Muscle strength is associated with COVID-19 hospitalization in adults 50 years of age and older

Running head: Muscle strength & COVID-19 hospitalization

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Abstract

Background. Weak muscle strength has been associated with a wide range of adverse health outcomes. Yet, whether individuals with weaker strength are more at risk for hospitalization due to severe COVID-19 is still unclear. The objective of this study was to investigate the independent association between muscle strength and COVID-19 hospitalization.

Methods. Data from 3600 adults 50 years of age and older were analyzed using logistic models adjusted for several chronic conditions, body mass index, age, and sex. Hand grip strength was repeatedly measured between 2004 and 2017 using a handheld dynamometer. COVID-19 hospitalization during the lockdown was self-reported in summer 2020 and was used an indicator of COVID-19 severity.

Results. Results showed that higher grip strength was associated with a lower risk of COVID-19 hospitalization (adjusted odds ratio [OR] per increase of 1 SD in grip strength = .64, 95% confidence interval [95% CI] = .45–.87, p = .015). Results also showed that age (OR for a 10-year period = 1.70, 95% CI = 1.32–2.20, p < .001) and obesity (OR = 2.01, 95% CI = 1.00–3.69, p = .025) was associated with higher risk of COVID-19 hospitalization. Sensitivity analyses using different measures of grip strength as well as robustness analyses based on rare-events logistic regression and COVID-19 patients were consistent with the main results.

Conclusion. Muscle strength is an independent risk factor for COVID-19 severity in adults 50 years of age and older.

Keywords: coronavirus disease 2019, hospitalization, muscle strength, physical fitness, risk factors, sarcopenia.

Introduction

As of January 27, 2021, more than 100 million people were diagnosed with the coronavirus disease 2019 (COVID-19) and over 2 million died due to this infection (1). The majority of infected people are asymptomatic (2, 3) or have mild symptoms such as fever, cough, dyspnea, fatigue, or anosmia/dysgeusia (4, 5). However, severe COVID-19 symptoms can also be life-threatening and require to be hospitalized (6). Thus, identifying risk factors for severe COVID-19 is important to inform clinical decisions and public-health strategies.

Several risk factors have already been identified, including older age, male sex, as well as underlying health conditions such as obesity, cardiovascular disease, respiratory disease, kidney disease, diabetes, and cancer (7-9). In addition to these established risk factors for severe COVID-19, the latest studies suggest that physical fitness should also be considered (10-12). For example, maximal exercise capacity was associated the risk of COVID-19 hospitalization (11), slower walkers showed higher risk of severe COVID-19 than brisk walkers (12), and the overall level of fitness was associated with survival in COVID-19 hospitalized patients (13). Whether muscle strength, another dimension of physical fitness, is a risk factor of severe COVID-19 remains unclear.

Muscle strength is an indicator of muscle function, which is essential to health (14, 15), and has shown to be a robust predictor of multiple diseases and all-cause mortality (14, 16-18). Therefore, muscle strength should be considered as a potential risk factor for severe COVID-19 (19). The objective of this study was to investigate the association between muscle strength and COVID-19 severity. We hypothesized that maximal muscle strength would be independently and inversely associated with COVID-19 hospitalization.

Methods

Study overview

Data from the Survey of Health, Ageing and Retirement in Europe (SHARE) were collected every two years between 2004 and 2017 (7 waves of data collection) on adults 50 years of age and older living in 27 European countries (n = 139556). From June to September 2020, SHARE participants (n = 52310) responded to the SHARE COVID-19 questionnaire (20). Questions included whether they had been tested positive for the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and whether this infection had resulted in hospitalization. To be included in the study, participants should be aged 50 years or older, have completed at least one SHARE questionnaire between 2004 and 2017, and have indicated whether they were infected

by the SARS-CoV-2 and/or they were hospitalized due to COVID-19 in the SHARE COVID-19 questionnaire (Figure 1). SHARE was approved by the Ethics Committee of the University of Mannheim (waves 1-4) and the Ethics Council of the Max Plank Society (waves 4-7).

Measures

Outcome: COVID-19 hospitalization

Hospitalization due to COVID-19 was derived from the question: "*Have you, or anyone close to you, been hospitalized due to an infection from the coronavirus?*". If participants answered "*yes*", the interviewer asked who was hospitalized. Participants who indicated they were hospitalized were included in the analyses as COVID-19 hospitalized. If the participant indicated that their "*spouse or partner*" was hospitalized, the spouse or partner was included in the analyses as COVID-19 hospitalized.

