Quadriceps muscle strength is a discriminant predictor of dependence in daily activities in nursing home residents

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Abstract

Objective

This study aimed to explore the relationship between dependence in Activities of Daily Living and muscle strength, muscle morphology and physical function in older nursing home residents, taking possible confounders into consideration.

Methods

A total of 30 nursing home residents (age, 85.6±7.1 years) were included in this observational cross-sectional study. Performance of basic Activities of Daily Living (ADL) was assessed with the Resident Assessment Instrument and categorized as either independent or dependent. Isometric grip, quadriceps and elbow-flexor strength were determined by hand-dynamometry, muscle thickness and echo intensity by B-mode ultrasonography, a sit-to-stand task by using a stop watch and physical activity by the German-Physical-Activity Questionnaire. Degree of frailty was evaluated according to Fried’s frailty criteria, whereas cognition, depression, incontinence, pain and falls were part of the Resident Assessment Instrument.

Results

Dependence in Activities of Daily Living was negatively correlated with physical activity (r = -0.44, p = .015), handgrip (r = -0.38, p = .038), elbow-flexor (r = -0.42, p = .032) and quadriceps strength (r = -0.67, p < .001), analysed by Spearman’s correlation. Chronic diseases (r = -0.41, p = .027) and incontinence (r = -0.39, p = .037) were positively correlated with ADL while the other variables were not related. Only quadriceps strength remained significant with logistic regression (Wald(1) = 4.7, p = .03), when chronic diseases, quadriceps and handgrip strength were considered (R² .79). 11 kg was the best fitting value in this
sample to predict performance in Activities of Daily Living, evaluated with Receiver-Operating Characteristic analysis, with a sensitivity of 100% and a specificity of 79%.

**Conclusion and implication**

Quadriceps strength had a positive independent relationship with performance in ADL in the nursing home residents studied. Although a large prospective study is needed to verify the results, maintaining quadriceps strength above 11 kg may be helpful in retaining independence in this cohort.

**Introduction**

In 2017, 15.7% of the Swiss population aged 80 years and over were institutionalized [1]. The demand for long-term care is expected to expand [2] since life expectancy will continue to increase in industrialized countries [3], with an expected rise of the old-old population by 300% in 2050 [4]. Admission of older persons to nursing homes is dependent on cognitive and/or functional impairment in combination with a lack of assistance in daily home life, which often leads to dependence in activities of daily living (ADL) [5]. In 30–50% of these people, dependence actually increases within the first 18 months of institutionalization due to further functional decline [6, 7], which adversely affects quality of life [8] and health care costs [7]. Prevention of physical decline in nursing home residents is, therefore, essential to maintain a certain amount of independence, with beneficial effects for the individual as well as for the health care system.

The ability of nursing home residents to perform ADL independently is associated with multiple factors, both modifiable and non-modifiable, but is mainly dependent on age, chronic disease and disability, with the latter factor being the most discriminant predictor [9]. Physical disability in old age is highly associated with low muscle strength, which decreases progressively due to an age-related decline in muscle mass and quality [10]. Muscle strength is reduced by up to 50% in people aged 80 years and over [11], with highest rates of loss in physically inactive individuals [12, 13] that are institutionalized in nursing homes [14].

Previous studies involving community dwelling older people have shown the relevance of quadriceps strength for e.g. independent performance of sit-to-stand tasks [15, 16] and the effortless execution of ADL [15, 17]. In older people in need of long-term care, only a few studies investigated whether quadriceps strength relates to the level of required care and findings were inconclusive [18–20]. A positive association between quadriceps strength and ADL performance was confirmed by intervention studies that have shown training to be effective in improving physical function even in non-healthy, non-robust, ADL-dependent older adults suffering from disuse-related muscle weakness [21–26]. However, the optimal program remains unclear [23]. Therefore, specifying the underlying physical determinants of dependence in basic ADL of institutionalized older adults would help to determine the most important component of a specific training program.

In the present study, we aimed to investigate whether muscle structure, strength, function or physical activity were predictive variables of dependence in ADL in nursing home residents, when accounting for cognition, depression, falls, incontinence, chronic disease, sedative medication and pain.
Methods

Study design

A cross-sectional study of muscle characteristics and physical function of nursing home residents was undertaken in a long-term care institution in Switzerland between August and December 2017. Recruitment targeted older adults, aged 65 years and over. Exclusion criteria were a) an inability to understand study content and provide signed informed consent; b) severely impaired decision making (Cognitive performance scale > 4 points) [27]; c) a history of acute lower limb pathology (fracture and/or surgery within the last 6 months); d) skin disorders involving the anterior thigh and/or arm; e) limb paralysis; and f) confinement to bed.

Nursing home residents were screened by the senior nurse for exclusion criteria based on the last RAI assessment. Only participants who were deemed competent to consent and voluntarily agreed to participate were considered for study inclusion. All study procedures complied with the principles of the Declaration of Helsinki for ethical research in humans and the study received approval from the local ethics committee (project-ID 2017-00839).

Details are presented in the following report, which adheres to the reporting guidelines for cross-sectional studies [28].

Sample size

Sample size was calculated a priori using published data for quadriceps strength in nursing home residents [20]. A total sample size of 19 participants was required to ensure sufficient statistical power ($\beta = 0.2$) to detect a 25% difference in strength between ADL independent and dependent groups ($\alpha = .05$). It has been previously shown that disabled older adults, as defined by self-reported independence in basic and instrumental ADL, exhibit up to 50% lower muscle strength than non-disabled individuals [17].

