Association of body size and muscle strength with incidence of coronary heart disease and cerebrovascular diseases: a population-based cohort study of one million Swedish men

Karri Silventoinen,[1] Patrik K E Magnusson,[2] Per Tynelius,[3] G David Batty[4,5] and Finn Rasmussen[3,5]*

Accepted 1 October 2008

Background Muscle strength and body size may be associated with coronary heart disease (CHD) and stroke risk. However, perhaps because of a low number of cases, existing evidence is inconsistent.

Methods Height, weight, systolic (SBP) and diastolic blood pressure (DBP), elbow flexion, hand grip and knee extension strength were measured in young adulthood in 1 145 467 Swedish men born between 1951 and 1976. Information on own and parental social position was derived from censuses. During the register-based follow-up until the end of 2006, 12 323 CHD and 8865 stroke cases emerged, including 1431 intracerebral haemorrhage, 1316 subarachoid haemorrhage and 2944 intracerebral infarction cases. Hazard ratios (HR) per 1 SD in the exposures of interest were computed using Cox proportional hazard model.

Results Body mass index (BMI, kg/m^2) showed increased risk with CHD and intracerebral infarction, whereas for intracerebral and subarachoid haemorrhage both under- and overweight was associated with increased risk. Height was inversely associated with CHD and all types of stroke. After adjustment for height, BMI, SBP, DBP and social position, all strength indicators were inversely associated with disease risk. For CHD and intracerebral infarction, grip strength showed the strongest association (HR = 0.89 and 0.91, respectively) whereas for intracerebral and subarachoid haemorrhage, knee extension strength was the best predictor (HR = 0.88 and 0.92, respectively).

Conclusion Body size and muscle strength in young adulthood are important predictors of risk of CHD and stroke in later life. In addition to adiposity, underweight needs attention since it may predispose to cerebrovascular complications.

Keywords Body mass index, muscle strength, body height, coronary disease, stroke

[1] Department of Public Health, University of Helsinki, Finland.
[2] Department of Medical Epidemiology and Biostatistics, Karolinska Institute, Stockholm, Sweden.
[3] Division of Epidemiology, Stockholm Centre of Public Health, Sweden.
[4] MRC Social & Public Health Sciences Unit, University of Glasgow, Glasgow, UK.
[5] Department of Public Health Sciences, Karolinska Institute, Stockholm, Sweden.
* Corresponding author. Child and Adolescent Public Health Epidemiology Group, Department of Public Health Sciences, Karolinska Institute, Norrbacka, SE-171 76 Stockholm, Sweden. E-mail: finn.rasmussen@phs.ki.se

Introduction

Obesity is one of the most important modifiable risk factors for coronary heart disease (CHD),[1] and there is strong evidence that it is independently associated with increased risk of cerebrovascular diseases.[2] In addition to adipose mass, muscle mass may have important effect on risk of cardiovascular diseases (CVD). Previous studies have shown that skeletal muscle strength is inversely associated with the incidence of CVD[3–5] as well as several metabolic factors, such as impaired glucose tolerance or type 2 diabetes,[6] hyperinsulinemia[7] and both the prevalence[8–10] and incidence of the metabolic syndrome.[11] These associations may be partly explained by the fact that muscle strength is an indicator of general physical fitness, which is closely associated with risk of CVD.[12] However, there is increasing evidence suggesting that muscle tissue is an important organ influencing human metabolism and thus can directly affect risk of metabolic diseases.[13] This is in accordance with previous studies showing that higher lean body mass at baseline is associated with lower mortality.[14,15] Even when muscle strength is closely associated with muscle mass, a previous study found that grip strength was associated with incidence of CVD in men even after arm muscle area and fat free mass were taken into account suggesting independent effect.[5]

There are, however, several factors which can contribute to the associations between strength and CVD incidence. First, muscle mass is correlated with both stature and weight. Tall stature is known to be associated with lower CHD risk.[16] For cerebrovascular diseases this association is less clear: a Scottish study, for instance, found a clear inverse association between stature and haemorrhagic stroke, whereas the association with ischaemic stroke was weaker and statistically non-significant.[17] Thus, when analysing the effect of muscle mass on risk of CVD, the role of body size needs to be taken into account. Second, it is well known that both obesity[18] and height[19] are associated with social position, and it is likely that socioeconomic differences exist for muscle strength as well. Given that social position is associated with risk of metabolic diseases,[20] it may confound associations between body size, muscle strength and CVD risk.

In this study, we aim to analyse the association between muscle strength, relative weight and stature and their interactions, if any in young adulthood with CHD and stroke incidence in a very large cohort of Swedish men. Additionally, we will examine whether socioeconomic factors can explain these relationships. The large sample size also gives us the opportunity to explore stroke type-specific effects with adequate power.

Data and methods

The anthropometric data were derived from the Swedish Military Service Conscription Register.