Independent variable: Muscle strength

Hand grip strength (kg) was used as an indicator of muscle strength and was measured twice with each hand (alternating between hands) using a handheld dynamometer (Smedley, S Dynamometer, TTM, Tokyo, 100 kg). Participants were instructed to stand (preferably) or sit, with the elbow flexed at a 90° angle, the wrist in a neutral position, and the upper arm in a vertical position against the trunk. Interviewers applied standardized instructions to ensure that the grip was performed with maximum effort. The maximum value was used as an indicator of muscle strength (14, 21). Grip strength was assessed at each data-collection wave, but only the most recent measure was included in the analyses.

Covariates and established risk factors

The following covariates were included in the analysis: *Age* (in 2020, when responding to the SHARE COVID-19 questionnaire), *sex* (male, female), height (cm), *body mass index* (normal: <25, overweight: ≥25 and <30, obese: ≥30 kg/m^2), *cardiovascular disease* (heart attack, including myocardial infarction or coronary thrombosis, or any other cardiovascular problem including congestive heart failure, high blood cholesterol, high blood pressure or hypertension, stroke or cerebral vascular disease), *respiratory disease* (includes chronic bronchitis or emphysema, and asthma), *diabetes*, *cancer*, *chronic kidney disease*, and *rheumatoid arthritis*. All these covariates are established risk factors for severe COVID-19 (7-9) and were measured using self-reported questionnaires. When a participant had repeated measurements on a

variable, the most recent measure was included in the analyses. As recommended (17, 22, 23), self-reported height (cm) was included in the analyses to ensure that the associations observed between muscle strength and COVID-19 hospitalization was not due to a difference in height.

Data analyses

Main analyses

Three logistic regression models were fitted. Model 0 tested the association between muscle strength and COVID-19 hospitalization, adjusting only for height. Model 1 tested the association between the established risk factors (i.e., age, sex, height, body mass index, cardiovascular disease, respiratory disease, diabetes, cancer, chronic kidney disease, and rheumatoid arthritis) and COVID-19 hospitalization. Model 2 tested the association between grip strength and COVID-19 hospitalization, while adjusting for the established risk factors. Age was centered on mean age (i.e., 68.8 years) and divided by 10, so that the coefficient yielded effects of an increased odds of COVID-19 hospitalization over a 10-year period (24). Grip strength was standardized so that the coefficient yielded effects associated with an increase of 1 SD. Statistical analyses were conducted in R using the glm package. Statistical assumptions associated with general logistic models were met (i.e., normality of the residuals, multicollinearity, and undue influence). To illustrate the association between grip strength and COVID-19 hospitalization from the estimates obtained in Model 2, we computed the odds ratio of hospitalization in individuals with weaker and stronger grip strength by centering grip strength on mean – 1 standard deviation (SD) and mean + 1SD, respectively.

Sensitivity analyses

Two sensitivity analyses were conducted. In the first sensitivity analysis, average grip strength over the study duration (i.e., from wave 1 to 7) replaced the most recent measure to test the association with a more stable level of muscle strength. The second sensitivity analysis included grip strength assessed only in the wave preceding the SHARE COVID-19" questionnaire" (i.e., wave 7) (N = 2884) to shorten the time between the measure of grip strength and the COVID-19 hospitalization event.

Robustness analyses

Tow robustness analyses were conducted. In the first robustness analysis, the dataset was analyzed using a rare-events logistic regression (25), which corrects for the bias associated with

rare events. To account for the estimated fraction of patients hospitalized due to COVID-19 in the European population from June to September 2020, we used a tau parameter of 84/100000 based on COVID-19 hospitalization data that were available from May 2020 on (Table S3). These data are thought to underestimate the true number of COVID-19 hospitalization as the ones earlier than May 2020 were not included, thereby likely overcorrecting the results of the analysis. In addition, we corrected for our case-control sampling design using the weighting method (R Zelig package) (26). The second robustness analysis included only patients who were tested positive to the COVID-19 (N = 289) to examine whether muscle strength is a risk factor in the population of COVID-19 patients. This subsample was based on the question: "*Have you, or anyone close to you, been tested for the coronavirus and the result was positive, meaning that the person had the COVID disease?*".

