EPIDEMIOLOGY

# Strength Training and the Risk of Type 2 Diabetes and Cardiovascular Disease

ERIC J. SHIROMA[1,2,3], NANCY R. COOK[2,3], JOANN E. MANSON[2,3], MV MOORTHY[3], JULIE E. BURING[2,3], ERIC B. RIMM[3,4], and I-MIN LEE[2,3]

[1]*Laboratory of Epidemiology and Population Science, Intramural Research Program of the National Institutes of Health, National Institute on Aging, Bethesda, MD;* [2]*Division of Preventive Medicine, Brigham and Women's Hospital, Harvard Medical School, Boston, MA;* [3]*Department of Epidemiology, Harvard T.H. Chan School of Public Health, Boston, MA; and* [4]*Department of Nutrition, Harvard School of Public Health, Boston, MA*



**ABSTRACT**

SHIROMA, E. J., N. R. COOK, J. E. MANSON, MV MOORTHY, J. E. BURING, E. B. RIMM, and I-M. LEE. Strength Training and the Risk of Type 2 Diabetes and Cardiovascular Disease. *Med. Sci. Sports Exerc.*, Vol. 49, No. 1, pp. 40–46, 2017. **Purpose**: This study aimed to examine the association of strength training with incident type 2 diabetes and cardiovascular disease risk. **Methods**: We followed 35,754 healthy women (mean age = 62.6 yr, range = 47.0–97.8) from the Women's Health Study, who responded to a health questionnaire that included physical activity questions in 2000, assessing health outcomes through annual health questionnaire through 2014 (mean ± SD follow-up = 10.7 ± 3.7 yr). Incident type 2 diabetes (*N* cases = 2120) and cardiovascular disease (*N* cases = 1742) were confirmed on medical record review. Cases of cardiovascular disease were defined as confirmed cases of myocardial infarction, stroke, coronary artery bypass graft, angioplasty, or cardiovascular disease death. **Results**: Compared with women who reported no strength training, women engaging in any strength training experienced a reduced rate of type 2 diabetes of 30% (hazard ratio = 0.70, 95% confidence interval = 0.61–0.80) when controlling for time spent in other activities and other confounders. A risk reduction of 17% was observed for cardiovascular disease among women engaging in strength training (hazard ratio = 0.83, 95% confidence interval = 0.72, 0.96). Participation in both strength training and aerobic activity was associated with additional risk reductions for both type 2 diabetes and cardiovascular disease compared with participation in aerobic activity only. **Conclusions**: These data support the inclusion of muscle-strengthening exercises in physical activity regimens for reduced risk of type 2 diabetes and cardiovascular disease, independent of aerobic exercise. Further research is needed to determine the optimum dose and intensity of muscle-strengthening exercises. **Key Words:** RESISTANCE TRAINING, EPIDEMIOLOGY, WOMEN, LONGITUDINAL STUDY

Federal physical activity guidelines recommend muscle-strengthening activities at least twice a week in addition to at least 150 min·wk$^{-1}$ of moderate-to-vigorous aerobic physical activity for health benefits (27). Although the primary rationale for including muscle-strengthening activities in the guidelines was musculoskeletal health (18), muscle-strengthening activities have recently been associated with reduced risk factors of type 2 diabetes and cardiovascular disease (18,26,30). However, there is little research directly examining the longitudinal associations of weight lifting and strength training with incident type 2 diabetes and cardiovascular disease risk (2,8,9,18).

Several biological mechanisms support a hypothesis of muscle-strengthening activities reducing the risk of type 2 diabetes and cardiovascular disease. Resistance training has been shown to increase muscle mass, reduce body mass index (BMI), improve insulin sensitivity, and increase glucose transport (17,26,30). The majority of literature investigating the association of muscle-strengthening exercises with type 2 diabetes and cardiovascular disease risk has been limited to short-term randomized control trials examining biomarkers of type 2 diabetes and cardiovascular risk (18,26). A recent meta-analysis of randomized controlled trials has highlighted that weight lifting alone or in combination with aerobic exercise increases muscle size, reduces weight, lowers cardiovascular risk factors, and increases glycemic control (30). Interestingly, this meta-analysis also directly compared the

Address for correspondence: Eric J Shiroma, Sc.D., M.Ed., 7201 Wisconsin Ave., Gateway Bldg., Suite 3C309, Bethesda, MD 20814; E-mail: Eric.shiroma@nih.gov.
Submitted for publication February 2016.
Accepted for publication July 2016.
Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's Web site (www.acsm-msse.org).