The study was approved by the Ethics Committee, Stockholm, Sweden and follows the rules and principles of the Helsinki declaration. Conscription examination, which predates active military service, was mandatory by law for all male Swedish citizens in our study cohort born 1951–76, and only those with a severe handicap or a chronic disease were exempted. Age at the time of the conscription examination (1969–94) varied from 16 to 25 years (median age 18.2 years), but only 1.36% of the participants were younger than 17 or older than 20 years. During the conscription examination, diastolic (DBP) and systolic blood pressure (SBP), elbow flexion, hand grip and knee extension strength as well as height and weight in underclothes and without shoes were measured according to a protocol.[21,22] The exact measurement protocol was regarded as confidential information by the Swedish Army and was not revealed to us. However, we checked in preliminary analyses that there were no systematic differences in the mean values of the measures between conscription offices suggesting that a uniform protocol was used. We also confirmed that the values of elbow flexion, hand grip and knee extension strength in these data were close to values in a previous study of 31- to 35-year-old Finnish men.[23] Body mass index (BMI, kg/m^2) was used as an indicator of relative weight, and in stratified analyses it was categorized according to the standard World Health Organization classification: underweight ($<18.5\,kg/m^2$), normal weight ($18.5–24.9\,kg/m^2$), overweight ($25–29.9\,kg/m^2$), obese ($30–34.9\,kg/m^2$) and very obese ($\geqslant35\,kg/m^2$).[24] In the whole dataset we had 1 160 082 men, but DBP or SBP measures were missing or invalid in 13 836 men (the limits for accepted values were 40–100 mm Hg for DBP and 100–180 mm Hg for SBP) and strength measures were missing or invalid for additionally 779 men. This resulted in an analytical sample of 1 145 467 participants. Information on own and parental education and occupational socioeconomic position (SEP) were derived from the Swedish Population and Housing Censuses conducted in 1960, 1970, 1980 and 1990 as described in detail elsewhere.[25]

The follow-up data (1969–2006) were based on the Swedish Cause of Death Register, Swedish Hospital Discharge Register and Statistics Sweden's Emigration Register, which cover the entire Swedish population, and were linked to the anthropometric data using personal identity numbers. Fatal and non-fatal cases were identified according to the Eighth, Ninth and Tenth Revisions of the Swedish version of the International Classification of Diseases (ICD) for CHD (410–414 for ICD8 and ICD9 and I20–I25 for ICD10), any stroke (430–438, 344 for ICD8, 430–438, 342, 344 for ICD9 and I60–I66, G45 for ICD10), intracerebral haemorrhage (431 for ICD8 and ICD9 and I61–I62 for ICD10), subarachoid haemorrhage (430 for ICD8 and ICD9 and I60 for ICD10) and intracerebral infarction

(432–434 for ICD8, 433–434 for ICD9 and I63 for ICD10). The follow-up time was calculated in days from conscription to death or hospitalization from the disease (cases), deaths from other causes or emigration (censored observations) or to 31 December 2006 (whichever came first). Due to a lag in the Cause of Death Register, information on causes of death was available only until December 2004, while date of death was available until December 2006. Thus, we censored those persons who died but were not hospitalized during 2005–06 at the end of 2004. The total follow-up time was 27.6 million person-years and the medium follow-up time 24.4 years. During the follow-up period, 12 323 CHD and 8865 stroke cases emerged including 1431 intracerebral haemorrhage, 1316 subarachoid haemorrhage and 2944 intracerebral infarction cases.

Statistical methods

The data were analysed using Cox proportional hazard models. The proportional hazard assumption for multiple endpoints was tested graphically and no evidence for violation was found (data not shown but are available from the corresponding author). When analysing continuous variables, the results are presented as standardized hazard ratios (HRs) by transforming each variable to have a mean of 0 and a SD of 1. The HRs presented are for a 1 SD increase in each of the exposure variables (BMI, height and strength). Socioeconomic variables were treated as categorical variables in the modelling. All statistical models were carried out by the Stata statistical package (version 9.2).

Results

Table 1 presents basic statistics for the anthropometric measures at baseline and for the disease outcomes during the follow-up in the categories of baseline BMI. Mean BMI in this young male cohort was low (21.6 kg/m^2 SD 2.83), with 9% of the participants underweight, 81% normal weight, 8% overweight and 2% obese. As expected, blood pressure and muscle strength increased steadily with increasing BMI. Crude disease incidences were somewhat higher in the underweight than in the normal weight category, but otherwise they increased steadily with increasing BMI.

