

Is grip strength a useful single marker of frailty?

HOLLY SYDDALL[1], CYRUS COOPER[1], FINBARR MARTIN[3], ROGER BRIGGS[2], AVAN AIHIE SAYER[1,2]

[1]MRC Environmental Epidemiology Unit, [2]University Geriatric Medicine, University of Southampton, Southampton, UK
[3]Department of Ageing and Health, Guy's and St Thomas' Hospital Trust, London, UK

Address correspondence to: A. Aihie Sayer, MRC Environmental Epidemiology Unit, Southampton General Hospital, Southampton, SO16 6YD, UK. Fax: (+44) 023 8070 4021. Email: aas@mrc.soton.ac.uk

Abstract

Background: chronological age is widely used as a marker of frailty in clinical practice. However there can be wide variation in frailty between individuals of a similar age. Grip strength is a powerful predictor of disability, morbidity and mortality which has been used in a number of frailty scores but not as a single marker of frailty.
Objective: to investigate the potential of grip strength as a single marker of frailty in older people of similar chronological age.
Design: cross-sectional study with prospective collection of mortality data.
Setting: North Hertfordshire, UK.
Subjects: 717 men and women, aged 64–74, born and still living in North Hertfordshire, who took part in a previous study to investigate the relationship between size at birth and ageing processes in later life.
Methods: the number of significant associations between grip strength and the ageing markers was compared with numbers between chronological age and the ageing markers.
Results: in men, lower grip strength correlated significantly with ten ageing markers compared to chronological age which was significantly associated with seven. In women, there were six significant relationships for grip compared to three for age. The greater number of relationships between grip strength and ageing markers was not explained by the association between grip strength and age, and remained after adjustment for adult size.
Conclusions: grip strength was associated with more markers of frailty than chronological age within the narrow age range studied. Grip strength may prove a more useful single marker of frailty for older people of similar age than chronological age alone. Its validity in a clinical setting needs to be tested.

Keywords: *frailty, ageing, grip strength*

Introduction

Chronological age and frailty are closely related and age in years is frequently used as a marker of frailty in clinical practice. However there can be wide variation in frailty between individuals of a similar age and the ability to distinguish them using chronological age is limited. Alternative markers of frailty have been sought and a number of scores have been developed for use in the research setting [1], but there is no single widely accepted score and their complexity has precluded their use in routine clinical practice.

Grip strength is included in many of these scores. Loss of grip strength is strongly associated with increasing chronological age [2] but, independent of this relationship, it appears to be a powerful predictor of disability, morbidity and mortality. Lower grip strength is associated with incident as well as prevalent disability, suggesting that age-related loss of muscle mass and volitional muscle strength can be a cause as well as a consequence of physical disability [3–6]. Studies looking at the influence of grip strength on morbidity have focused on musculoskeletal disorders, for example higher muscle strength is related to increased bone mass and lower risk of fracture [7, 8]. However the most striking association is with future mortality. Grip strength in mid-life [9] and later years [10] predicts long-term survival.

These associations suggest that grip strength may be a good marker of frailty [11]. We compared the use of grip strength and chronological age as single markers of frailty

using data from a study of ageing in older people aged 64–74 years.

Methods

Between 1994 and 1995 a community sample of 717 men and women aged 64–74 years participated in a study designed to investigate whether rates of ageing were associated with growth in early life [12]. Ethical approval for the study was obtained from the North Hertfordshire Local Research Ethics Committee. Four trained research nurses carried out home visits and obtained a detailed medical and social history. Blood pressure was also measured during the visit. Following this, subjects were invited to attend a clinic for anthropometry, including height and weight, and assessment of ageing markers in different body systems.

Grip strength was measured using a Harpenden dynamometer [13] and skin thickness determined by ultrasound [14]. A simple tooth count was carried out after removal of any dentures. Hearing acuity was determined using pure-tone manual audiometry and cognitive function was assessed with the AH4 IQ test. The detailed eye examination included measurement of distance visual acuity with a Bailey-Lovey logMAR chart [15] and determination of intra-ocular pressure using a Perkins applanation hand-held tonometer [16]. Slit lamp examination allowed grading of nuclear lens opacity with the LOCSIII system [17] and clinical classification of age-related macular degeneration. Blood investigations included haemoglobin, creatinine, albumin and alkaline phosphatase levels.