Data collection

Participant demographics. Participant demographics, medications history, medical history and independence in ADL were obtained using the Long-Term Care Facility Resident Assessment Instrument (RAI; Minimum Data Set Version 2.0). For assessment of ADL, urinary incontinence, cognitive performance and depressive symptoms, observations were judged and encoded by one of four nurses who were experienced RAI-item coders. All nurses had received the same training on the use of the tool in its application. Detailed RAI items are shown in Table 1.

One investigator, a physiotherapist, trained and experienced in musculoskeletal assessments and ultrasonography, completed the following test series for all participants.

Muscle strength. Maximal isometric quadriceps and elbow-flexor muscle strength, as the highest of two trials, was evaluated using a hand-held dynamometer (Microfet2<sup>®</sup>, CompuFET, Hoggan Health Industries, Biometrics Europe). For measurement of elbow-flexor strength, the participant was seated on a chair, elbow flexed at 90˚ and forearm supinated. For measurement of quadriceps strength, the participant was seated on a plinth, with their back resting against a firm support, thighs fully supported, knees flexed to 90˚ and the lower legs hanging freely. The curved transducer pad of a hand-held dynamometer was positioned at 80% of the forearm and tibial length respectively, to resist maximal isometric force of the elbow flexors and quadriceps. The participants were asked to push against the dynamometer as hard as possible for 3 seconds. Strength was measured in Newtons (N), and converted into Kilograms (kg) by dividing N by 9.81. Torque was calculated in Newtonmeters (Nm) by multiplying force by the lever arm length of the forearm and tibia respectively. Hand-held dynamometry has been shown to
be a valid and reliable technique to assess isometric strength in older adults [29, 30]. Test-retest reliability of hand-held dynamometry is high when assessed by a trained examiner using a standardized protocol [31]; with intra-rater reliability Intraclass Correlation Coefficient (ICC) ranging between 0.90 and 0.98 [29].

Handgrip strength was measured with a hand dynamometer (Jamar ®, Lafayette, USA) according to the standardized protocol recommended by the American Society of hand therapists [32].

Muscle morphology. Real-time, B-mode ultrasonography (Nemio MX Type SSA-590A, Toshiba, Japan) with a 12 MHz linear transducer array (45 mm footprint) was used to obtain transverse images of the dominant extremities. Images of the rectus femoris/vastus intermedius as well as the biceps brachii/brachialis were taken using a previously published protocol for community-dwelling older adults [33, 34], and post-processed using semi-automated MATLAB code (MathWorks ®, Massachusetts, USA). Muscle thickness and primary muscle echotexture statistics were subsequently calculated, with the mean of two images taken for further analysis.

The thickness of the muscles was defined as the distance between the inner border of the fascial layer that distinguishes muscles from superficial fat and bone. Ultrasound-based measures of thigh tissue thickness are highly correlated with the gold standard of Magnetic Resonance Imaging ($r = 0.99$) [35] and have a reported intra-rater reliability of ICC 0.88-.099 in older people [33, 36].

For grayscale analysis, settings of the ultrasound scanner (gain, time gain control, dynamic range value, focus and power) were adjusted to assure good quality of the images and kept constant for all participants; depth was readjusted to individual muscle thickness. Echogenicity of rectus femoris and biceps brachii was defined as the average grayscale within a rectangular region of interest and recorded as unspecified units (UU) 0–255. The analysis method has

| RAI items                                      | Units and classification                                      |
|-----------------------------------------------|---------------------------------------------------------------|
| age                                           | years                                                        |
| height                                        | meters                                                       |
| weight                                        | kilogram                                                     |
| urinary continence                            | 4-point-scale from 0 (= continent) to 4 (= always incontinent, no bladder control) |
| pain intensity                                | Numeric Analog Scale from 0 (= no pain) to 10 (= worst pain)  |
| falls                                         | frequency within last three months                           |
| cognitive performance                         | Minimum Data Set Cognitive Performance Scale (scale ranging from 0 (= intact cognition) to 6 (= severely limited cognition) |
| frequency of depressive symptoms              | scale from 0 (symptoms weren’t shown) to 2 (symptoms shown on 6/7 days/week) |
| amount and type of chronic diseases           | metabolic, musculoskeletal, neurological, psychiatric, respiratory disease, renal insufficiency, vertigo and cancer |
| regular intake of medication                  | antidepressants, sedatives and muscle relaxants              |
| self-performance in activities of daily living (ADL) | bed mobility, transfer, walking in a room, walking in a corridor, locomotion on the ward, locomotion outside the ward, dressing, eating/drinking, toilet use and personal hygiene over the past 7 days, each rated on a scale from 0 (independent) to 4 (fully dependent), full range of possible outcome 0–40. Categorization as independent in ADL when total score = 0, which reflected no need for assistance or staff oversight. Categorization as dependent when total score $\geq 1$, which reflected a need for assistance or staff oversight in at least one activity |

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been previously shown to have high intra-rater reliability, with a reported ICC of 0.97–0.99 [37]. High muscle echo intensity is associated with low tissue density in CT scans [38] and high adipose tissue content in muscle biopsies [39].

**Functional mobility.** Functional mobility was estimated using the sit-to-stand task repeated 5 times [40]. A chair with a straight backrest, 40 cm seat height and without armrests was placed against a solid support. Participants were instructed to complete 5 sit-to-stand maneuvers as fast as possible without the use of their arms. The time taken for completion was recorded. Times in excess of 13.6 seconds are associated with increased disability [41].

