Muscle strength, disability and mortality

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The aims of this review are to address (1) the role of muscle strength in the disablment process and (2) muscle strength as a predictor of length of life using data from prospective studies. Functional limitations, such as slow walking speed, predispose older people to disabilities. How much strength is needed for daily motor tasks such as walking varies according to other impairments present. For example, when postural balance is good, only minimum amount of strength is needed for walking. However, in the presence of balance impairment, having good level of strength may help to compensate for the deficit. Having strength well above the required level indicates reserve capacity. It was studied using data from the Honolulu Heart Program launched in 1965 among 8006 men initially aged 45-68 years, whether reserve of strength would be protective of development of future disability. All men with documented diseases at baseline were excluded from the analyses. Those men who were in the lowest third of the distribution of grip strength at baseline were at two to three times greater risk of developing disabilities assessed 25 years later compared to the highest third. It is possible that before they reach the disability level, those with greater reserve of strength may afford to lose more strength, for example following bed rest and inactivity associated with an illness. Midlife grip strength was also found to predict long-term total mortality; those with poorer strength at baseline were more likely to die over the follow-up period of 30 years. The association between muscle strength and disability is largely explained by biomechanical mechanisms. However, the mechanism explaining the association between muscle strength and mortality risk still remains to be explored.

Decline in physical functioning leading to disability creates a considerable burden for many older people. There is great variability in functional decline in old age, and the process may originate from diseases, life style behaviors, psychosocial and socio-demographic factors, genetic predisposition or the combination of the above. Finding ways to improve everybody’s possibilities for a long healthy life is the most widely accepted goal for gerontological research. Concepts such as active life expectancy or disability-free life expectancy have gained increasing interest (Guralnik, Ferrucci, Simonsick, Salive, Wallace, 1995). Active life expectancy refers to the expected length of life without disability or need for external help. Disability is usually defined as a gap between an individual’s capabilities and environmental requirements, and is often studied by asking the participants about difficulties they experience while performing activities relevant to their lives (Leveille, Resnick, Balfour, 2000). A recent American study reported that the probability of a non-disabled 65-year-old man’s surviving to age 80 and then being non-disabled prior to death was 26%. For a 65-year-old woman, the probability of surviving to age 85 and being non-disabled prior to death was 18% (Leveille, Guralnik, Ferrucci, Langlois, 1999).

The aim of this paper is to review the role of muscle strength in the process of disability in old age, as well as to address the association of muscle strength and the length of life.

Strength change with age

Most of the information about age-related strength changes is currently still based on cross-sectional data (Lindle et al., 1997). In published longitudinal studies, the participants have been a selected group of people or the numbers have been small (Asmussen, Fruengard, Norgaard, 1975; Aniansson, Sperling, Rundgren, 1983; Greig, Botella, Young, 1993; Grimbly, 1995), or the follow-up period has been fairly short (Bassey, Harries, 1993). As measurements made in large studies involving older participants have to be cost-effective for the researchers and not too burdensome to participants, handgrip strength has often been used as an indicator of overall muscle strength (Kallman, Plato, Tobin, 1990; Bassey et al., 1993). Use of grip strength as a feasible model to describe overall strength changes is supported by its significant correlation with other strength measures: $r = 0.638$ for elbow flexion, $r = 0.524$ for knee extension, $r = 0.515$ for trunk extension,
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and $r = 0.437$ for trunk flexion (Rantanen, Era, Kauppinen, Heikkinen, 1994a).

The Baltimore Longitudinal Study on Aging combined cross-sectional and longitudinal data to describe age-related change in strength. Handgrip strength was found to increase up to the thirties and to start to decrease with accelerated speed after the forties (Kallman et al., 1990; Metter, Conwit, Tobin, Fozard, 1997). However, great inter-individual differences are evident in strength decline with increasing age. For example, Kallman et al. (1990) found that over an average nine-year follow-up period, 15% of the subjects aged 60 and over did not show any strength decline.