Using the National Health Service Central Register, the study participants were followed up for 4 years 10 months until the end of 1999 and information on deaths collected. Cause of death was classified according to the International Classification of Diseases (9th revision).

Statistical analysis

Skewed variables were $\log_e$ transformed to normal distributions for analysis. The characteristics of the subjects were initially described using means and standard deviations, and tabulations of frequency and percentage distributions. Correlation and regression analyses were then used to investigate the relationship between age, grip and each of the ageing markers. Linear regression models were used for continuously distributed ageing markers, and logistic regression models for markers with binary or ordinal distributions. The associations with all cause mortality were determined using Cox's proportional hazards model. A series of hierarchical analyses was carried out for each ageing marker. Firstly the univariate relationship between grip strength and each ageing marker was explored. Secondly, the univariate relationship between chronological age and each ageing marker was considered. Finally, grip and age were considered simultaneously in relation to each ageing marker. In this way, the independent mutually adjusted relationships between grip and age and each marker of ageing were assessed. The 5% significance level was used to identify significant associations. Analyses were repeated using a measure of grip strength adjusted for height. Men and women were analysed separately throughout. All statistical analyses were carried out using Stata, release 7.

Results

The study sample comprised 411 (57%) men and 306 (43%) women. There was no difference in the average age of the men and women (mean 67.5 years) but grip strength was substantially higher in men (mean 38.3 kg, SD 7.1 kg) than women (mean 22.5 kg, SD 5.3 kg, $P < 0.0001$ for difference). The other major associations with grip strength were age and current size. Grip strength decreased with increasing age ($r = -0.18$, $P = 0.002$ men, $r = -0.18$, $P = 0.001$ women) and lower height ($r = 0.29$, $P < 0.0001$ men, $r = 0.19$, $P = 0.0007$ women). The associations between grip strength, chronological age and markers of ageing in different body systems for men and women are described in Tables 1 and 2.

In men, lower grip strength correlated significantly with ten ageing markers in univariate analyses: decreased cognitive function, increased lens opacity, higher hearing threshold, poorer visual acuity, lower haemoglobin, higher alkaline phosphatase, fewer teeth, increased risk of walking problems, self-reported generalised arthritis and fracture. This compared with chronological age which was significantly associated with seven of the recognised markers of ageing in this group: cognitive function, lens opacity, hearing threshold, visual acuity, haemoglobin, number of teeth and fracture after age 50. After adjustment for chronological age, grip strength remained significantly associated with all the same markers of ageing except hearing threshold and number of teeth, demonstrating that the associations between grip strength and a wide range of markers of ageing were not explained by grip being related to age.

Univariate analyses for women identified six significant correlations with lower grip strength: decreased cognitive function, thinner skin, higher hearing threshold, increased risk of walking problems, self-reported myocardial infarction and generalised arthritis. Chronological age was associated significantly with three of the ageing markers: cognitive function, lens opacity and visual acuity. Grip strength was no longer associated with cognitive function after adjustment for chronological age but the five other correlations remained.

The relationship between grip strength, chronological age and all cause mortality was also investigated. Thirty-seven men and 15 women had died during the 4 year 10 month follow-up period. The all cause mortality rate was higher for men than women (hazard ratio 1.88, 95% CI 1.03, 3.43, $P = 0.04$). In the men, grip strength was