	Not Hospitalized (N = 3517)		**Hospitalized** (N = 83)		*p*-value
Studied factor					
Muscle strength (kg, SD)	34.5	11.8	31.9	11.45	.027*
Established risk factors					
Age (years, SD)	68.8	8.6	73.0	10.7	<.001
Sex					
Female	1986	56.5%	43	51.2%	
Male	1531	43.5%	40	48.2%	.463
Body mass index (kg/m^2)					
Normal: <25	1411	40.1%	24	28.9%	
Overweight: ≥25 and <30	1420	40.4%	36	43.4%	
Obese: ≥30	686	19.5%	23	27.7%	.064
Cardiovascular disease					
No	1721	48.9%	32	38.6%	
Yes	1796	51.1%	51	61.4%	.072
Respiratory disease					
No	3336	94.9%	75	90.4%	
Yes	181	5.1%	8	9.6%	.118
Diabetes					
No	3177	90.3%	71	85.5%	
Yes	340	9.7%	12	14.5%	.206
Cancer					
No	3365	95.7%	80	96.4%	
Yes	152	4.3%	3	3.6%	.968
Rheumatoid arthritis					
No	3229	91.8%	73	88.0%	
Yes	288	8.2%	10	12.0%	.289
Chronic kidney disease					
No	3464	98.5%	79	95.2%	
Yes	53	1.5%	4	4.8%	.052

Table 1. Sample characteristics by hospitalization status. *P*-values are based on the analysis of variance and chi-square tests for continuous and categorical variables, respectively, testing the association between hospitalization (vs. non-hospitalization) and these variables. SD = standard deviation, *p-value is based on muscle strength accounting for height.

	Model 0		**Model 1**		**Model 2**	
Variables	OR (95% CI)	*p*	OR (95% CI)	*p*	OR (95% CI)	*p*
Intercept	.02 (.02; .03)	<.001	.015 (.01; .02)	<.001	.012 (.01; .02)	<.001
Hand grip strength	.60 (.45; .81)	<.001			.64 (.45; .92)	.015
Height	1.54 (1.15; 2.04)	.003	1.31 (.96; 1.77)	.089	1.06 (1.06; 2.00)	.020
Age			1.70 (1.32; 2.20)	<.001	1.50 (1.14; 1.97)	.003
Sex (ref. Female)						
Male			.79 (.43; 1.43)	.427	1.26 (.62; 2.51)	.518
Body mass index (ref. Normal)						
Overweight			1.44 (.85; 2.49)	.179	1.53 (.90; 2.64)	.121
Obese			2.01(1.09; 3.69)	.025	2.11 (1.14; 3.88)	.016
Cardiovascular disease (ref. No)						
Yes			1.06 (.66; 1.73)	.811	1.03 (.64; 1.67)	.912
Respiratory disease (ref. No)						
Yes			1.52 (.66; 3.08)	.278	1.50 (.65; 3.05)	.295
Diabetes (ref. No)						
Yes			1.19 (.59; 2.19)	.601	1.09 (.54; 2.01)	.806
Cancer (ref. No)						
Yes			.67 (.16; 1.85)	.504	.63 (.15; 1.74)	.438
Rheumatoid arthritis (ref. No)						
Yes			1.17 (.55; 2.24)	.669	1.07 (.50; 2.07)	.850
Chronic kidney disease (ref. No)						
Yes			2.44 (.71; 6.41)	.104	2.29 (.66; 6.05)	.134

Table 2. Results of the logistic models testing the association of established risk factors and grip strength with COVID-19 hospitalization. Age was centered on mean age (i.e., 68.8 years) and divided by 10, so that the coefficient yielded effects of an increased odds of COVID-19 hospitalization over a 10-year period. Hand grip strength was standardized so that the coefficient yielded effects associated with an increase of 1 standard deviation. OR = Odds Ratio; 95% CI = 95% Confidence Interval.

Results

The study sample included 3600 individuals (68.8 ± 8.8 years, 2044 females), from which 83 (2.3 %) were hospitalized due to COVID-19 (Figure 1). Table 1 summarizes the characteristics of the participants stratified by COVID-19 hospitalization status. COVID-19 hospitalization (vs. no hospitalization) was associated with older age ($p < .001$), higher body mass index ($p = .062$), cardiovascular disease ($p = .064$), chronic kidney disease ($p = .052$), and weaker muscle strength ($p = .027$). The number of participants who completed their last measure of grip strength in wave 1, 2, 3, 4, 6, and 7 was 10, 7, 3, 39, 188, 413, and 2940, respectively.