**Physical activity.** The German physical activity 50+ questionnaire was used to calculate energy expenditure (kcal/week) [42]. The questionnaire has a test-retest reliability of $r = 0.52–0.6$ [42] and is widely used in German speaking countries to evaluate physical activity in older people.

**Frailty.** Physical frailty was evaluated according to Fried’s frailty criteria [43]. Participants were characterized as “not frail”, “pre-frail” or “frail” according to the number of positive criteria identified (0, 1–2 and $\geq 3$, respectively).

### Statistical analysis

The Statistical Package for the Social Sciences (SPSS Statistics, Version 23.0. IBM Corporation, Armonk, NY) was used for analysis. Shapiro-Wilk test was used to test for normality. Dependent on data distribution, descriptive statistics are presented as mean ± standard deviation or median (range); differences between the ADL groups were analyzed using independent t-tests and Mann-Whitney-U-test. Relationships of ADL performance with independent variables were identified by Spearman’s correlation coefficients and binary logistic regression analysis. Receiver-Operating Characteristic (ROC) curve was utilized for sensitivity/specificity analysis of predictors of ADL performance.

### Results

#### Characteristics of study population

Of 177 nursing home residents who were screened, 30 fulfilled the eligibility criteria and were included in the study (mean age (SD) 85.7 (7.1) years, 76.7% female). 43% of the study sample were categorized as pre-frail, 57% as frail, 97% had $\geq$ two chronic diseases, 30% experienced depressive symptoms, 20% took sedative medication, 62% were cognitively impaired, while 70% were diagnosed with dementia, 23% had fallen, 34% experienced pain and 28% were incontinent. Four participants were excluded from strength measurements due to concerns associated with the risk of osteoporotic fracture and 14 were incapable of rising from a chair without using their arms. Given that only half of the participants could rise from a chair 5 times without using their arms, functional mobility was dichotomized into the categories “able to complete 5STS” and “unable to complete 5STS” for further analysis.

Of the 30 participants, 16 were categorized as independent and 14 as dependent in ADL based on items of the RAI. There were no statistically significant differences between groups in terms of age, weight, height, number of years institutionalized, medication history, as well as for muscle morphology, functional mobility and physical activity. The group dependent in ADL experienced a significantly higher number of chronic diseases and more severe incontinence, lower handgrip, elbow-flexor and quadriceps strength. Quadriceps strength of participants independent in ADL was greater by a median of 4.3 kg than those dependent in ADL (Fig 1).

Characteristics of participants are presented in Table 2.
Quadriceps strength, in the present study, was not related to body weight. Therefore, actual strength values in kg were used for analysis. To aid comparison with previous research, quadriceps strength was also expressed as a ratio of strength \([\text{N}/\text{body weight (kg)}]\).

Of the group that was independent in ADL (n = 16), 9 participants could complete the 5STS, while 7 could not. Of the group that was dependent in ADL (n = 14), 5 participants could complete the 5STS, while 9 were not able to complete the 5STS.

**Correlations of ADL category with demographics, medical and medications history**

The level of ADL dependence significantly correlated with a higher number of comorbidities \((r_s = .41, p = .027)\) and incontinence \((r_s = .39, p = .037)\), but was not associated with sex, age, falls, cognitive performance, sedative medication, depressive mood, pain or physical frailty at the univariate level (S1 Appendix).

**Correlations of ADL category with muscle strength, muscle morphology, functional mobility and physical activity**

Dependence in ADL was weakly associated with lower handgrip strength \((r_s = -0.38, p = .038)\), lower elbow-flexor strength \((r_s = -0.42, p = .032)\) and lower physical activity \((r_s = -0.44, p = .015)\) but moderately correlated with lower quadriceps strength \((r_s = -0.67, p < .001)\). There
was no correlation of ADL dependence with muscle morphology and functional mobility/the ability to rise from a chair 5 times (S2 Appendix).

**Regression and ROC analysis**

To determine factors that were predictive of ADL performance, binary logistic regression was undertaken iteratively using different combinations of covariates, including the factor with the highest correlation with ADL (quadriceps strength) and factors that were moderately correlated with ADL (handgrip strength, elbow-flexor strength, urinary incontinence and number of chronic diseases) at the univariate level (S1 and S2 Appendices).

The combination of variables that best explained the variance in ADL performance included quadriceps strength, chronic diseases and handgrip strength (S3 Appendix). Approximately 79% of the variance was explained by these three factors (Nagelkerke’s $R^2 = 0.786$).

However, quadriceps strength was the only independent predictor of dependence with an

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Table 2. Participants’ characteristics of the ADL dependent and independent group.