Table 1. Grip strength and age in relation to markers of ageing in men

	Univariate correlation coefficients[a]				Mutually adjusted correlation coefficients[b]				
Characteristic	Grip	*P*-value	Age	*P*-value	Grip	*P*-value	Age	*P*-value	Model R^2
Cognitive function (AH4)	0.17	0.0009	−0.11	0.03	0.15	0.003	−0.08	0.10	3.4
Hearing threshold (dBA)	−0.10	0.04	0.19	<0.001	−0.07	0.17	0.17	0.001	3.4
Lens opacity (LOCSIII)	−0.19	0.0002	0.13	0.01	−0.17	0.001	0.10	0.06	4.0
Visual acuity (normal score)	−0.14	0.003	0.10	0.04	−0.13	0.01	0.08	0.11	2.7
Intraocular pressure (mm Hg)	0.02	0.75	0.04	0.39	0.02	0.63	0.05	0.35	0.2
Systolic blood pressure (mm Hg)	0.06	0.24	0.08	0.12	0.07	0.13	0.09	0.07	1.1
Skin thickness (mm)	0.04	0.43	−0.02	0.75	0.04	0.46	−0.01	0.86	0.2
Haemoglobin (g/dl)	0.15	0.003	−0.16	0.002	0.12	0.01	−0.13	0.007	3.9
Albumin	0.07	0.18	−0.00	0.95	0.07	0.18	0.01	0.86	0.4
Alkaline phosphatase	−0.11	0.03	0.07	0.13	−0.10	0.05	0.06	0.26	1.5
	Univariate odds ratios (OR)[c]				Mutually adjusted odds ratios (OR)[d]				
	Per SD	*P*-value	Per year	*P*-value	Per SD	*P*-value	Per year	*P*-value	Model R^2
Macular degeneration	0.87	0.23	0.98	0.72	0.86	0.19	0.97	0.55	0.4
Number of teeth[e]	0.82	0.03	1.17	<0.001	0.87	0.13	1.16	<0.001	1.6
Walking problems[e]	0.63	0.001	1.11	0.07	0.65	0.002	1.08	0.19	3.1
Myocardial infarction	0.85	0.25	1.10	0.12	0.88	0.37	1.10	0.16	1.0
Stroke	0.75	0.27	1.02	0.84	0.75	0.28	1.00	1.00	1.0
Urinary tract infection	0.90	0.45	1.07	0.25	0.92	0.57	1.06	0.30	0.5
Hypothyroidism	0.90	0.88	1.03	0.92	0.91	0.89	1.02	0.94	0.1
Generalised arthritis	0.74	0.01	1.05	0.37	0.75	0.02	1.02	0.66	1.6
Fracture since age 50 years	0.53	0.001	1.18	0.04	0.55	0.001	1.14	0.11	6.9
	Univariate hazard ratios (HR)[f]				Mutually adjusted hazard ratios (HR)[f]				
	Per SD	*P*-value	Per year	*P*-value	Per SD	*P*-value	Per year	*P*-value	Model deviance
All cause mortality	0.59	0.001	0.98	0.73	0.57	<0.001	0.93	0.30	430.4

[a]Univariate Pearson correlation coefficients for each continuously distributed characteristic in relation to grip, and separately in relation to age.
[b]Partial correlation coefficients for each continuously distributed characteristic in relation to grip and age simultaneously, together with the percentage R^2 statistic from a regression model of the characteristic on grip and age simultaneously.
[c]Univariate odds ratios for each binary characteristic in relation to grip, and separately in relation to age.
[d]Mutually adjusted odds ratios from logistic regression models for each binary characteristic in relation to grip and age simultaneously, together with the percentage pseudo R^2 statistics for these models.
[e]Odds ratios for a worse outcome, and model percentage pseudo R^2 statistics, obtained from ordinal logistic regression models as number of teeth and walking problems were analysed as ordinal variables.
[f]Univariate and mutually adjusted hazard ratios for mortality risk from Cox Proportional Hazards models and model deviance.

significantly correlated with all cause mortality. This was not seen in the women. Chronological age, within the 10-year age range tested, was not related to all cause mortality in the men or women.

In view of the known strong associations between grip strength and adult size, the analyses were repeated after adjustment for height (Tables 3 and 4). The pattern of associations remained similar suggesting that grip, independent of adult size, was associated with a wide range of ageing markers including all cause mortality in the men.

Discussion

We have demonstrated that grip strength is significantly associated with more markers of frailty than chronological age in a group of older men and women within a 10-year age range. It is unlikely that loss of grip strength lies on the final common pathway for biological ageing although the recent finding reported in *Nature* that nematode ageing is also associated with gradual, progressive deterioration of muscle suggests that this is a species-wide ageing phenomenon [18]. The wide range of associations with ageing in other systems is more likely to reflect that loss of grip strength is a particularly specific marker of the underlying ageing processes because of the rarity of muscle-specific diseases contributing to change in muscle function. Ageing markers are defined by their relationship to chronological age over a lifespan, yet we demonstrated that a number of the markers used and all cause mortality were not related to chronological age in this study. This reflects the fact that variation in frailty between individuals of a similar age can be greater than that associated with differences over a 10-year age span and highlights the difficulties of using chronological age to differentiate such people.