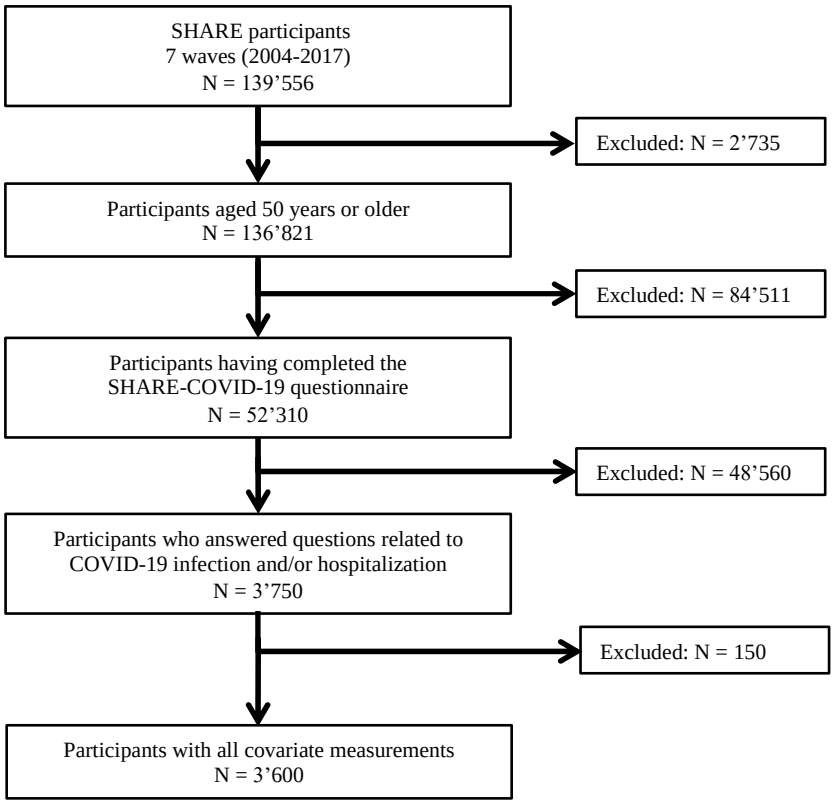

Figure 1. Flow Chart

Univariate model

Model 0 showed that the most recent measure of maximal grip strength was associated with COVID-19 hospitalization (OR = .60, 95% CI = .45–.81, $p < .001$, per increase of 1 SD in grip strength) (Table 2).

Established risk factors and COVID-19 hospitalization

Model 1 showed that older individuals were at higher risk of COVID-19 hospitalization than younger individuals (adjusted odds ratio [OR] = 1.70, 95% confidence interval [95% CI] = 1.32–2.20, $p < .001$). The OR was also higher in obese individuals than in individuals with a normal body mass index (OR = 2.01, 95% CI = 1.0–3.69, $p = .025$). The other associations were not statistically significant (ps > .089) (Table 2).

Grip strength and COVID-19 hospitalization

Model 2 showed that the most recent measure of maximal grip strength (34.43 ± 11.79 kg; mean ± SD) was associated with the risk of COVID-19 hospitalization (OR = .64, 95% CI = .45–.92, $p = .015$ per increase of 1 SD in grip strength) (Table 2). Results showed that the odds ratio was

higher in individuals with weaker grip strength (mean − 1SD = 22.64 kg, OR = .019, 95% CI = .01–.03, $p < .001$), compared to individuals with stronger grip strength (mean + 1SD = 46.22 kg, OR = .008, 95% CI = .003–.016, $p < .001$) (Figure 2). When grip strength was included in the model, the association of age (OR = 1.50, 95% CI = 1.14–1.97, $p = .003$) and body mass index (OR = 2.11, 95% CI = 1.14–3.88, $p = .016$) with COVID-19 hospitalization remained significant (Table 2).