| Characteristic (unit) | ADL independent | ADL dependent | equality of means/medians |
|-----------------------|-----------------|---------------|--------------------------|
|                       | Mean (SD)/Median (range) | Mean (SD)/Median (range) | t/U | p
| **Demographics**      |                 |               |                          |
| Age† (years)          | 87.0 (15)       | 86.0 (35)     | U = 100.5                | .64 |
| Weight† (kg)          | 66.5 (52.2)     | 68.0 (51)     | U = 98.0                 | .58 |
| Height† (m)           | 1.64 (0.23)     | 1.59 (0.21)   | U = 80.5                 | .19 |
| Incontinence (0–4 points) | 0 (1)         | 0 (4)         | U = 68                   | .038* |
| Pain intensity (0–10) | 0.53 (0.74)     | 0.64 (1.60)   | t(18.1) = -.234          | .82 |
| Falls (number)        | 0.63 (1.63)     | 0.29 (0.47)   | t(17.8) = .797           | .44 |
| Cognitive performance (0–6) | 1.0 (3)      | 2.0 (3)       | U = 79                   | .24 |
| Depressive symptoms (0–32) | 1.62 (3.95)   | 0.71 (1.27)   | t(25) = 0.815            | .42 |
| Chronic diseases (number) | 2.75 (1.24)   | 3.86 (1.29)   | t(27.1) = -2.387         | .024* |
| Medication (number)   | 0.81 (0.40)     | 0.79 (0.43)   | U(27.0) = .176           | .86 |
| Institutionalization (years) | 2.9 (2.2)    | 3.4 (1.8)     | t(27.8) = -.572          | .57 |
| **Muscle strength**   |                 |               |                          |
| Handgrip strength† (kg) | 16.0 (22)      | 13.3 (13)     | U = 63.0                 | .043* |
| Quadriceps strength† (kg) | 13.1 (5.7)    | 8.8 (6.9)     | U = 18.5                 | <.001* |
| Quadriceps strength† (N) | 128.2 (56.4)  | 85.4 (63.3)   | U = 18.5                 | <.001* |
| Strength/body weight (N/kg) | 2.1 (0.7)     | 1.4 (0.4)     | t(16.7) = 2.797          | .013* |
| Quadriceps torque† (N/m) | 39.1 (18.8)   | 26.8 (20.3)   | U = 20                   | .001* |
| Torque/body weight (N/m/kg) | 0.6 (0.2)    | 0.4 (0.1)     | t(16.9) = 2.763          | .013* |
| Elbow-flexor strength† (kg) | 9.7 (7.3)     | 7.0 (9.5)     | U = 43.0                 | .036* |
| **Muscle morphology** |                 |               |                          |
| Quadriceps thickness (mm) | 17.7 (4.7)    | 18.7 (6.7)    | t(28) = -.465            | .65 |
| Rectus femoris grayscale† (UU) | 117.2 (78)   | 115.5 (101)   | U = 109.0                | .92 |
| Elbow-flexor thickness† (mm) | 24.8 (18)    | 26.5 (16)     | U = 111                  | .98 |
| Biceps brachii grayscale† (UU) | 132 (81)     | 133 (86)      | U = 111                  | .98 |
| **Functional mobility** |                 |               |                          |
| 5 sit-to-stand (sec)   | 20.3 (11.6)    | 20.6 (12.3)   | t(8.0) = -.051           | .96 |
| Physical activity (kcal/week) | 842 (879)    | 508 (1347)    | t(21.9) = .792           | .44 |

* significant difference
† data not normally distributed, differences determined with the Mann-Whitney-U test, p equates exact significance

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Odds Ratio (OR) of 0.353 (95% CI 0.138–0.905, p = .030), indicating a 65% lower risk of being dependent when quadriceps strength increased by 1 kg (Table 3).

The ROC curve for analysis of sensitivity and specificity of quadriceps strength to identify people independent and dependent in ADL showed an area under the curve of 0.89. Strength of 11.25 kg was the best fitting value with a sensitivity of 100% and a specificity of 79%. Sensitivity and specificity of quadriceps strength values are shown in Table 4.

**Discussion**

This study aimed to evaluate potential muscle-related predictors of dependence in ADL in nursing homes residents, taking cognitive function, depression, pain, urinary incontinence, chronic diseases, medication and falls into consideration.

### Table 3. Binary logistic regression with inclusion analysis of the variables quadriceps strength, chronic diseases and physical activity.

| predictor         | Regression coefficient (B) | Significance level (p) | Exp(B) = OR | 95% CI for Exp(B) |
|-------------------|-----------------------------|------------------------|-------------|-------------------|
| quadriceps strength | -1.040                      | .030                   | 0.353       | 0.138–0.905       |
| chronic diseases  | 1.325                       | .074                   | 3.763       | 0.877–16.139      |
| handgrip strength | -0.213                      | .390                   | 0.809       | 0.498–1.313       |
| constant          | 10.863                      | .067                   | 52183.975   |                   |

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### Table 4. Coordinates of ROC curve analysis for accuracy of quadriceps strength in detecting residents of nursing homes dependent in ADL.

| Quadriceps strength (kg) greater than or equal to | Sensitivity | 1-specificity |
|---------------------------------------------------|-------------|---------------|
| 5.800                                             | 1.000       | 1.000         |
| 7.000                                             | 1.000       | .929          |
| 7.350                                             | 1.000       | .857          |
| 7.550                                             | 1.000       | .786          |
| 7.900                                             | 1.000       | .643          |
| 8.450                                             | 1.000       | .571          |
| 8.750                                             | 1.000       | .500          |
| 9.300                                             | 1.000       | .429          |
| 10.150                                            | 1.000       | .357          |
| 10.600                                            | 1.000       | .286          |
| 11.250                                            | 1.000       | .214          |
| 11.950                                            | .833        | .214          |
| 12.150                                            | .750        | .214          |
| 12.300                                            | .667        | .214          |
| 12.550                                            | .583        | .214          |
| 12.850                                            | .583        | .143          |
| 13.100                                            | .500        | .071          |
| 13.350                                            | .417        | .071          |
| 13.600                                            | .333        | .071          |
| 13.900                                            | .333        | 0.000         |
| 14.950                                            | .250        | 0.000         |
| 16.650                                            | .083        | 0.000         |
| 18.500                                            | 0.000       | 0.000         |

‡ Best fitting quadriceps strength value to detect dependent/independent performance of ADL

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Odds Ratio (OR) of 0.353 (95% CI 0.138–0.905, p = .030), indicating a 65% lower risk of being dependent when quadriceps strength increased by 1 kg (Table 3).