Table 2. Grip strength and age in relation to markers of ageing in women

	Univariate correlation coefficients[a]				Mutually adjusted correlation coefficients[b]				
Characteristic	Grip	*P*-value	Age	*P*-value	Grip	*P*-value	Age	*P*-value	Model R^2
Cognitive function (AH4)	0.12	0.03	−0.16	0.007	0.10	0.09	−0.14	0.02	2.7
Hearing threshold (dBA)	−0.12	0.03	0.07	0.22	−0.11	0.05	0.05	0.36	1.8
Lens opacity (LOCSIII)	0.02	0.77	0.12	0.04	0.04	0.49	0.12	0.03	1.6
Visual acuity (normal score)	−0.10	0.09	0.14	0.01	−0.07	0.22	0.13	0.02	2.7
Intraocular pressure (mm Hg)	−0.00	0.98	−0.05	0.40	−0.01	0.84	−0.06	0.32	0.3
Systolic blood pressure (mm Hg)	0.00	1.00	0.05	0.38	0.01	0.87	0.05	0.37	0.3
Skin thickness (mm)	0.17	0.004	−0.09	0.13	0.15	0.007	−0.06	0.33	3.1
Haemoglobin (g/dl)	0.07	0.25	−0.07	0.21	0.05	0.35	−0.06	0.28	0.8
Albumin	0.11	0.06	−0.03	0.58	0.10	0.08	−0.02	0.78	0.5
Alkaline phosphatase	−0.07	0.19	0.09	0.12	−0.06	0.29	0.07	0.20	1.1
	Univariate odds ratios (OR)[c]				Mutually adjusted odds ratios (OR)[d]				
	Per SD	*P*-value	Per yr	*P*-value	Per SD	*P*-value	Per yr	*P*-value	Model R^2
Macular degeneration	0.93	0.52	1.08	0.16	0.95	0.69	1.08	0.17	0.6
Number of teeth[e]	0.89	0.26	1.03	0.57	0.90	0.30	1.01	0.77	0.1
Walking problems[e]	0.62	0.002	1.00	0.98	0.62	0.002	0.97	0.67	3.0
Myocardial infarction	0.50	0.03	1.31	0.08	0.54	0.05	1.25	0.16	8.3
Stroke	0.68	0.31	1.03	0.89	0.67	0.31	0.99	0.96	1.7
Urinary tract infection	1.07	0.59	0.92	0.15	1.03	0.79	0.92	0.16	0.6
Hypothyroidism	0.65	0.06	1.05	0.66	0.66	0.07	1.01	0.93	2.4
Generalised arthritis	0.65	0.001	1.02	0.69	0.65	0.001	0.99	0.90	3.1
Fracture since age 50 years	0.77	0.07	1.08	0.25	0.79	0.10	1.07	0.33	1.4
	Univariate hazard ratios (HR)[f]				Mutually adjusted hazard ratios (HR)[f]				
	Per SD	*P*-value	Per yr	*P*-value	Per SD	*P*-value	Per yr	*P*-value	Model deviance
All cause mortality	1.18	0.54	1.00	0.98	1.18	0.53	1.01	0.94	170.5

[a]Univariate Pearson correlation coefficients for each continuously distributed characteristic in relation to grip, and separately in relation to age.
[b]Partial correlation coefficients for each continuously distributed characteristic in relation to grip and age simultaneously, together with the percentage R^2 statistic from a regression model of the characteristic on grip and age simultaneously.
[c]Univariate odds ratios for each binary characteristic in relation to grip, and separately in relation to age.
[d]Mutually adjusted odds ratios from logistic regression models for each binary characteristic in relation to grip and age simultaneously, together with the percentage pseudo R^2 statistics for these models.
[e]Odds ratios for a worse outcome, and model percentage pseudo R^2 statistics, obtained from ordinal logistic regression models as number of teeth and walking problems were analysed as ordinal variables.
[f]Univariate and mutually adjusted hazard ratios for mortality risk from Cox Proportional Hazards models and model deviance.

There are limitations to our study that require consideration. Grip strength is strongly associated with current size as well as age. However, grip remained significantly associated with the markers of frailty even after adjustment for age and current height. Grip strength was not associated with mortality in the women but there were few deaths among the women, and there was probably insufficient power to detect this relationship in the relatively short follow up period. We identified significant correlations between grip strength and a number of ageing markers but the proportion of variance explained by the models was small. Nevertheless it was of similar magnitude to the proportion of variance explained by the models including chronological age which has established relationships with the ageing markers chosen. The proportion of variance explained in regression models is often small because of unmeasured and unmeasurable sources of variation. Therefore the relationships demonstrated between grip strength and ageing in a number of systems may be meaningful and explain the well-documented links between grip strength and disability, morbidity, and mortality.