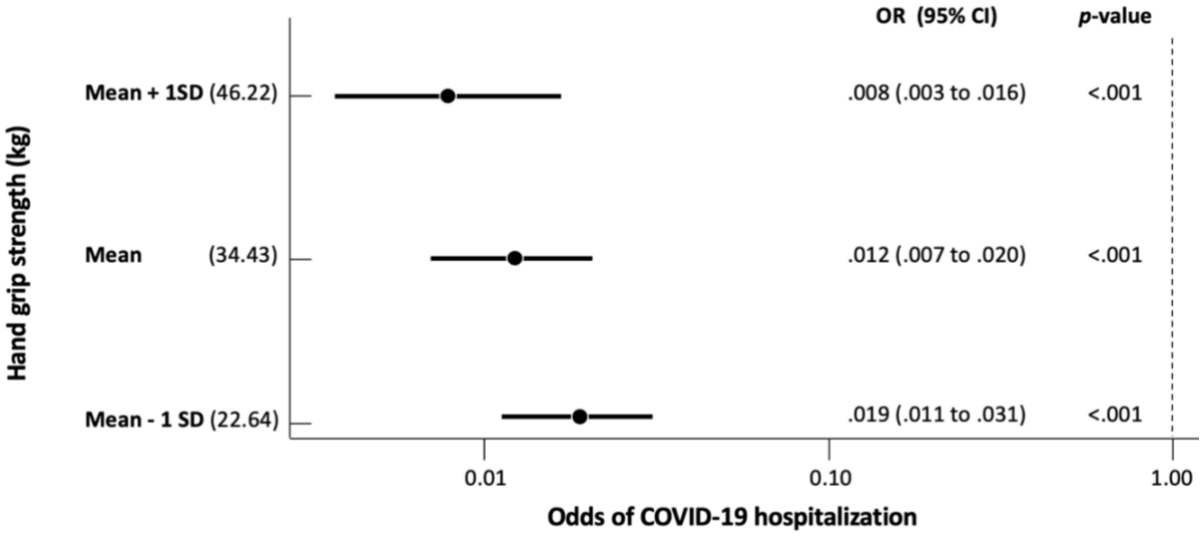

Figure 2. Association between hand grip strength and the odds of being hospitalized due to COVID-19. Odds ratios (OR) were adjusted for age, sex, height, body mass index, cardiovascular disease, respiratory disease, chronic kidney disease, rheumatoid arthritis, diabetes, and cancer (see Model 2). 95% CI = 95% confidence interval.

Sensitivity and robustness analyses

The sensitivity (Tables S1 and S2) and robustness analyses (Tables S4 and S5) yielded similar results as the main analysis. Specifically, results of the sensitivity analyses showed that muscle strength averaged across the 7 waves (OR = .62, 95% CI = .42–.92, $p = .017$) and muscle strength assessed only in wave 7 (OR = .65, 95% CI = .44–.96, $p = .029$) were associated with the risk of COVID-19 hospitalization. Results of the robustness analysis based on the rare-events logistic regression showed that the most recent measure of maximal grip strength was associated with the risk of COVID-19 hospitalization (OR = .63, 95% CI = .43–.92, $p = .016$). Finally, results of the robustness analysis that included only patients who were tested positive to COVID-19 showed that the most recent measure of maximal grip strength was associated with the risk of COVID-19 hospitalization (OR = .56, 95% CI = .33–.94, $p = .031$).

Discussion

Recent findings suggest that physical fitness should be considered as a risk factor for severe COVID-19 (10-12). Here, muscle strength was assessed using hand grip strength and severe COVID-19 was derived from self-reported COVID-19 hospitalization. Results showed that weaker muscle strength was associated with a higher risk of severe COVID-19, after adjusting for established risk factors for severe COVID-19. Hence, our study lends direct empirical support for the hypothesized relationship between muscle strength and COVID-19 severity.

The association between muscle strength and COVID-19 severity can be explained by the essential role of muscle in health and disease (14). Particularly, skeletal muscle weakness has been shown to affect the motor function, respiratory function and has been linked to poor immune response and metabolic stress when facing acute infection (19, 27-29). Therefore, adults with weaker muscle strength may be more vulnerable to SARS-CoV-2 infection and at higher risk of developing severe forms of COVID-19. This hypothesis is indirectly supported by previous results. For example, some conditions associated with muscle weakness such as age, chronic diseases, and cancer have been identified as risk factors for COVID-19 severity (30-32). Likewise, patients with sarcopenia have been associated with an impaired respiratory function (33), which is the function affected by SARS-CoV-2. Finally, our findings are consistent with recent studies showing that other dimensions of physical fitness are associated with an increased risk of COVID-19 hospitalization (10-13).