The ROC curve for analysis of sensitivity and specificity of quadriceps strength to identify people independent and dependent in ADL showed an area under the curve of 0.89. Strength of 11.25 kg was the best fitting value with a sensitivity of 100% and a specificity of 79%. Sensitivity and specificity of quadriceps strength values are shown in Table 4.
Of the investigated parameters, greater handgrip-strength, elbow-flexor strength, quadriceps strength and physical activity, as well as less incontinence and chronic diseases, were positively associated with the ability to independently perform basic ADL whereas quadriceps strength was the only independent predictor.

The positive relationship observed between quadriceps strength and ADL performance is consistent with a previous study in which functional performance was evaluated in older people with dementia in need of long-term care [20]. ADL-independent participants in their study had 40–45% higher strength than ADL-dependent, while ours differed by about 33%. Suzuki and colleagues specifically included people diagnosed with dementia, whereas the present study also included participants without dementia and of different cognitive performance levels. Interestingly, neither quadriceps strength nor ADL dependence was related to cognitive performance in our population. This is opposed to previously reported findings [44] and might be due to the small size of our sample.

The present findings do not correspond with other studies in which the level of care was observed to be independent of quadriceps strength in old, physically disabled people [18, 19]. These earlier studies differed in regard to the assessment instrument (care time [19], respectively a non-specified instrument [18] versus RAI), included ADL (basic and instrumental ADL [19] respectively non-specified assessment [18] versus basic ADL) and categorization of ADL performance (3-point scale [18, 19] versus dichotomous classification). However, the main difference is potentially the type of ADL on which the categorization is based. In contrast to most basic activities, many instrumental ADL, such as the regulation of finances and telephone use, do not require appreciable quadriceps strength. Hence, it could be expected that when ADL dependence is categorized on the basis of instrumental activities, it is unlikely to be correlated with quadriceps strength.

Consequently, the present study adds the following new information to previous findings: 1. the relationship between low quadriceps strength and ADL dependence may be valid for residents in nursing homes independent of cognitive performance; 2. quadriceps strength not only has a significant relation to dependence in basic ADL but also has a strong independent association with ADL dependence regardless of muscle structure, muscle function, physical activity and important confounding factors of demographics, medical and medication history.

It is an interesting outcome that low quadriceps strength but not low muscle thickness or high echo intensity was associated with ADL dependence. One possible explanation for this finding could be that a decline in motor cortical properties rather than changes in muscle morphology accounted for low voluntary strength in our population. Muscle weakness associated with aging has diverse underlying mechanisms and is not solely explained by atrophy of muscle [45]. The nervous system’s overall ability to maximally activate a muscle, including descending drive from the motor cortex, also declines with age and significantly contributes to decreased voluntary contraction of available musculature [46]. Particularly in older-old individuals, voluntary activation, defined as “the level of voluntary drive during an effort” [47, 48] is diminished [49–51] and may account for up to one third of the loss in force production [52].

Furthermore, it seems contradictory that an older person may have adequate quadriceps strength to rise from a chair independently but is not able to complete the repeated sit-to-stand exercise (5STS). However, while poor performance on the STS test (>10–13 seconds) has been shown to predict incidence of disability in older community-living older adults [40, 53], its sensitivity is limited (50%) and its clinical use could be largely restricted to high functioning, community-living older people [54]. Quadriceps strength is one important underlying precondition of the ability to stand up from a chair [55], however, it is not the only determinant. In most elderly nursing home residents the ability to rise from a standard-height chair is also dependent on the use of arms and arm rests [56] and, when not constrained by artificially
imposed time limits, may still be performed independently. Completion of the 5STS test, in comparison, requires more complex abilities, as it is performed without the use of arms and is timed. Hence, the 5STS test needs coordinated contraction and high contraction speed (power) of multiple lower extremity muscles, including the gluteal and ankle dorsiflexor muscles [57–59]. Secondly, successful completion of 5STS also requires balance, proprioception and tactile sensation [58], all of which also decrease with age and disease. Thirdly, voluntary functional strength in older people might be mainly explained by reduced voluntary activation due to changes in central and peripheral nervous systems [46]. The functional mobility task of 5STS with its physical requirements, therefore, may not reflect the abilities necessary to live an ADL independent, nursing home life. Rather, quadriceps strength would appear to be a better predictor of ADL disability than the 5STS test in this population of lesser functioning older people.

An isometric quadriceps strength of > 11 kg predicted ADL-independence by 100% and ADL-dependence by 79% in this study sample. The findings show that quadriceps strength was of high importance for explaining the variance in ADL performance; an improvement of 1 kg lowers the risk of becoming dependent by 65%. Intervventional studies have shown that exercise programs of 8–12 weeks, including resistance exercises 2–3 times weekly, were effective in increasing quadriceps strength in older, nursing home residents by a minimum of 3 kg [18, 22]. Thus, nursing home residents with physical disability may be able to improve ADL independence through quadriceps strengthening. This finding supports the call for preventive measures to avoid functional decline in nursing home dwellers [7].

Previous research has established that quadriceps strength differs significantly in community living older people independent in ADL (3.5–3.8 N/kg) from those partially dependent (2.2–2.9 N/kg) [15], when independence is considered as being able to e.g. walk 50 m without any personal or device support and without loss of normal speed and safety. In comparison, the present study showed that frail, disabled, nursing home residents of the same age were only half as strong, with the independent group having a median strength of 2.1 N/kg, compared to the ADL dependent group with median strength of 1.4 N/kg. However, approximately half of the participants could still perform usual nursing-home ADL, such as walking a few meters with a walker and rising from a chair with the use of arm rests, without supervision or assistance of another person.