When we analysed socioeconomic differences in height, BMI and strength indicators, we found that men with better education and higher occupational SEP were taller and had slightly lower BMI than those with lower social position (Table 2). For strength, however, the social gradient differed between the strength indicators: whereas elbow flexion and hand grip strength was higher among those with lower education and occupational SEP, knee extension strength showed a less clear social gradient. Social differences according to mother's and

Table 1 Baseline characteristics (mean and SD) and CHD and stroke events during follow-up (incidence rates and number of cases) according to baseline BMI

	Baseline BMI (kg/m^2)				
Baseline characteristics	<18.5	18.5–24.9	25–29.9	30–34.9	⩾35
Height (cm)	179.4 (6.76)	179.2 (6.46)	178.9 (6.51)	179.1 (6.71)	179.0 (6.66)
BMI (kg/m^2)	17.7 (0.69)	21.3 (1.61)	26.7 (1.32)	31.8 (1.34)	37.6 (2.60)
SBP (mm Hg)	125.7 (10.71)	128.3 (10.75)	131.8 (10.77)	134.4 (11.02)	136.8 (11.26)
DBP (mm Hg)	67.4 (9.65)	67.3 (9.90)	68.5 (10.46)	70.4 (11.04)	72.4 (11.46)
Elbow flexion strength (N)	311 (61)	388 (79)	445 (91)	463 (98)	474 (105)
Hand grip strength (N)	548 (86)	619 (95)	654 (104)	658 (110)	658 (114)
Knee extension strength (N)	467 (91)	570 (111)	639 (125)	666 (134)	685 (148)
Incidence rates per 10 000 person-years (number of cases)					
CHD	4.26 (1110)	4.13 (9256)	6.97 (1544)	10.1 (336)	12.4 (77)
All stroke	3.44 (914)	2.99 (6848)	3.76 (855)	5.69 (196)	7.99 (52)
Intracerebral haemorrhage	0.58 (155)	0.45 (1038)	0.77 (176)	1.31 (45)	2.61 (17)
Subarachoid haemorrhage	0.63 (168)	0.45 (1031)	0.42 (95)	0.49 (17)	0.77 (5)
Intracerebral infarction	1.05 (279)	0.99 (2274)	1.32 (301)	1.97 (68)	3.38 (22)
Mean age at baseline (years)	18	18	18	18	18
Mean age at the end of follow-up (years)	44	42	41	40	39
Median follow-up time (years)	26	24	23	22	21
Number of million person-years	2.61	22.39	2.21	0.33	0.06
Number of participants	102 128	940 671	9 8677	15 520	3086

Table 2 The proportion of participants and means and SDs of height, BMI and muscle strength by subject's own and parental social position and education

				Muscle strength (N)		
	Percentage	Height (cm)	BMI (kg/m^2)	Elbow flexion	Hand grip	Knee extension
Own social position						
Higher level non-manuals	7	180.4 (6.31)	21.1 (2.32)	365 (78)	605 (95)	552 (110)
Middle level non-manuals	12	179.7 (6.34)	21.3 (2.47)	376 (81)	615 (96)	559 (112)
Lower level non-manuals	7	179.3 (6.40)	21.4 (2.62)	376 (82)	610 (97)	554 (115)
Farmers	1	179.1 (6.45)	21.7 (2.61)	410 (88)	646 (102)	542 (11)
Skilled workers	22	178.5 (6.42)	21.7 (2.84)	396 (85)	627 (98)	562 (116)
Unskilled workers	22	178.6 (6.55)	21.8 (3.06)	388 (85)	615 (99)	555 (118)
Unclassified	29	179.6 (6.54)	21.9 (2.91)	391 (85)	612 (98)	596 (119)
Own education						
Higher education	16	180.3 (6.34)	21.2 (2.35)	372 (80)	611 (95)	562 (112)
Secondary education	44	179.0 (6.47)	21.6 (2.81)	389 (85)	617 (98)	566 (117)
Basic education	25	178.8 (6.52)	21.8 (3.04)	393 (85)	618 (99)	571 (120)
Less than basic education	2	177.0 (6.45)	21.6 (3.04)	392 (88)	617 (102)	532 (117)
Missing	13	179.4 (6.55)	21.9 (3.00)	387 (85)	615 (99)	585 (119)
Father's social position						
Higher level non-manuals	6	180.3 (6.38)	21.2 (2.33)	376 (82)	607 (96)	574 (117)
Middle level non-manuals	19	179.9 (6.47)	21.4 (2.54)	381 (83)	613 (96)	572 (116)
Lower level non-manuals	10	179.6 (6.45)	21.4 (2.65)	380 (82)	611 (96)	567 (116)
Farmers	5	179.1 (6.37)	21.6 (2.68)	400 (86)	635 (101)	547 (115)
Skilled workers	25	178.8 (6.48)	21.8 (2.93)	390 (85)	618 (98)	568 (118)
Unskilled workers	29	178.7 (6.51)	21.8 (3.04)	360 (85)	617 (99)	564 (118)
Unclassified	6	179.3 (6.49)	21.9 (2.88)	392 (85)	613 (97)	596 (118)
Father's education						
Higher education	9	180.5 (6.39)	21.2 (2.30)	378 (82)	608 (96)	578 (116)
Secondary education	33	179.6 (6.48)	21.6 (2.71)	387 (84)	615 (97)	578 (117)
Basic education	7	179.3 (6.43)	21.8 (2.89)	392 (85)	615 (97)	585 (118)
Less than basic education	44	178.7 (6.47)	21.8 (2.98)	389 (85)	619 (99)	559 (117)
Missing	7	178.6 (6.54)	21.6 (2.89)	383 (85)	614 (99)	556 (117)
Mother's social position						
Higher level non-manuals	2	180.6 (6.40)	21.2 (2.36)	377 (83)	606 (96)	580 (117)
Middle level non-manuals	9	180.2 (6.44)	21.5 (2.51)	385 (83)	614 (96)	582 (117)
Lower level non-manuals	14	179.7 (6.45)	21.6 (2.69)	385 (83)	614 (97)	576 (117)
Farmers	0	178.7 (6.46)	21.8 (2.89)	402 (87)	637 (103)	551 (115)
Skilled workers	7	178.8 (6.51)	21.8 (2.97)	389 (85)	616 (98)	570 (118)
Unskilled workers	31	178.9 (6.48)	21.8 (2.94)	388 (84)	618 (98)	562 (117)
Unclassified	37	179.0 (6.50)	21.6 (2.85)	388 (85)	616 (98)	567 (118)
Mother's education						
Higher education	8	180.6 (6.40)	21.3 (2.36)	383 (83)	611 (96)	584 (117)
Secondary education	26	179.8 (6.49)	21.6 (2.73)	388 (85)	615 (97)	581 (118)
Basic education	15	179.4 (6.47)	21.7 (2.82)	390 (85)	616 (97)	581 (118)
Less than basic education	46	178.6 (6.45)	21.7 (2.94)	386 (84)	617 (98)	554 (116)
Missing	5	178.6 (6.55)	21.8 (3.00)	389 (86)	615 (99)	574 (119)