Among the strengths of the present study are the large sample size, the longitudinal design, and a measure of hand grip strength based on a well-established procedure. Moreover, the results were consistent across multiple independent variables, different statistical approaches, and two different population samples (i.e., general population and patients tested positive to COVID-19). However, potential limitations should be noted. First, the established risk factors were assessed with self-reported questionnaires, which may have reduced measurement validity. Second, the latest assessment of these factors was in 2017, that is two years before participants' potential infection to COVID-19. Therefore, participants may have contracted a disease between the assessment of these heath conditions and the COVID-19 pandemic, which may have resulted in a misclassification bias. Third, COVID-19 severity was inferred by COVID-19 hospitalization. However, this measure lacks sensitivity. For example, the questionnaire did not assess the lengths of hospitalization or whether the patients have to be transferred to intensive cate unit, which would have allowed to assess with a finer grained COVID-19 severity. Similarly, our sample did not included participants who were hospitalized during the

data collection (except when the information can be extract from the spouse or partners) and participants who died due to COVID-19. These limitations may explain the absence of statistical evidence supporting the effect of established risk factors for COVID-19 hospitalization (34, 35).

Conclusion

This study shows that muscle strength is associated with the risk of severe COVID-19 in adults 50 years of age and older. These findings further highlight muscle strength as an important factor to monitor in COVID-19 patients (19, 36, 37). Finally, hand grip strength could improve the accuracy of composite scores used to predict COVID-19 severity (19, 38, 39).

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Statement of Conflict of Interest and Adherence to Ethical Standards: All authors declare that they have no conflict of interests.

Author Contributions: All the authors designed the study. S.S. cleaned the data. B.C. analyzed the data. B.C., M.P.B. drafted the manuscript. All authors critically appraised the manuscript, worked on its content, and approved its submitted version.

Ethical approval: This study was part of the SHARE study, approved by the relevant research ethics committees in the participating countries

Inform Consent: All participants provided written informed consent.

Funding: B.C. is supported by an Ambizione grant (PZ00P1_180040) from the Swiss National Science Foundation (SNSF).

Data sharing: This SHARE dataset is available at http://www.share-project.org/data-access.html.

Acknowledgements: *This paper uses data from SHARE Waves 1, 2, 3 (SHARELIFE), 4, 5,6, 7 and 8 (DOIs: 10..6103/SHARE.w1.600, 10..6103/SHARE.w2.600, 10..6103/SHARE.w3.600,*

10..6103/SHARE.w4.600, 10..6103/SHARE.w5.600, 10..6103/SHARE.w6.600, 10.6103/SHARE.w7.711, 10.6103/SHARE.w8cabeta.001). The SHARE data collection was primarily funded by the European Commission through FP5 (QLK6-CT-2001-00360), FP6 (SHARE-I3: RII-CT-2006-062193, COMPARE: CIT5-CT-2005-028857, SHARELIFE: CIT4-CT-2006-028812) and FP7 (SHARE-PREP: no.211909, SHARE-LEAP: no.227822, SHARE M4: no.261982). Additional funding from the German Ministry of Education and Research, the Max Planck Society for the Advancement of Science, the U.S. National Institute on Aging (U01_AG09740-13S2, P01_AG005842, P01_AG08291, P30_AG12815, R21_AG025169, Y1-AG-4553-01, IAG_BSR06-11, OGHA_04-064, HHSN271201300071C) and from various national funding sources is gratefully acknowledged (see www.share-project.org).

Supplemental Material

Sensitivity analyses

Robustness analyses

Table S1. Results based on average hand grip strength (2004-2017)