Some limitations of this cross-sectional study should be mentioned. Firstly, observations of behavior and emotions by nursing staff entailed the risk that some actions of the participants could have been unrecognized and therefore not recorded adequately. However, the observation period included seven days in which residents were closely observed by a trained nurse attentive to precise assessment. Therefore, the risk of information bias was likely to be small. Even though RAI data were obtained by different assessors, data can still be assumed sufficiently reliable since inter-rater reliability of the RAI items has been shown to be 0.63–0.92 (weighted Kappa) [60]. Secondly, physical activity measures were based on self-report and behavioral observations of nursing staff. Although previous studies have questioned the accuracy of self-reported measures of physical activity in older populations [61], participants were closely monitored during the study so that any discrepancy between reported and actual activity was likely to be small. Thirdly, the number of participants who could complete the timed sit-to-stand task was rather small. Findings with regard to this variable could therefore be underpowered. However, even when the participants were categorized into two groups depending on their ability to complete the task, results did not change. Therefore, the results were assumed to be valid for this cohort. Fourthly, a causal relationship between ADL performance and quadriceps strength cannot be made due to the nature of the cross-sectional study design. However, the results indicate a strong association between ADL dependence and low
quadriceps strength and longitudinal studies have demonstrated beneficial effects of quadriceps' strength training on physical function [21–26]. Fifthly, the study sample only included participants from one nursing home. Therefore, the results of the sample might not be generalizable to a wider population of older, frail nursing home residents. The study did, however, include a wide variety of participants with regard to ADL performance. Therefore, the participants could be considered representative of the target population.

Conclusions
This study has shown that strength, physical activity and incontinence were potentially modifiable factors associated with ADL dependence in nursing home residents, with quadriceps strength being the only independent predictor of dependence in ADL, independent of age, frailty status, co-morbidities and cognitive function. Although further research is required, interventions aimed at increasing these physical abilities with a specific focus on enhancing leg muscle strength beyond target threshold values may be a useful strategy for reducing dependence in ADL of nursing home dwellers.

Supporting information
S1 Appendix. Correlations of ADL category with demographics. (DOCX)
S2 Appendix. Correlations of ADL category with muscle-related parameter. (DOCX)
S3 Appendix. Binary logistic regression. (DOCX)
S4 Appendix. STROBE statement—Checklist. (DOCX)

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References
1. bfs. Gesundheit im Alter https://www.bfs.admin.ch/bfs/de/home/statistiken/gesundheit/gesundheitszustand/alter.html: Bundesamt für Statistik; 2017 [cited 2019 January 21].
2. Crimmins EM. Lifespan and Healthspan: Past, Present, and Promise. Gerontologist. 2015; 55(6):901–11. https://doi.org/10.1093/geronj/gnv130 PMID: 26561272.
3. Kontis V, Bennett JE, Mathers CD, Li G, Foreman K, Ezzati M. Future life expectancy in 35 industrialised countries: projections with a Bayesian model ensemble. Lancet. 2017; 389(10076):1323–35. https://doi.org/10.1016/S0140-6736(16)32381-9 PMID: 28236464.
4. United Nations DoEaSA. World Population Ageing2017 January 21, 2019:[2–42 pp.].
5. Luppa M, Luck T, Weyerer S, König HH, Brahler E, Riedel-Heller SG. Prediction of institutionalization in the elderly. A systematic review. Age Ageing. 2010; 39(1):31–8. https://doi.org/10.1093/ageing/afp202 PMID: 19934075.
6. Jerez-Roig J, de Brito Macedo Ferreira LM, Torres de Araujo JR, Costa Lima K. Functional decline in nursing home residents: A prognostic study. PLoS One. 2017; 12(5):e0177353 (1–14). https://doi.org/10.1371/journal.pone.0177353 PMCID: 28493946.
7. Laffon de Mazieres C, Morley JE, Levy C, Agnes F, Barbagallo M, Cesarì M, et al. Prevention of Functional Decline by Reframing the Role of Nursing Homes? J Am Med Dir Assoc. 2017; 18(2):105–10. https://doi.org/10.1016/j.jamda.2016.11.019 PMID: 28126135.
8. Volkers KM, de Kieviert JF, Wittingen HP, Scherder EJ. Lower limb muscle strength (LLMS): why sedentary life should never start? A review. Arch Gerontol Geriatr. 2012; 54(3):399–414. https://doi.org/10.1016/j.archger.2011.04.018 PMID: 21601928.
9. Shen Y, Chen J, Chen X, Hou L, Lin Y, Yang M. Prevalence and Associated Factors of Sarcopenia in Nursing Home Residents: A Systematic Review and Meta-analysis. J Am Med Dir Assoc. 2019; 20 (1):5–13. https://doi.org/10.1016/j.jamda.2018.09.012 PMID: 30409494.
10. Azegami M, Ohira M, Miyoshi K, Kobayashi C, Hongo M, Yanagihashi R, et al. Effect of single and multi-joint lower extremity muscle strength on the functional capacity and ADL/IADL status in Japanese community-dwelling older adults. Nurs Health Sci. 2007; 9(3):168–76. https://doi.org/10.1111/j.1442-2018.2007.00317.x PMID: 17686474.
21. Aguirre LE, Villareal DT. Physical Exercise as Therapy for Frailty. Nestle Nutr Inst Workshop Ser. 2015; 83:83–92. https://doi.org/10.1159/000382065 PMID: 26524568.