Table 3 HRs (95% CIs) for the relation of BMI with CHD and stroke incidence

	Model 1	Model 2	Model 3
CHD (kg/m^2)			
<18.5	0.86 (0.81–0.91)	0.85 (0.79–0.90)	0.82 (0.77–0.88)
18.5–24.9	1.00	1.00	1.00
25–29.9	1.98 (1.88–2.09)	1.87 (1.77–1.98)	1.74 (1.64–1.84)
30–34.9	3.23 (2.90–3.61)	2.81 (2.52–3.15)	2.50 (2.22–2.81)
⩾35	4.69 (3.74–5.87)	3.83 (3.04–4.81)	3.23 (2.54–4.10)
All stroke (kg/m^2)			
<18.5	1.03 (0.96–1.10)	0.99 (0.92–1.06)	0.96 (0.88–1.03)
18.5–24.9	1.00	1.00	1.00
25–29.9	1.38 (1.29–1.49)	1.38 (1.28–1.49)	1.37 (1.26–1.47)
30–34.9	2.25 (1.96–2.60)	2.20 (1.90–2.54)	2.08 (1.78–2.42)
⩾35	3.50 (1.67–4.60)	3.31 (2.51–4.37)	3.20 (2.40–4.26)
Intracerebral haemorrhage (kg/m^2)			
<18.5	1.17 (0.99–1.38)	1.15 (0.97–1.38)	1.09 (0.90–1.33)
18.5–24.9	1.00	1.00	1.00
25–29.9	1.85 (1.58–2.17)	1.76 (1.49–2.08)	1.80 (1.51–2.15)
30–34.9	3.32 (2.46–4.48)	2.88 (2.11–3.93)	2.83 (2.03–3.93)
⩾35	7.26 (4.49–11.74)	5.75 (3.48–9.50)	5.87 (3.49–9.88)
Subarachoid haemorrhage (kg/m^2)			
<18.5	1.28 (1.09–1.51)	1.22 (1.02–1.45)	1.19 (0.99–1.44)
18.5–24.9	1.00	1.00	1.00
25–29.9	1.00 (0.81–1.23)	1.00 (0.80–1.24)	0.99 (0.79–1.24)
30–34.9	1.24 (0.77–2.01)	1.22 (0.75–1.99)	0.96 (0.55–1.67)
⩾35	2.10 (0.87–5.05)	2.03 (0.84–4.90)	2.02 (0.83–4.90)
Intracerebral infarction (kg/m^2)			
<18.5	0.92 (0.81–1.04)	0.86 (0.76–0.98)	0.86 (0.75–0.99)
18.5–24.9	1.00	1.00	1.00
25–29.9	1.50 (1.33–1.69)	1.52 (1.34–1.72)	1.46 (1.28–1.67)
30–34.9	2.45 (1.92–3.12)	2.45 (1.91–3.13)	2.37 (1.83–3.05)
⩾35	4.76 (3.13–7.24)	4.69 (3.04–7.16)	4.46 (2.88–6.89)

Model 1, adjusted for birth cohort, conscription age and conscription office.
Model 2, additionally adjusted for SBP, DBP, elbow flexion strength, grip strength and knee extension strength.
Model 3, additionally adjusted for own and parental education and SEP treated as categorized variables.

father's education and occupational SEP were similar to those found for own social position.