The limitations of chronological age as a predictor of frailty are often overlooked in the clinical setting where age alone is used to guide management decisions. In recognition of this, the first standard in the recent National Service Framework for Older People focuses on rooting out age discrimination [19] and in the Reith Lectures, Tom Kirkwood suggested that we should 'get rid of age from the medical record altogether and let the patient's biological state speak for itself' [20]. However, quantifying frailty, or the closely related concept of biological age, remains problematic and scores that have been developed for this purpose are rarely used outside the research setting.

Table 3. Height-adjusted-grip strength and age in relation to markers of ageing in men

	Univariate correlation coefficients[a]				Mutually adjusted correlation coefficients[b]				
Characteristic	Grip	*P*-value	Age	*P*-value	Grip	*P*-value	Age	*P*-value	Model R^2
Cognitive function (AH4)	0.14	0.005	−0.11	0.03	0.13	0.01	−0.09	0.07	2.8
Hearing threshold (dBA)	−0.08	0.11	0.19	<0.001	−0.05	0.28	0.18	<0.001	3.7
Lens opacity (LOCSIII)	−0.18	<0.001	0.13	0.01	−0.16	0.002	0.10	0.04	4.2
Visual acuity (normal score)	−0.14	0.003	0.10	0.04	−0.13	0.008	0.08	0.09	2.8
Intraocular pressure (mm Hg)	0.04	0.43	0.04	0.39	0.05	0.36	0.05	0.32	0.4
Systolic blood pressure (mm Hg)	0.09	0.06	0.08	0.12	0.11	0.03	0.09	0.06	1.7
Skin thickness (mm)	−0.01	0.92	−0.02	0.75	−0.01	0.88	−0.02	0.74	0.0
Haemoglobin (g/dl)	0.15	0.003	−0.16	0.002	0.13	0.01	−0.14	0.006	4.0
Albumin	0.08	0.11	−0.00	0.95	0.08	0.11	0.01	0.86	0.6
Alkaline phosphatase	−0.10	0.05	0.07	0.13	−0.09	0.09	0.06	0.22	1.3
	Univariate odds ratios (OR)[c]				Mutually adjusted odds ratios[d]				
	Per SD	*P*-value	Per yr	*P*-value	Per SD	*P*-value	Per yr	*P*-value	Model R^2
Macular degeneration	0.91	0.39	0.98	0.72	0.90	0.36	0.98	0.62	0.2
Number of teeth[e]	0.81	0.02	1.17	<0.001	0.85	0.08	1.16	<0.001	1.6
Walking problems[e]	0.64	0.001	1.11	0.07	0.65	0.002	1.09	0.15	3.1
Myocardial infarction	0.87	0.33	1.10	0.12	0.89	0.44	1.10	0.14	1.0
Stroke	0.72	0.19	1.02	0.84	0.72	0.20	1.00	0.99	1.3
Urinary tract infection	0.90	0.47	1.07	0.25	0.92	0.57	1.07	0.29	0.5
Hypothyroidism	0.69	0.57	1.03	0.92	0.69	0.58	1.01	0.98	1.1
Generalised arthritis	0.74	0.01	1.05	0.37	0.75	0.02	1.03	0.59	1.6
Fracture since age 50 years	0.49	<0.001	1.18	0.04	0.50	<0.001	1.15	0.09	8.6
	Univariate hazard ratios (HR)[f]				Mutually adjusted hazard ratios (HR)[f]				
	Per SD	*P*-value	Per yr	*P*-value	Per SD	*P*-value	Per yr	*P*-value	Model deviance
All cause mortality	0.66	0.006	0.98	0.73	0.64	0.005	0.94	0.43	434.4

[a]Univariate Pearson correlation coefficients for each continuously distributed characteristic in relation to height adjusted grip, and separately in relation to age.
[b]Partial correlation coefficients for each continuously distributed characteristic in relation to height adjusted grip and age simultaneously, together with the percentage R^2 statistic from a regression model of the characteristic on height adjusted grip and age simultaneously.
[c]Univariate odds ratios for each binary characteristic in relation to height adjusted grip, and separately in relation to age.
[d]Mutually adjusted odds ratios from logistic regression models for each binary characteristic in relation to height adjusted grip and age simultaneously, together with the percentage pseudo R^2 statistics for these models.
[e]Odds ratios for a worse outcome, and model percentage pseudo R^2 statistics, obtained from ordinal logistic regression models as number of teeth and walking problems were analysed as ordinal variables.
[f]Univariate and mutually adjusted hazard ratios for mortality risk from Cox Proportional Hazards models and model deviance.