Data on handgrip strength was available in The Honolulu Heart Program, a prospective population based study established in 1965. Participants at Exam 1 were 8006 men aged 45–68 years who were of Japanese ancestry and living in Hawaii. At follow-up, after an average 27 years, 3741 men, age range 71–96 years, participated. The average annualized change strength among the survivors was $-1.0\%$ (Rantanen, Masaki, Foley, Izmirlan, White, Guralnik, 1998). A steeper decline (more than 1.5%/year) was associated with older age at baseline, greater weight decrease and presence of chronic conditions, such as stroke, diabetes, arthritis, coronary heart disease and chronic obstructive pulmonary disease. Despite the overall downward trend in strength with age, the age-adjusted correlation between baseline and follow-up strength was strong ($r = 0.557$, $P < 0.001$) indicating that those who had greater muscle strength at baseline were likely to be on the top of the distribution also 27 years later.

**Muscle strength as a predictor of disability**

With increasing age, muscle strength may eventually decline to a level where weakness starts to restrict the ability to carry out everyday tasks. Cross-sectional studies have demonstrated that muscle strength is significantly, however, not linearly, associated with functional limitations such as walking speed (Rantanen et al., 1994b; Buchner, Larson, Wagner, Kopsell, DeLateur, 1996; Rantanen, Era, Heikkinen, 1996; Ferrucci et al., 1997). A certain minimum level of muscle strength is needed to do necessary everyday tasks, such as climbing stairs, carrying a grocery bag or opening jars (Buchner et al., 1996). Below this minimum threshold level, people are unable to do the task. A reserve capacity exists when strength is well above the required level. This indicates that strength is adequate for the tasks, and that a further increase in strength does not necessarily improve performance (Buchner et al., 1996). Reserve capacity can be seen as a safety margin that helps prevent disability from developing, for example, following inactivity and de-conditioning associated with an illness. It is possible that those with greater strength reserve may lose more strength without reaching the threshold for disability.

The concept of reserve of strength as a factor protecting from future disability has been addressed only in few studies. The Honolulu Heart Program data was used to determine whether handgrip strength measured during mid-life predicts old age functional limitations and disability in initially healthy men, in particular, whether those having greater strength in midlife would be protected from old age disabilities (Rantanen et al., 1999a). Everybody with a documented disease at baseline was excluded. The participants were 6089 healthy 45–68 years-old men whose maximal handgrip strength was measured at baseline. Altogether, 2259 men died over the follow-up and 3218 survivors participated in the disability assessment 25 years after the baseline. Functional limitations included slow customary walking speed ($\leq 0.4$ m $s^{-1}$) and inability to rise from a seated position without using the arms. Multiple self-reported upper extremity, mobility and self-care disability outcomes were also assessed. After adjustment for potential confounders, a clear gradient in risk of functional limitations and disability 25 years later was found according to handgrip strength tertiles (fig. 1). The odds ratio of walking speed $\leq 0.4$ m $s^{-1}$ was 2.87 (95% confidence interval [CI] 1.76–4.67) in those in the lowest third, and 1.79 (95% CI 1.14–2.81) in the middle third of grip strength vs. those in the highest third. The risk of self-care disability was more than two times greater in the lowest vs. the highest grip strength tertile (fig. 2). Adjusting for multiple potential confounders and adding chronic conditions identified at follow-up to the models predicting disability, reduced the odds ratios related to grip strength only minimally. This study showed that middle-aged men with higher handgrip strength were protected from old age disabilities regardless of the diseases that may have developed over the 25-year follow-up (Rantanen et al., 1999a).

![Fig. 1. Functional limitations 25 years after grip strength was tested. Participants were 6089 men aged 45–68 years who had no documented diseases at baseline. They were categorized into tertiles based on the distribution of baseline handgrip strength. Walking speed was measured over a distance of 3.05 meters. In sit-to-stand test, the participant was asked to stand up from a seated position without using the help of the arms and the performance was observed (Rantanen et al., 1999a).](image-url)
Co-impairments