Given that crude disease incidences showed some evidence for increased morbidity in underweight men, we first analysed CHD and stroke risk by categorized BMI (Table 3). Compared with normal weight men, underweight men showed increased risk for intracerebral and subarachoid haemorrhage whereas for CHD and intracerebral infarction, disease risk was lower in underweight men. In overweight and obese men, risk was increased for CHD and all types of stroke. For subarachoid haemorrhage, the risk increase in obese persons was, however, much lower than for the other types of stroke and not statistically significant. Adjustment for DBP, SBP and the three measures of strength (Model 2) as well as own and parental education and occupational SEP (Model 3) attenuated the increased risk for intracerebral and subarachoid haemorrhage in underweight men, and it remained marginally statistically significant only for subarachoid haemorrhage. In the overweight and obese categories, the adjustments for these risk factors attenuated the risks, but the associations held.

Table 4 presents the standardized HRs for height in relation to the three strength indicators. Since we found some non-linearity in the association between

Table 4 HRs (95% CIs) for 1 SD increase in height and muscle strength in relation to CHD and stroke incidence

	Model 1	Model 2	Model 3	Model 4
CHD				
Height	0.80 (0.79–0.82)	0.80 (0.79–0.82)	0.83 (0.82–0.85)	0.85 (0.83–0.87)
Elbow flexion strength	1.09 (1.07–1.11)	0.99 (0.97–1.01)	0.95 (0.93–0.97)	1.01 (0.99–1.04)
Grip strength	0.97 (0.95–0.99)	0.96 (0.94–0.98)	0.89 (0.88–0.91)	0.95 (0.93–0.98)
Knee extension strength	1.02 (1.00–1.04)	0.92 (0.91–0.94)	0.92 (0.90–0.94)	0.95 (0.93–0.98)
All stroke				
Height	0.91 (0.89–0.93)	0.91 (0.89–0.92)	0.93 (0.91–0.95)	0.94 (0.92–0.97)
Elbow flexion strength	1.02 (1.00–1.04)	0.99 (0.96–1.01)	0.96 (0.94–0.99)	1.00 (0.98–1.04)
Grip strength	0.97 (0.95–0.99)	0.97 (0.95–0.99)	0.95 (0.93–0.97)	0.99 (0.96–1.01)
Knee extension strength	0.96 (0.94–0.98)	0.92 (0.90–0.95)	0.93 (0.90–0.95)	0.94 (0.91–0.97)
Intracerebral haemorrhage				
Height	0.87 (0.83–0.92)	0.87 (0.82–0.92)	0.87 (0.82–0.92)	0.88 (0.83–0.94)
Elbow flexion strength	1.08 (1.03–1.14)	1.03 (0.97–1.09)	0.94 (0.89–1.01)	1.06 (0.99–1.15)
Grip strength	0.98 (0.93–1.03)	0.99 (0.93–1.05)	0.92 (0.87–0.98)	0.99 (0.92–1.06)
Knee extension strength	0.98 (0.92–1.03)	0.92 (0.86–0.97)	0.88 (0.82–0.93)	0.90 (0.83–0.96)
Subarachoid haemorrhage				
Height	0.90 (0.85–0.95)	0.89 (0.84–0.94)	0.92 (0.86–0.97)	0.93 (0.88–0.99)
Elbow flexion strength	0.94 (0.89–1.00)	1.00 (0.94–1.07)	0.98 (0.91–1.05)	1.04 (0.96–1.12)
Grip strength	0.96 (0.91–1.01)	0.95 (0.90–1.02)	0.93 (0.88–0.99)	0.96 (0.89–1.03)
Knee extension strength	0.89 (0.84–0.94)	0.92 (0.86–0.98)	0.92 (0.86–0.99)	0.93 (0.86–1.00)
Intracerebral infarction				
Height	0.87 (0.84–0.91)	0.88 (0.84–0.91)	0.91 (0.88–0.95)	0.93 (0.89–0.97)
Elbow flexion strength	1.00 (0.97–1.04)	0.94 (0.90–0.98)	0.92 (0.88–0.96)	0.95 (0.90–1.00)
Grip strength	0.95 (0.91–0.98)	0.94 (0.90–0.98)	0.91 (0.88–0.95)	0.96 (0.91–1.01)
Knee extension strength	0.99 (0.95–1.03)	0.93 (0.90–0.98)	0.94 (0.90–0.99)	0.99 (0.94–1.04)

Model 1, adjusted for birth cohort, conscription age and conscription office.
Model 2, additionally adjusted for categorized BMI, continuous BMI, height, SBP and DBP.
Model 3, additionally adjusted for own and parental education and SEP treated as categorized variables.
Model 4, additionally adjusted for all indicators of muscle strength.