The findings from this study suggest that grip strength could be a more useful single marker of frailty for people of a similar age than chronological age alone. Perhaps it is now time for its validity to be tested in a clinical setting.

Key points

- Chronological age is widely used as a marker of frailty in clinical practice, however there can be wide variation between individuals of the same age and the ability of chronological age to distinguish the frailty of people within a narrow age range is limited.
- Grip strength is a powerful predictor of disability, morbidity and mortality and is used in many scores of frailty but its potential as a single marker of frailty is not known.
- Grip strength was associated with more markers of frailty than chronological age in men and women within a 10 year age range.
- Grip strength may prove a more useful single marker of frailty for older people of similar age than chronological age alone and its validity in a clinical setting needs to be tested.

Conflicts of interest

None declared.

Funding

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Table 4. Height-adjusted-grip strength and age in relation to markers of ageing in women

	Univariate correlation coefficients[a]				Mutually adjusted correlation coefficients[b]				
Characteristic	Grip	*P*-value	Age	*P*-value	Grip	*P*-value	Age	*P*-value	Model R^2
Cognitive function (AH4)	0.10	0.10	−0.16	0.007	0.07	0.22	−0.14	0.01	3.0
Hearing threshold (dBA)	−0.12	0.03	0.07	0.22	−0.11	0.06	0.06	0.28	1.9
Lens opacity (LOCSIII)	0.03	0.62	0.12	0.04	0.05	0.39	0.13	0.03	1.7
Visual acuity (normal score)	−0.07	0.24	0.14	0.01	−0.04	0.44	0.14	0.02	2.3
Intraocular pressure (mm Hg)	−0.00	0.96	−0.05	0.40	−0.01	0.83	−0.06	0.30	0.4
Systolic blood pressure (mm Hg)	0.03	0.66	0.05	0.38	0.04	0.54	0.06	0.31	0.4
Skin thickness (mm)	0.15	0.009	−0.09	0.13	0.14	0.02	−0.06	0.27	2.6
Haemoglobin (g/dl)	0.06	0.30	−0.07	0.21	0.05	0.40	−0.06	0.27	0.8
Albumin	0.12	0.04	−0.03	0.58	0.11	0.05	−0.01	0.81	1.4
Alkaline phosphatase	−0.08	0.18	0.09	0.12	−0.06	0.26	0.08	0.20	1.2
	Univariate odds ratios (OR)[c]				Mutually adjusted odds ratios[d]				
	Per SD	*P*-value	Per year	*P*-value	Per SD	*P*-value	Per year	*P*-value	Model R^2
Macular degeneration	0.92	0.48	1.08	0.16	0.95	0.64	1.08	0.16	0.6
Number of teeth[e]	0.90	0.31	1.03	0.57	0.91	0.35	1.02	0.70	0.1
Walking problems[e]	0.60	0.001	1.00	0.98	0.59	0.001	0.98	0.73	3.7
Myocardial infarction	0.48	0.02	1.31	0.08	0.51	0.03	1.24	0.17	9.5
Stroke	0.63	0.22	1.03	0.89	0.63	0.22	0.99	0.95	2.4
Urinary tract infection	1.08	0.53	0.92	0.15	1.05	0.69	0.93	0.17	0.6
Hypothyroidism	0.66	0.07	1.05	0.66	0.67	0.07	1.01	0.92	2.3
Generalised arthritis	0.64	<0.001	1.02	0.69	0.64	<0.001	1.00	0.96	3.3
Fracture since age 50 years	0.79	0.09	1.08	0.25	0.81	0.14	1.07	0.32	1.3
	Univariate hazard ratios (HR)[f]				Mutually adjusted hazard ratios (HR)[f]				
	Per SD	*P*-value	Per year	*P*-value	Per SD	*P*-value	Per year	*P*-value	Model deviance
All cause mortality	1.26	0.40	1.00	0.98	1.26	0.40	1.01	0.92	170.1