The prevalence of severe walking limitation, an underlying factor for dependence in old age, increases with age (fig. 3). As most studies have focused on independent effects of various impairments, little information is available on the risk of disability that results from the combined effects of multiple impairments, termed here as co-impairments. Duncan, Chandler, Studensky, Hughes, Prescott (1993) suggested that decline in function may be better explained by the accumulation of deficits across multiple domains rather than by any single specific impairment. Tinetti, Inouye, Gill, Doucet (1995) found that when the number of impairments (lower and upper extremity, sensory and affective impairments) increased from zero to one to two to three or more, the proportion of participants experiencing functional dependence doubled from 7% to 14% to 28% to 60%, respectively. The impact of co-impairments on disability may be greater than the sum of single impairments involved. Cross-sectionally, the odds of severe walking limitation was ten times greater among those who had both strength and balance impairments compared to those who had only one or the other (Rantanen, Guralnik, Ferrucci, Leveille, Fried, 1999b). Knee extension strength and standing balance as predictors of development of future severe walking limitation were studied among 758 women who did not have severely walking at baseline and who were followed prospectively for three years with six semi-annual follow-up data collection rounds (Rantanen et al., 2001). Severe walking limitation was defined as customary walking speed of less than 0.4 m s⁻¹ and inability to walk one quarter of a mile, or being unable to walk. Over the course of the study, 173 women severely developed walking limitation. The cumulative incidence of severe walking limitation from the first to the sixth follow-up was: 7.8%, 12.0%, 15.1%, 19.5%, 21.2%, and 22.8%. In Cox regression models, both strength and balance were significant predictors of new walking limitation. The relative risk (RR) of onset of severe walking limitation adjusted for age, height, weight and race was more than five times greater in the group with poorest balance and strength (RR 5.12, 95% CI 2.68–9.80) compared to the group with best balance and strength (fig. 4). Among those who had good balance, strength was not associated with risk of developing walking limitation whereas among those with balance impairment good muscle strength decreased the risk of future walking limitation. The presence of co-impairments was a powerful predictor of new severe walking limitation, an underlying

Fig. 2. Disabilities 25 years after grip strength was tested. Participants were 6089 men aged 45–68 years who had no documented diseases at baseline. They were categorized into tertiles based on the distribution of baseline handgrip strength (Rantanen et al., 1999a).

Fig. 3. Prevalence of severe walking limitation in older women defined as customary walking speed in a 4-meter test of 0.4 m s⁻¹ or less and self-reported inability to walk 400 m (Rantanen et al., 1999b).

Fig. 4. Relative Risks (RR, 95% Confidence Interval) of severe walking disability in groups based on the combined distribution of knee extension strength tertiles and balance categories in older women not severely walking disabled at baseline. Strength and balance were measured at baseline and severe walking disability was prospectively followed for three years with semi-annual follow-up tests (Rantanen et al., 2001).
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because of dependence in older people. Substantial reduc-
tion in the risk of walking limitation could potentially
be achieved even if interventions were successful in
correcting one of the impairments, as a deficit in only
one physiologic system may be compensated for by
good capacity in another system. Studying co-impair-
ments is particularly appropriate in older people, be-
cause with increasing age the proportion of those
having impairments in multiple physiologic systems
increases. To develop prevention and rehabilitation
programs aimed at decreasing severe walking limita-
tion, risk factors for incident walking limitation need to
be understood.