BMI and the disease outcomes, we adjusted the results for both categorized and continuous BMI in Models 2–4 (the parameter estimates for BMI not shown). Height was inversely associated with CHD and stroke incidence including all types of stroke. Adjustment for BMI, SBP and DBP (Model 2) as well as own and parental social position (Model 3) attenuated the risk estimates only slightly, and they remained statistically significant. Grip and knee extension strength showed inverse association with most disease outcomes in the unadjusted models (Model 1). Adjustment for BMI, SBP and DBP (Model 2) as well as own and parental social position (Model 3) somewhat strengthened these inverse associations. In contrast to the two other strength indicators, elbow flexion strength showed positive or no association with all disease outcomes in the unadjusted

models (Model 1). However, after the adjustment for the other risk factors, the positive associations between elbow flexion strength and the disease risk was eliminated (Model 3). In the final model with mutual control for all strength indicators (Model 4), knee extension strength showed a stronger inverse association with any type of stroke, intracerebral haemorrhage and subarachoid haemorrhage than grip or elbow flexion strength. No difference between grip and knee extension strength were seen for CHD (Model 4); for intracerebral infarction, elbow flexion strength showed the strongest inverse association.

Finally, we analysed interaction effects between BMI and muscle strength categorized in quartiles for CHD and any stroke and found that these interaction effects were statistically non-significant for all strength indicators (P-values varied from

0.12 to 0.74). Owing to the small number of cases, no interaction tests were done for type-specific stroke.

Discussion

In this large cohort of young Swedish men, we found that knee extension and grip strength were inversely associated with CHD and stroke incidences including intracerebral haemorrhage, subarachoid haemorrhage and intracerebral infarction. These results support the findings of two previous studies where grip strength was associated with lower CVD mortality in middle age and elderly populations.[3,4] Elbow flexion strength showed a positive association with disease risk, but this association disappeared when BMI and social position (own and parental) were added to the multivariable model. This suggests that high elbow flexion strength in young men is associated with socioeconomic and lifestyle factors predisposing to higher CVD risk in later life. We also found that knee extension strength had a stronger protective effect on stroke risk—including intracerebral and subarachoid haemorrhage—than grip or elbow flexion strength. Further studies analysing the associations between different muscle groups and metabolic factors are thus warranted. However, it is also possible that knee extension strength could be a better proxy indicator of general fitness and physical activity than elbow flexion and grip strength. After mutual adjustment for other strength indicators, the predictive power of them for the health outcomes in the present analyses decreased strongly. This is to be expected since as we have reported earlier,[21] they show moderate mutual correlations ($r = 0.43$–0.54). In these analyses, knee extension strength showed somewhat stronger association with most of the disease outcomes than grip or elbow flexion strength.

Adiposity was strongly and positively associated with both CHD and stroke incidence, as found also in previous studies,[1,2] and the risk increased in similar ways in all categories of muscle strength. Underweight was associated with higher incidence of intracerebral and subarachoid haemorrhage but lower incidence of intracerebral infarction and CHD when compared with normal weight men. This is in accordance with several previous studies, which also found an increased risk of haemorrhagic stroke in lean persons;[2,26–28] because of small number of haemorrhagic stroke cases in these studies, this risk estimate was statistically significant in only one.[27] Adjustment for SBP, DBP, muscle strength as well as own and parental social position, however, partly explained this increased risk in underweight men in our study. These results were supported by our previous study in the Finnish middle-aged population, which found that underweight was associated with low social position, marginalization and poor health behaviour, especially in men.[29] It is noteworthy that, because mean BMI was low in our data, underweight

was not rare (9% of our study subjects belonged to this category). It is likely that a major proportion of the men who were underweight at conscription examination in young adulthood increased in weight during the following decades. This suggests that individuals that are underweight in young adulthood but normal weight during middle age may still be at increased risk for cerebrovascular complications later in life.

We also found that tall stature was associated with lower CHD and stroke incidence. For CHD, this association has previously been reported in multiple studies and confirmed by a large twin study reporting similar association within twin pairs discordant for height and CHD mortality.[16] In contrast, the associations between height and type-specific stroke are still open for discussion. A Scottish study reported that height was strongly associated with haemorrhagic stroke but more weakly and statistically non-significantly with ischaemic stroke.[17] Similar results were found in a study of South Korean men.[30] However, a Japanese study reported that height was inversely associated with intracerebral infarction in men and women, although the risk estimate was statistically significant only for women.[31] In the same study, a non-significant inverse association was found between height and haemorrhagic stroke among men. It is noteworthy that in all of these three studies, the number of cases of specific types of stroke was small, which is likely to explain the discrepancy in these results. In contrast, in our study with much greater statistical power, the negative association of height with haemorrhagic stroke and intracerebral infarction was largely similar.