22. Cadore EL, Casas-Herrero A, Zambom-Feraresi F, Idiote F, Millor N, Gomez M, et al. Multicomponent exercises including muscle power training enhance muscle mass, power output, and functional outcomes in institutionalized frail nonagenarians. Age. 2014; 36(2):773–85. https://doi.org/10.1007/s11357-013-9586-z PMID: 24030238.

23. de Labra C, Guimaraes-Pinheiro C, Maseda A, Lorenzo T, Millan-Calenti JC. Effects of physical exercise interventions in frail older adults: a systematic review of randomized controlled trials. BMC Geriatr. 2015; 15:154. https://doi.org/10.1186/s12877-015-0155-4 PMID: 26626157.

24. Krist L, Dimeo F, Keil T. Can progressive resistance training twice a week improve mobility, muscle strength, and quality of life in very elderly nursing-home residents with impaired mobility? A pilot study. Clin Interv Aging. 2013; 8:443–8. https://doi.org/10.2147/CIA.S42136 PMID: 23637524.

25. Arrieta H, Rezola-Parдо C, Gil SM, Irazusta J, Rodriguez-Larrad A. Physical training maintains or improves gait ability in long-term nursing home residents: A systematic review of randomized controlled trials. Maturitas. 2018; 109:45–52. https://doi.org/10.1016/j.maturitas.2017.12.003 PMID: 29452781.

26. Arrieta H, Rezola-Parдо C, Gil SM, Virgala J, Iturburu M, Anton I, et al. Effects of Multicomponent Exercise on Frailty in Long-Term Nursing Homes: A Randomized Controlled Trial. J Am Geriatr Soc. 2019; 67(6):1145 –51. https://doi.org/10.1111/jgs.15824 PMID: 30891748.

27. Morris JN, Fries BE, Mehr DR, Hawes C, Phillips C, Mor V, et al. MDS Cognitive Performance Scale. J Gerontol. 1994; 49(4):M174–82. https://doi.org/10.1093/geronj/49.4.m174 PMID: 8014399.

28. von Elm E, Altman DG, Egger M, Pocock SJ, Gotzsche PC, Vandenbroucke JP, et al. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement: guidelines for reporting observational studies. Int J Surg. 2014; 12(12):1495–9. https://doi.org/10.1016/j.ijsu.2014.07.013 PMID: 25046131.

29. Arnold CM, Warkentin KD, Chilibeck PD, Magnus CR. The reliability and validity of handheld dynamometry for the measurement of lower-extremity muscle strength in older adults. Journal of strength and conditioning research / National Strength & Conditioning Association. 2010; 24(3):815–24. https://doi.org/10.1519/JSC.0b013e3181aa36b8 PMID: 19661831.

30. Stark T, Walker B, Phillips JK, Fejer R, Beck R. Hand-held dynamometry correlation with the gold standard isokinetic dynamometry: a systematic review. PM R. 2011; 3(5):472–9. https://doi.org/10.1016/j.pmrj.2010.10.025 PMID: 21570036.

31. Bohannon RW. Test-retest reliability of hand-held dynamometry during a single session of strength assessment. Physical therapy. 1986; 66(2):206–9. https://doi.org/10.1093/ptj/66.2.206 PMID: 3945674.

32. Shechtman O, Sindhu BS. Grip Strength. In: ASTH, editor. Clinical Assessment Recommendations, 3rd edition2013.

33. Agyapong-Badu S, Warner M, Samuel D, Narici M, Cooper C, Stokes M. Anterior thigh composition measured using ultrasound imaging to quantify relative thickness of muscle and non-contractile tissue: a potential biomarker for musculoskeletal health. Physiological measurement. 2014; 35(10):2165–76. https://doi.org/10.1088/0967-3334/35/10/2165 PMID: 25243984.

34. Delaney S, Worsley P, Warner M, Taylor M, Stokes M. Assessing contractile ability of the quadriceps muscle using ultrasound imaging. Muscle Nerve. 2010; 42(4):530–8. https://doi.org/10.1002/mus.21725 PMID: 20665511.

35. Mechelli F, Arendt-Nielsen L, Stokes M, Agyapong-Badu S. Validity of Ultrasound Imaging Versus Magnetic Resonance Imaging for Measuring Anterior Thigh Muscle, Subcutaneous Fat, and Fascia Thickness. Methods Protoc. 2019; 2(3). https://doi.org/10.3390/mps2030056 PMID: 31295906.

36. Mayans D, Cartwright MS, Walker FO. Neuromuscular ultrasonography: quantifying muscle and nerve measurements. Phys Med Rehabil Clin N Am. 2012; 23(1):133–48, xii. https://doi.org/10.1016/j.pmr.2011.11.009 PMID: 22236880.

37. Harris-Love MO, Seamon BA, Teixeira C, Ismail C. Ultrasound estimates of muscle quality in older adults: reliability and comparison of Photoshop and ImageJ for the grayscale analysis of muscle echogenicity. PeerJ. 2016; 4:e1721. https://doi.org/10.7717/peerj.1721 PMID: 26926339.

38. Siipila S, Suominen H. Muscle ultrasonography and computed tomography in elderly trained and untrained women. Muscle Nerve. 1993; 16(3):294–300. https://doi.org/10.1002/mus.880160305 PMID: 8446128.