Muscle strength and mortality

Longevity and mortality are central research questions
in gerontology. The length of life may well be the best
single indicator of the general health of a population.
When studying muscle strength as a predictor of length
of life, the association is potentially confounded by
many factors, which need to be considered when mod-
elling the association. Poor muscle strength has been
found to be associated with older age, lower body
weight (Era et al., 1994; Rantanen et al., 1998), presence
of chronic diseases (Häkkinen, Hannonen, Häkkinen,
1995; Bernard et al., 1998; Rantanen et al., 1998) phys-
ical inactivity (Rantanen et al., 1992; Rantanen, Era,
Heikkinen, 1997; Rantanen et al., 1999c) and lower
education (Rantanen et al., 1992). All these factors are
known predictors of increased mortality risk and may
confound the association between strength and mortal-
ity (Kaplan, Seeman, Cohen, Knudsen, Guralnik,
1989). Only few studies have addressed muscle strength
itself as a predictor of mortality (Phillips, 1986; Fujita
et al., 1995; Laukkanen, Heikkinen, Kauppinen, 1995).
In middle aged men followed for six years, the risk of
mortality was more than two times greater among those
in the lower half of grip strength vs. the higher half
(Fujita et al., 1995). In 75-year-old men and women,
poor strength tested in multiple muscle groups pre-
dicted increased mortality over a follow-up of four
years (Laukkanen et al., 1995). Among geriatric pa-
tients poor muscle strength was found to predict in-
creased mortality during acute illnesses (Phillips,
1986). These studies suggest that good strength is an
important predictor of survival. To study whether the
association between muscle strength and mortality was
independent of potential confounders such as chronic
diseases status and body weight, Honolulu Heart
Program data was used for the analyses (Rantanen
et al., 2000). All participants with documented diseases
at baseline were excluded. The eligible participants
were 6040 healthy men aged 45–68 years at baseline
living on Oahu, Hawaii. Handgrip strength and Body
Mass Index were measured at baseline in 1965–70 when
participants were 45–68 years of age. Mortality was
followed prospectively over 30 years. The death rates
per 1000 person years were 24.8 in the lowest, 18.5 in
the middle and 14.0 in the highest third of baseline grip
strength. In Cox regression models, within each tertile
of grip strength BMI showed only minimal effect on
mortality. In contrast, in each category of BMI there
was a gradient of decreasing mortality risk with increas-
ing grip strength. Among those with BMI < 20, the
adjusted relative risks (RR) of mortality over 30 years
were 1.36 (95% confidence interval, 95% CI 1.14–1.63)
for those in the lowest third of strength at baseline, 1.27
(95% CI 1.02–1.58) in the middle, and 0.92 (95% CI
0.66–1.29) in the highest third. Correspondingly, for
those with BMI 20–24.99 the RR of death were 1.25
(95% CI 1.08–1.45), 1.14 (95% CI 1.00–1.32) and 1.0
(referent). In those with BMI ≥ 25, the RR were 1.39
(95% CI 1.16–1.65) in the lowest, 1.27 (95% CI
1.08–1.49) in the middle and 1.14 (95% CI 0.98–1.32)
in the highest third of grip strength. Models were
adjusted for age, education, occupation, smoking,
physical activity and body height. Handgrip strength
measured in midlife was a significant predictor of mor-
tality over 30 years in a group of initially healthy men.

Several potential mechanisms may explain why mid-
life grip strength predicts long-term mortality. One
explanation could be earlier life influences that affect
mid-life muscle strength. Good strength could be an
indicator of better childhood living environment and
early life nutrition. In addition, mid-life strength may
be modified by earlier life-style characteristics, such as
exercise habits, or other factors such as type of work, or
early life diseases that have been cured but have had a
negative effect on strength (Rantanen et al., 1992; Hovi,
Era, Rautonen, Siimes, 1993). Secondly, poor muscle
strength could be a risk factor for diseases. Even though
poor muscle strength has been reported in people with
chronic conditions, there is very little information on
whether strength predicts incident diseases. Some evi-
dence exists that poor strength precedes the develop-
ment of insulin resistance and predicts diabetes and
may be an etiologic factor in osteoarthritis (Lazarus,
Sparrow, Weiss, 1997; Slemenda, et al., 1997). Thirdly,
high grip strength may indicate a reserve of muscle
mass, which is important when recovering from
trauma. In addition to muscle mass, maximal voluntary
muscle strength, is determined by neural drive from
motor cortex to muscles (Galea, 1996; Enoka, 1997;
Jubrias, Odderson, Esselman, Conley, 1997). Maximal
voluntary strength is thus, in fact, an indicator of the
functioning of both the neural and the muscular
systems, and may be an overall indicator of a per-
son’s vigor or stamina, that tracks into survival into
old age.

In summary, muscle strength is independently asso-
ciated with mortality risk. However, the mechanism
behind the association between muscle strength and
mortality risk is currently not completely understood.
Perspectives

It is confirmed by many observational studies that muscle strength is a powerful risk factor for functional limitations, disability and mortality in old age. The mechanisms behind the association of strength and future disability or mortality are not well understood. The association between strength and functional limitations, such as walking or stair climbing likely has a biomechanical explanation. Strength is modifiable and improves with training. Whether this improvement is translated into functional benefits still needs to be studied more carefully. However, in a high-risk population consisting of very old, frail women recuperating from an acute illness, multicomponent exercise program including strength training improved walking ability, a functional limitation often preceding disability (Timonen, Rantanen, Ryyänen, Taimela, Timonen, Sulkava, 2002). Whether improving strength will reduce the risk of disability and mortality has not been addressed in experimental studies, as establishing such a design in a controlled way would be highly challenging.

Key words: aging; epidemiology; disablement process; walking.

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References