[a]Univariate Pearson correlation coefficients for each continuously distributed characteristic in relation to height adjusted grip, and separately in relation to age.
[b]Partial correlation coefficients for each continuously distributed characteristic in relation to height adjusted grip and age simultaneously, together with the percentage R^2 statistic from a regression model of the characteristic on height adjusted grip and age simultaneously.
[c]Univariate odds ratios for each binary characteristic in relation to height adjusted grip, and separately in relation to age.
[d]Mutually adjusted odds ratios from logistic regression models for each binary characteristic in relation to height adjusted grip and age simultaneously, together with the percentage pseudo R^2 statistics for these models.
[e]Odds ratios for a worse outcome, and model percentage pseudo R^2 statistics, obtained from ordinal logistic regression models as number of teeth and walking problems were analysed as ordinal variables.
[f]Univariate and mutually adjusted hazard ratios for mortality risk from Cox Proportional Hazards models and model deviance.

References

1. Bourliere F. Indices of physiological age. In Danon D, Shock NW, Marois M eds. Aging: A Challenge to Science and Society. Volume 1 Biology. Oxford: Oxford University Press, 1981: 269–70.

2. Bassey EJ, Harries UJ. Normal values for handgrip strength in 920 men and women aged over 65 years, and longitudinal changes over 4 years in 620 survivors. Clin Sci (Colch) 1993; 84: 331–7.

3. Rantanen T, Guralnik JM, Foley D *et al*. Midlife hand grip strength as a predictor of old age disability. JAMA 1999; 281: 558–60.

4. Giampaoli S, Ferrucci L, Cecchi F *et al*. Hand-grip strength predicts incident disability in non-disabled older men. Age Ageing 1999; 28: 283–8.

5. Hughes S, Gibbs J, Dunlop D, Edelman P, Singer R, Chang RW. Predictors of decline in manual performance in older adults. J Am Geriatr Soc. 1997; 45: 905–10.

6. Phillips SK, Woledge RC, Bruce SA *et al*. A study of force and cross-sectional area of adductor pollicis muscle in female hip fracture patients. J Am Geriatr Soc 1998; 46: 999–1002.

7. Taaffe DR, Cauley JA, Danielson M *et al*. Race and sex effects on the association between muscle strength, soft tissue, and bone mineral density in healthy elders: the Health, Aging, and Body Composition Study. J Bone Miner Res 2001; 16: 1343–52.

8. Hughes VA, Frontera WR, Dallal GE, Lutz KJ, Fisher EC, Evans WJ. Muscle strength and body composition: associations with bone density in older subjects. Med Sci Sports Exerc 1995; 27: 967–74.

9. Rantanen T, Harris T, Leveille SG *et al*. Muscle strength and body mass index as long-term predictors of mortality in initially healthy men. J Gerontol A Biol Sci Med Sci. 2000; 55: M168–73.

10. Laukkanen P, Heikkinen E, Kauppinen M. Muscle strength and mobility as predictors of survival in 75–84-year-old people. Age Ageing 1995; 24: 468–73.

11. Fried LP, Tangen CM, Walston J *et al.* Frailty in older adults: evidence for a phenotype. J Gerontol A Biol Sci Med Sci 2001; 56: M146–56.

12. Aihie Sayer A, Cooper C, Evans JR *et al.* Are rates of ageing determined in utero? Age Ageing 1998; 27: 579–83.

13. Weiner JS, Lourie JA eds. International Biology: A Guide to Field Methods. Oxford: Blackwell Scientific Publications, 1969.

14. Tan CY, Statham B, Marks R, Payne PA. Skin thickness measurement by pulsed ultrasound: its reproducibility, validation and variability. Br J Dermatol 1982; 106: 657–67.

15. Bailey IL, Lovie JE. New design principles for visual acuity letter charts. Am J Optom Physio Opt 1976; 53: 740–5.

16. Krieglstein G, Waller W. Goldmann applanation versus hand applanation and Schiotz indentation tonometry. Graefes Arch Clin Exp Ophthal 1975; 194: 11.

17. Chylack LT, Wolfe JK, Singer DM *et al.* The lens opacities classification system III. Arch Ophthal 1993; 111: 831–36.

18. Herndon LA, Schmeissner PJ, Dudaronek JM *et al.* Stochastic and genetic factors influence tissue-specific decline in ageing *C. elegans*. Nature 2002; 419: 808–14.

19. National Service Framework for Older People. 23633 1P 55K Mar 01 (CWP). London: Department of Health, 2001.

20. Kirkwood T. The End of Age. London: Profile Books Ltd, 2001.

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