Our study has not only several advantages but also some limitations. The main advantage is the large sample size which, as described, allowed us to analyse type-specific stroke with adequate power. It is also noteworthy that conscription examination was mandatory by law in our birth cohorts, and thus participation bias because of self-selection does not exist. However, because disability or a severe chronic disease was a valid reason to be exempted, our cohort represents mainly healthy Swedish men at baseline. We also have information both on parental and own socioeconomic position from censuses with nearly 100% participation, which is probably less prone to reporting bias than self-reported data.

A clear limitation is that since our study design was based on utilizing conscription data, we had information only on men and thus our results cannot be directly generalized to women. Further, our data were not originally collected for other than scientific purposes, and detailed measurement protocols of strength indicators were not revealed by the Swedish army. Thus, we do not know exactly which muscle groups were tested. However, as indicated, the strength values correspond closely to values in adult Finnish male population,[23] and the correlations of

nearby muscle groups are found to be very high.[32] Further, we have also previously reported that these strength indicators show moderate mutual correlations, and also the expected correlations were found within brother pairs suggesting at least satisfactory reliability.[21] However, it is plausible that the reliability of our measures may still be lower than in many other epidemiological cohorts. This may dilute the association between muscle strength and further CVD incidence, which should thus in this study be regarded as the lower limit of this association. If the measurement errors vary between the strength measures, it may also partly explain differences in the size of the associations between these strength measures and further CVD incidence. A limitation is also that we had information only on a limited number of risk factors of CVD. If we had had more detailed measures, for example on health behavioural factors, they may have partly explained the reported associations.

In conclusion, high muscle strength was associated with lower risk of CHD and stroke incidence. BMI showed positive association with risk of CHD and intracerebral infarction, whereas for intracerebral and subarachoid haemorrhage both under- and overweight were associated with increased risk. Height was inversely associated with CHD and all types of stroke. Our results show that body size and muscle strength in young adulthood are important predictors of further CVD risk.

Funding

KEY MESSAGES

- High muscle strength in young males is associated with lower CHD and stroke incidence and this association is similar in normal weight, overweight and obese persons.

- Obesity showed to be associated with increased risk of CHD, intracerebral haemorrhage stroke and intracerebral infarction whereas for subarachoid haemorrhage stroke the association was much weaker.

- Underweight men showed increased risk for intracerebral and subarachoid haemorrhage stroke.

References

1 Jousilahti P, Tuomilehto J, Vartiainen E, Pekkanen J, Puska P. Body weight, cardiovascular risk factors, and coronary mortality. 15-year follow-up of middle-aged men and women in eastern Finland. *Circulation* 1996;**93**:1372–79.

2 Hu G, Tuomilehto J, Silventoinen K, Sarti C, Mannisto S, Jousilahti P. Body mass index, waist circumference, and waist-hip ratio on the risk of total and type-specific stroke. *Arch Intern Med* 2007;**167**:1420–27.

3 Rantanen T, Volpato S, Ferrucci L, Heikkinen E, Fried LP, Guralnik JM. Handgrip strength and cause-specific and total mortality in older disabled women: exploring the mechanism. *J Am Geriatr Soc* 2003;**51**:636–41.

4 Sasaki H, Kasagi F, Yamada M, Fujita S. Grip strength predicts cause-specific mortality in middle-aged and elderly persons. *Am J Med* 2007;**120**:337–42.

5 Gale CR, Martyn CN, Cooper C, Sayer AA. Grip strength, body composition, and mortality. *Int J Epidemiol* 2007; **36**:228–35.

6 Sayer AA, Dennison EM, Syddall HE, Gilbody HJ, Phillips DI, Cooper C. Type 2 diabetes, muscle strength, and impaired physical function: the tip of the iceberg? *Diabetes Care* 2005;**28**:2541–42.

7 Lazarus R, Sparrow D, Weiss ST. Handgrip strength and insulin levels: cross-sectional and prospective associations in the Normative Aging Study. *Metabolism* 1997;**46:** 1266–69.

8 Wijndaele K, Duvigneaud N, Matton L *et al*. Muscular strength, aerobic fitness, and metabolic syndrome risk in Flemish adults. *Med Sci Sports Exerc* 2007;**39**:233–40.

9 Sayer AA, Syddall HE, Dennison EM *et al*. Grip strength and the metabolic syndrome: findings from the Hertfordshire Cohort Study. *Q J Med* 2007;**100**:707–13.

