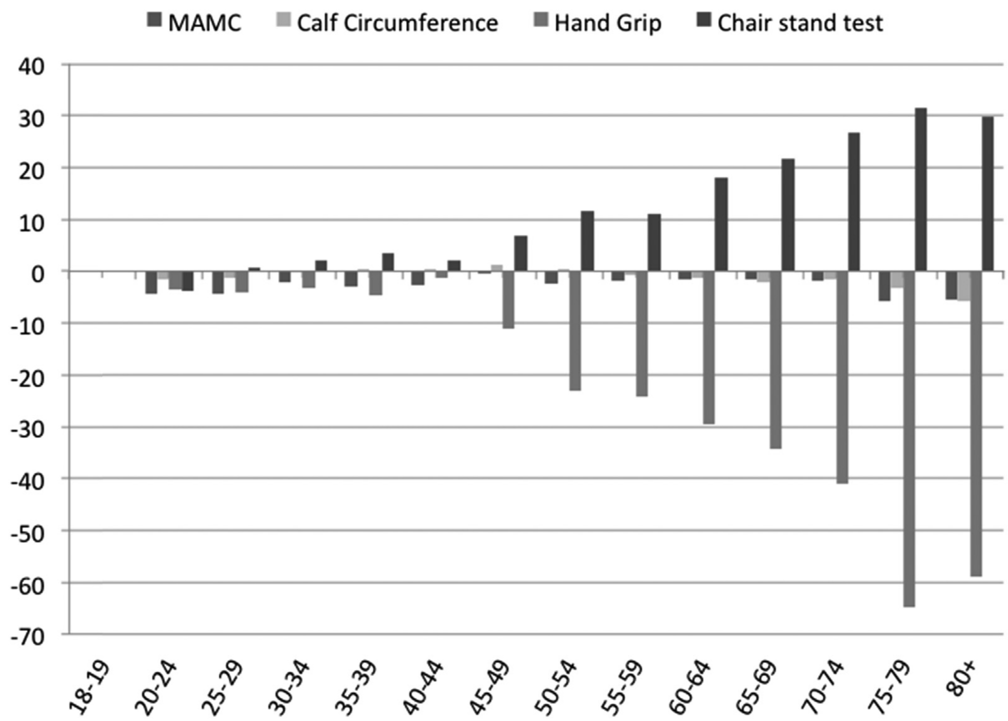

Fig. 5. Change (%) of muscle mass (calf circumference and MAMC), muscle strength (hand grip test) and physical performance (chair stand test) across age groups compared with the youngest group (18–19 years).

Given recent evidence that preserving or increasing muscle mass does not always avoid age-related declines in muscle strength,[10,23] and that interventions targeted at enhancing muscle anabolism have a partial impact on physical function and disability,[42,43] alternative treatment approaches are greatly needed.

Skeletal muscle mass and functional capacity are controlled by the dynamic interaction of numerous factors, encompassing, for example, physical activity, diet, and nutritional status.[44,45] Our results lend further support to interventions in younger cohorts, targeting the risk factors for late-life disability earlier in life in an effort to prevent, attenuate, or delay functional decline.[46,47] Efforts to preserve strength and endurance should begin before age 50, when it is still possible to maintain the skills that keep people mobile and independent later in life. Some instruments, such as SARC-F,[48,49] have been designed to screen for sarcopenia in older age groups in which the disease prevalence is high. A step forward might be achieved by developing tools that can identify individuals at risk for sarcopenia well before the decline in muscle mass and function reaches a critical threshold and significance.[22,50] Such an approach could allow the implementation of primary preventive strategies against sarcopenia, including specific exercise and nutritional interventions.[51–53]

Albeit dealing with a highly relevant issue, our study presents some limitations that need to be discussed. First, although anthropometric measures are established techniques for the estimation of lean body mass, they do not represent the gold standard for the quantification of muscle mass.[2] Many experts in sarcopenia believe that anthropometric measures are poor markers of muscle mass and cast doubts on their role in these kinds of studies.[54,55] The accumulation of fat within the skeletal muscle limits the ability of anthropometric measurements, such as calf circumference and MAMC, to estimate muscle mass. In this respect, it is important to highlight that the stability of anthropometric measurements across age observed in our study may be due, at least in part, to the inability to assess the amount of fat and connective tissue accumulated outside and inside the muscle. Because of these limitations, our findings on muscle mass should be considered with caution. Nevertheless, calf circumference and MAMC are potential markers of muscle mass; they are an inexpensive, simple, noninvasive measurement for a clinician and are suitable for the screening of sarcopenia at the population level.[24,25] Second, the type of evaluation could influence the assessment of some health metrics and physical performance. For example, the chosen setting of Milan EXPO 2015 could lead to an overestimation of blood pressure. Even though the blood pressure was measured according to recommendations from international guidelines, it is important to underline that the individuals who decided to participate in the study procedures were involved, before being assessed, in the usual exposition activities, such as walking, carrying bags, and eating. The activities, performed immediately before being evaluated, could have influenced the assessment. In particular, the physical performance evaluation of older individuals may have been more affected by tiring activities than younger individuals. Moreover, considering the type of check-up, we decided “a priori” to assess only the chair stand test and not the entire SPPB assessment. This choice was principally because people who stopped to perform the visit were not willing to have a long medical examination. Third, the results shown in this article were obtained from a cross-sectional survey. A deeper understanding of muscle mass and function age-trajectory changes requires the analysis of prospective data that are not available at this stage for our study. Finally, the Milan EXPO 2015 population included only white persons, so our results may not be applicable to other ethnic groups. However, it is important to highlight that our unselected sample of community-dwelling individuals is representative of the Italian population; for example, the rates of smokers and those with hypertension or diabetes are similar to other reference samples.[17]

Apart from these limitations, this study offers a unique opportunity to investigate the age trajectory of muscle mass and physical performance among an unselected population. Muscle strength and physical performance considerably decline with aging. Calf circumference and MAMC, indicators of muscle mass, show only a moderate decline with aging. Men generally performed better than women in all the tasks, and younger people outperformed older participants. Nevertheless, the age at which declines in physical ability began to appear, in the decade of the 40s, were consistent regardless of gender. Specifically, both men and women in that mid-life decade began to decrease their muscle strength. Successively, the decline continued through the next decades.

In conclusion, based on our observations, the assessment of muscle strength and physical performance should be recommended for the early detection of individuals at risk of sarcopenia.[56] Muscle mass and strength curves may be used to extract reference values for subsequent use in research as well as in the clinical setting. In particular, the analyses of trajectories of muscle parameters may help identify cutoffs for the estimation of risk of adverse events. However, despite the extensive research efforts, the mechanism responsible for the age-associated decline in muscle strength and function has not been completely elucidated.[57,58] A greater understanding of the mechanisms that impair muscle quality with aging may reveal targets for intervention aimed at improving mobility and preventing disability in late life.[59–61]

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