39. Reimers K, Reimers CD, Wagner S, Paetzke I, Pongratz DE. Skeletal muscle sonography: a correlative study of echogenicity and morphology. J Ultrasound Med. 1993; 12(2):73–7. https://doi.org/10.7863/jum.1993.12.2.73 PMID: 8468739.
40. Guralnik JM, Simonsick EM, Ferrucci L, Glynn RJ, Berkman LF, Blazer DG, et al. A short physical performance battery assessing lower extremity function: association with self-reported disability and prediction of mortality and nursing home admission. J Gerontol. 1994; 49(2):M85–94. https://doi.org/10.1093/geronj/49.2.m85 PMID: 8126356.

41. Guralnik JM, Ferrucci L, Pieper CF, Leveille SG, Markides KS, Ostir GV, et al. Lower extremity function and subsequent disability: consistency across studies, predictive models, and value of gait speed alone compared with the short physical performance battery. J Gerontol A Biol Sci Med Sci. 2000; 55(4):M221–31. https://doi.org/10.1093/gerona/55.4.m221 PMID: 10811512.

42. Huy C, Schneider S. [Instrument for the assessment of middle-aged and older adults’ physical activity: design, reliability and application of the German-PAQ-SO]. Z Gerontol Geriatr. 2008; 41(3):208–16. https://doi.org/10.1007/s00391-007-0474-y PMID: 18327696.

43. Fried LP, Tangen CM, Walston J, Newman AB, Hirsch C, Gottdiener J, et al. Frailty in older adults: evidence for a phenotype. J Gerontol A Biol Sci Med Sci. 2001; 56(3):M146–56. Epub 2001/03/17. https://doi.org/10.1093/gerona/56.3.m146 PMID: 11253156.

44. Chen WL, Peng TC, Sun YS, Yang HF, Liaw FY, Wu LW, et al. Examining the Association Between Quadriceps Strength and Cognitive Performance in the Elderly. Medicine (Baltimore). 2015; 94(32):e1335. https://doi.org/10.1097/MD.0000000000001335 PMID: 26266380.

45. Tieland M, Trouwborst I, Clark BC. Skeletal muscle performance and ageing. J Cachexia Sarcopenia Muscle. 2018; 9(1):3–19. https://doi.org/10.1002/jcsm.12238 PMID: 29151281.

46. Clark BC, Taylor JL. Age-related changes in motor cortical properties and voluntary activation of skeletal muscle. Curr Aging Sci. 2011; 4(3):192–9. PMID: 21529329.

47. Harridge SD, Kryger A, Stensgaard A. Knee extensor strength, activation, and size in very elderly people following strength training. Muscle Nerve. 1999; 22(7):831–9. https://doi.org/10.1002/(sici)1097-4598(199907)22:7<831::aid-mus4>3.0.co;2-3 PMID: 10398199.

48. Stevens JE, Stackhouse SK, Binder-Macleod SA, Snyder-Mackler L. Are voluntary muscle activation deficits in older adults meaningful? Muscle Nerve. 2003; 27(1):99–101. https://doi.org/10.1002/mus.10279 PMID: 12508301.

49. Lord SR, Murray SM, Chapman K, Munro B, Tiedemann A. Sit-to-stand performance depends on sensation, speed, balance, and psychological status in addition to strength in older people. J Gerontol A Biol Sci Med Sci. 2002; 57(8):M539–43. https://doi.org/10.1093/gerona/57.8.m539 PMID: 12145369.

50. Eriksrud O, Bohannon RW. Relationship of knee extension force to independence in sit-to-stand performance in patients receiving acute rehabilitation. Physical therapy. 2003; 83(6):544–51. PMID: 12775200.

51. Alexander NB, Galecki AT, Nyquist LV, Hofmeyer MR, Grunawalt JC, Grenier ML, et al. Chair and bed rise performance in ADL-impaired congregate housing residents. J Am Geriatr Soc. 2000; 48(5):526–33. https://doi.org/10.1111/j.1532-5415.2000.tb04999.x PMID: 10811546.

52. Van der Heijden MM, Meijer K, Willems PJ, Savelberg HH. Muscles limiting the sit-to-stand movement: an experimental simulation of muscle weakness. Gait Posture. 2009; 30(1):110–4. https://doi.org/10.1016/j.gaitpost.2009.04.002 PMID: 19419871.

53. Lord SR, Murray SM, Chapman K, Munro B, Tiedemann A. Sit-to-stand performance depends on sensation, speed, balance, and psychological status in addition to strength in older people. J Gerontol A Biol Sci Med Sci. 2002; 57(8):M539–43. https://doi.org/10.1093/gerona/57.8.m539 PMID: 12145369.

54. Zech A, Steib S, Sportwiss D, Freiberger E, Pfeifer K. Functional muscle power testing in young, middle-aged, and community-dwelling nonfrail and prefrail older adults. Arch Phys Med Rehabil. 2011; 92(6):967–71. https://doi.org/10.1016/j.apmr.2010.12.031 PMID: 21514567.
60. Mor V, Angelelli J, Jones R, Roy J, Moore T, Morris J. Inter-rater reliability of nursing home quality indicators in the U.S. BMC Health Serv Res. 2003; 3(1):20. https://doi.org/10.1186/1472-6963-3-20 PMID: 14596684.

61. Colbert LH, Matthews CE, Havighurst TC, Kim K, Schoeller DA. Comparative validity of physical activity measures in older adults. Med Sci Sports Exerc. 2011; 43(5):867–76. https://doi.org/10.1249/MSS.0b013e3181f7162 PMID: 20881882.