10 Jurca R, Lamonte MJ, Church TS *et al*. Associations of muscle strength and fitness with metabolic syndrome in men. *Med Sci Sports Exerc* 2004;**36**:1301–07.

11 Jurca R, Lamonte MJ, Barlow CE, Kampert JB, Church TS, Blair SN. Association of muscular strength with incidence of metabolic syndrome in men. *Med Sci Sports Exerc* 2005;**37**:1849–55.

12 Swain DP, Franklin BA. Comparison of cardioprotective benefits of vigorous versus moderate intensity aerobic exercise. *Am J Cardiol* 2006;**97**:141–47.

13 Tomas E, Kelly M, Xiang X *et al*. Metabolic and hormonal interactions between muscle and adipose tissue. *Proc Nutr Soc* 2004;**63**:381–85.

14 Heitmann BL, Erikson H, Ellsinger BM, Mikkelsen KL, Larsson B. Mortality associated with body fat, fat-free mass and body mass index among 60-year-old Swedish men — a 22-year follow-up. The study of men born in 1913. *Int J Obes* 2000;**24**:33–37.

[15] Bigaard J, Frederiksen K, Tjonneland A *et al*. Body fat and fat-free mass and all-cause mortality. *Obes Res* 2004;**12:** 1042–49.

[16] Silventoinen K, Zdravkovic S, Skytthe A *et al*. Association between height and coronary heart disease mortality: a prospective study of 35,000 twin pairs. *Am J Epidemiol* 2006;**163:**615–21.

[17] McCarron P, Hart CL, Hole D, Davey Smith G. The relation between adult height and haemorrhagic and ischaemic stroke in the Renfrew/Paisley study. *J Epidemiol Community Health* 2001;**55:**404–05.

[18] McLaren L. Socioeconomic status and obesity. *Epidemiol Rev* 2007;**29:**29–48.

[19] Silventoinen K, Lahelma E, Lundberg O, Rahkonen O. Body height, birth cohort and social background in Finland and Sweden. *Eur J Public Health* 2001;**11:**124–29.

[20] Silventoinen K, Pankow J, Jousilahti P, Hu G, Tuomilehto J. Educational inequalities in the metabolic syndrome and coronary heart disease among middle-aged men and women. *Int J Epidemiol* 2005;**34:**327–34.

[21] Silventoinen K, Magnusson PK, Tynelius P, Kaprio J, Rasmussen F. Heritability of body size and muscle strength in young adulthood: a study of one million Swedish men. *Genetic Epidemiol* 2008;**32:**341–9.

[22] Neovius M, Teixeira-Pinto A, Rasmussen F. Shift in the composition of obesity in young adult males in Sweden over a third of a century. *Int J Obes* 2008;**32:**832–6.

[23] Viitasalo JT, Era P, Leskinen AL, Heikkinen E. Muscular stregth profiles and anthropometry in random samples of men aged 31–35, 51–55 and 71–75 years. *Ergonomics* 1985;**28:**1563–74.

[24] WHO Expert Committee. Physical status: the use and interpretation of anthropometry. WHO Technical Reports Series. Geneva: WHO, 1995;854.

[25] Silventoinen K, Modig-Wennerstad K, Tynelius P, Rasmussen F. Association between intelligence and coronary heart disease mortality: a population-based cohort study of 682 361 Swedish men. *Eur J Cardiovasc Prev Rehabil* 2007;**14:**555–60.

[26] Song YM, Sung J, Davey Smith G, Ebrahim S. Body mass index and ischemic and hemorrhagic stroke: a prospective study in Korean men. *Stroke* 2004;**35:**831–36.

[27] Kurth T, Gaziano JM, Berger K *et al*. Body mass index and the risk of stroke in men. *Arch Intern Med* 2002;**162:**2557–62.

[28] Cui R, Iso H, Toyoshima H *et al*. Body mass index and mortality from cardiovascular disease among Japanese men and women: the JACC study. *Stroke* 2005;**36:** 1377–82.

[29] Sarlio-Lähteenkorva S, Silventoinen K, Jousilahti P, Hu G, Tuomilehto J. The association between thinness and socioeconomic disadvantage, health indicators, and adverse health behaviour: a study of 28 000 Finnish men and women. *Int J Obes* 2004;**28:**568–73.

[30] Song YM, Davey Smith G, Sung J. Adult height and cause-specific mortality: a large prospective study of South Korean men. *Am J Epidemiol* 2003;**158:**479–85.

[31] Hozawa A, Murakami Y, Okamura T *et al*. Relation of adult height with stroke mortality in Japan: NIPPON DATA80. *Stroke* 2007;**38:**22–26.

[32] Tiainen K, Sipilä S, Alen M *et al*. Shared genetic and environmental effects on strength and power in older female twins. *Med Sci Sports Exerc* 2005;**37:**72–78.