	Model 1 (without muscle strength)		Model 2 (with muscle strength)	
Variables	OR (95% CI)	*p*-value	OR (95% CI)	*p*-value
Intercept	.015 (.01; .02)	<.001	.012 (.01; .02)	<.001
Age	1.70 (1.32; 2.20)	<.001	1.50 (1.15; 1.97)	.003
Sex (ref. Female)				
Male	.79 (.43; 1.43)	.427	1.35 (.64; 2.79)	.419
Height	1.31 (.96; 1.77)	.089	1.48 (1.07; 2.04)	.016
Body mass index (ref. Normal)				
Overweight	1.44 (.85; 2.49)	.179	1.56 (.92; 2.71)	.104
Obese	2.01(1.09; 3.69)	.025	2.15 (1.16; 3.97)	.014
Cardiovascular disease (ref. No)				
Yes	1.06 (.66; 1.73)	.811	1.02 (.63; 1.67)	.922
Respiratory disease (ref. No)				
Yes	1.52 (.66; 3.08)	.278	1.53 (.66; 3.09)	.278
Diabetes (ref. No)				
Yes	1.19 (.59; 2.19)	.601	1.09 (.55; 2.02)	.787
Cancer (ref. No)				
Yes	.67 (.16; 1.85)	.504	.62 (.15; 1.73)	.431
Rheumatoid arthritis (ref. No)				
Yes	1.17 (.55; 2.24)	.669	1.10 (.51; 2.11)	.798
Chronic kidney disease (ref. No)				
Yes	2.44 (.71; 6.41)	.104	2.36 (.68; 6.20)	.118
Muscle strength			.62 (.42; .92)	.017

Table S2. Results based on hand grip strength assessed in wave 7

N = 2'884	Model 1 (without muscle strength)		Model 2 (with muscle strength)	
Variables	OR (95% CI)	*p*-value	OR (95% CI)	*p*-value
Intercept	.016 (.01; .03)	<.001	.012 (.01; .02)	<.001
Age	1.50 (1.11; 1.99)	<.007	1.31 (.96; 1.78)	.086
Sex (ref. Female)				
Male	.81 (.41; 1.59)	.538	1.31 (.58; 2.85)	.507
Height	1.25 (.87; 1.77)	.222	1.38 (.96; 1.97)	.079
Body mass index (ref. Normal)				
Overweight	1.53 (.84; 2.85)	.169	1.62 (.89; 3.03)	.119
Obese	2.12 (1.07; 4.22)	.031	2.24 (1.13; 4.47)	.021
Cardiovascular disease (ref. No)				
Yes	1.02 (.60; 1.75)	.933	.98 (.58; 1.69)	.955
Respiratory disease (ref. No)				
Yes	1.06 (.31; 2.66)	.915	1.05 (.31; 2.65)	.920
Diabetes (ref. No)				
Yes	1.34 (.62; 2.62)	.421	1.21 (.56; 2.39)	.589
Cancer (ref. No)				
Yes	.96 (.23; 2.67)	.944	.90 (.22; 2.53)	.865
Rheumatoid arthritis (ref. No)				
Yes	.99 (.37; 2.18)	.973	.89 (.33; 1.99)	.801
Chronic kidney disease (ref. No)				
Yes	.87 (.05; 4.22)	.891	.88 (.05; 4.27)	.899
Muscle strength			.65 (.44; .96)	.029

Table S3. Cumulative proportion of COVID-19 cases

Country	**Date***	**Cumulative cases**[a]	**Cumulative hospitalizations**	**Country population size in 2020** (rounded in millions)[b]	**Proportion** (cumulative case / pop size)	**Proportion** (cumulative hospitalization / pop size)
Belgium	15 July	65368	19663	11.6	0.564%	0.169%
Bulgaria	21 July	9348	NA	6.9	0.135%	NA
Croatia**	15 July	4356	601	4.1	0.106%	0.015%
Cyprus	15 July	1046	179	1.2	0.087%	0.015%
Czech Republic	8 July	12898	4361	10.7	0.121%	0.041%
Denmark	10 July	13189	2646	5.8	0.227%	0.046%
Estonia	8 July	2036	435	1.3	0.157%	0.033%
Finland	10 July	7342	NA	5.5	0.133%	NA
France	7 July	197224	95726	65.3	0.302%	0.147%
Germany	15 July	202132	23645	83.8	0.241%	0.028%
Greece	12 July	3810	NA	10.4	0.037%	NA
Hungary	15 July	4426	NA	9.7	0.046%	NA
Israel	4 July	29870	4263	8.7	0.343%	0.049%
Italy	5 July	246845	88123	60.5	0.408%	0.146%
Latvia	15 July	1215	191	1.9	0.064%	0.010%
Lithuania	7 July	2184	454	2.7	0.081%	0.017%
Luxembourg	15 July	4493	NA	0.6	0.749%	NA
Malta	15 July	633	47	0.4	0.158%	0.012%
Netherlands	10 July	51481	NA	17.1	0.301%	NA
Poland	8 July	37054	NA	37.8	0.098%	NA
Portugal	11 July	46234	4809	10.2	0.453%	0.047%
Romania	9 July	31223	17023	19.2	0.163%	0.089%
Slovakia	7 July	1816	NA	5.5	0.033%	NA
Slovenia	9 July	1782	379	2.1	0.085%	0.018%
Spain	10 July	257675	110718	46.8	0.551%	0.237%
Sweden	15 July	77909	NA	10.1	0.771%	NA
Switzerland	15 July	33913	4104	8.7	0.390%	0.047%
	Total:	1347502	377367	448.6	0.300%	0.084%

Note. [a]"COVID-19 Daily Epidemic Forecasting", by the Institute of Global Health, of the University of Geneva and the Swiss Data Science Center, ETH Zürich-EPFL. [b]United Nations Population Fund [c] Our World in Data (based on weekly numbers). *The date was selected to fall around the middle of the data collection period of the country; **Hospitalization data started in May 2020 (no hospitalization data were available before this period).

Table S4. Results based on the rare-events logistic regression with a tau parameter of 84/100,000

	Model 1 (without muscle strength)		Model 2 (with muscle strength)	
Variables	OR (95% CI)	*p*-value	OR (95% CI)	*p*-value
Intercept	5.6E-4 (3.3E-4; 9.7E-4)	<.001	4.4E-4 (2.5E-4; 8.0E-4)	<.001
Age	1.71(1.26; 2.31)	<.001	1.50 (1.10; 2.05)	.011
Sex (ref. Female)				
Male	.80 (.42; 1.50)	.482	1.30 (.64; 2.64)	.463
Height	1.30 (.96; 1.76)	.086	1.47 (1.06; 2.03)	.021
Body mass index (ref. Normal)				
Overweight	1.44 (.84; 2.47)	.182	1.54 (.90; 2.62)	.113
Obese	2.00 (1.09; 3.68)	.026	2.10 (1.15; 3.85)	.016
Cardiovascular disease (ref. No)				
Yes	1.05 (.65; 1.69)	.841	1.02 (.63; 1.63)	.946
Respiratory disease (ref. No)				
Yes	1.63 (.77; 3.46)	.202	1.63 (.77; 3.45)	.205
Diabetes (ref. No)				
Yes	1.23 (.63; 2.40)	.547	1.13 (.58; 2.18)	.724
Cancer (ref. No)				
Yes	.76 (.22; 2.59)	.656	.70 (.20; 2.44)	.578
Rheumatoid arthritis (ref. No)				
Yes	1.21 (.61; 2.38)	.591	1.11 (.56; 2.19)	.756
Chronic kidney disease (ref. No)				
Yes	2.70 (.92; 7.97)	.072	2.65 (.91; 7.75)	.075
Muscle strength			.63 (.43; .92)	.016

Table S5. Results in COVID-19 patients (N = 289)

	Model 1 (without muscle strength)		Model 2 (with muscle strength)	
Variables	OR (95% CI)	*p*-value	OR (95% CI)	*p*-value
Intercept	.15 (.07; .28)	<.001	.11 (.05; .22)	<.001
Age	1.72 (1.27; 2.36)	<.001	1.50 (1.08; 2.10)	.015
Sex (ref. Female)				
Male	.77 (.33; 1.76)	.537	1.55 (.54; 4.42)	.410
Height	1.33 (.88; 2.04)	.181	1.48 (.96; 2.30)	.074
Body mass index (ref. Normal)				
Overweight	1.80 (.88; 3.77)	.111	1.83 (.89; 3.86)	.103
Obese	1.49 (.63; 3.50)	.357	1.50 (.63; 3.57)	.353
Cardiovascular disease (ref. No)				
Yes	1.27 (.65; 2.52)	.479	1.14 (.57; 2.28)	.716
Respiratory disease (ref. No)				
Yes	1.16 (.33; 3.49)	.805	.97 (.28; 2.98)	.963
Diabetes (ref. No)				
Yes	.87 (.31; 2.21)	.782	.73 (.25; 1.91)	.541
Cancer (ref. No)				
Yes	1.02 (.14; 4.64)	.982	.96 (.13; 4.41)	.964
Rheumatoid arthritis (ref. No)				
Yes	1.10 (.40; 2.79)	.849	.97 (.35; 2.49)	.950
Chronic kidney disease (ref. No)				
Yes	1.35 (.25; 6.15)	.707	.94 (.17; 4.45)	.936
Muscle strength			.56 (.33; .94)	.031