0195-9131/17/4901-0040/0
MEDICINE & SCIENCE IN SPORTS & EXERCISE®

DOI: 10.1249/MSS.0000000000001063

effects of resistance exercise and aerobic exercise and found little to no difference between the two types of physical activity on the outcomes listed. It is unclear if these associations in short duration trials of biomarkers translate into reduced rates of incident disease.

The few studies examining weight lifting and incident cases of type 2 diabetes and cardiovascular disease have reported inconsistent results. An analysis of men from the Health Professional Follow-up Study, by Tanasescu et al. (25), reported that weight lifting was associated with a 23% risk reduction for coronary heart disease. However, a later analysis including 10 more years of follow-up of the same men, and that also examined stroke, by Chomistek et al. (2) found no significant association of weight lifting with cardiovascular disease (i.e., including coronary heart disease and stroke outcomes). When examining type 2 diabetes in this cohort, Grontved et al. (9) observed an inverse dose response of time spent weight lifting and incident type 2 diabetes, ranging from a 12% to 34% rate reduction. A recent analysis of the Nurses' Health Study reported that women engaging in muscle-strengthening exercises had a reduced risk of type 2 diabetes ranging from 7% to 40% (8).

Therefore, to provide additional information in a large prospective cohort of older women, we examined the associations of strength training with incident type 2 diabetes and cardiovascular disease.

## METHODS

**Study participants.** We analyzed data from the Women's Health Study (WHS)—a completed randomized trial examining low-dose aspirin and vitamin E for the prevention of cardiovascular disease and cancer among 39,876 healthy women, conducted from 1992 to 2004 (4,14,19). Women completed health questionnaires every 6 months during the first year, and then annually thereafter. After the scheduled conclusion of the trial, women have been followed in an observational study. For this study, the 37,162 women who returned the 96-month questionnaire (that included a question on strength training) were eligible. We excluded 1408 women with missing information on physical activity on this questionnaire, as described in the next section. For diabetes analyses, we excluded 2291 women with diabetes diagnosis before the 96-month questionnaire, resulting in an analysis sample of 33,463. For cardiovascular disease, we excluded 822 women with cardiovascular disease diagnoses before the 96-month questionnaire, resulting in an analysis sample of 34,932. Women provided written consent to participate, and the study was approved by the institutional review board of Brigham and Women's Hospital.

**Assessment of physical activity.** On the baseline health questionnaire and periodically during follow-up, women reported their walking pace, flights of stairs climbed, and time spent per week in various leisure time activities or groups of activities. A strength training question was added to the list of activities on the 96-month questionnaire (see Figure, Supplemental Digital Content 1, Physical Activity Questionnaire, Women's Health Study, http://links.lww.com/MSS/A755), "During the past year, what was your approximate time per week spent at each of the following recreational activities? Weight lifting/strength training." The physical activity questionnaire is based on the College Alumni Health Study questionnaire (1) and has been shown to be reliable and valid (29). In women, the 2-yr test–retest correlation was 0.59, and when compared with four past-week activity recalls and four 7-d diaries, physical activity estimates yielded correlations of 0.79 and 0.62, respectively (29). For the present analysis, we used physical activity assessments starting with the 96-month questionnaire and updated from the 120-, 144-, 168-, 192-, and 216-month follow-up questionnaires.

Women were categorized based on minutes per week spent strength training and aerobic activities during the past year. Aerobic activities included jogging, running, tennis/squash/racquetball, walking, bicycling, aerobic exercise/aerobic dance/exercise machines, lap swimming, stair climbing, and other aerobic activities (see Figure, Supplemental Digital Content 1, Physical Activity Questionnaire, Women's Health Study, http://links.lww.com/MSS/A755). The five categories were as follows: no participation, 1 to <20 $\text{min}\cdot\text{wk}^{-1}$, 20 to <60 $\text{min}\cdot\text{wk}^{-1}$, 60 to <120 $\text{min}\cdot\text{wk}^{-1}$, and ≥120 $\text{min}\cdot\text{wk}^{-1}$ of participation. "Lower-intensity and conditioning activities" included yoga, stretching, toning, and other lower-intensity exercises (see Figure, Supplemental Digital Content 1, Physical Activity Questionnaire, Women's Health Study, http://links.lww.com/MSS/A755).

**Assessment of covariates, cardiovascular disease, and type 2 diabetes.** Baseline information was collected on age, height, weight, smoking habits, menopausal status, hormone use, and parental history of myocardial infarction before age 60 yr. Dietary habits (including alcohol consumption) were assessed using a semiquantitative food questionnaire (28). All information, except for diet, was updated from the annual follow-up questionnaires.

We ascertained type 2 diabetes and cardiovascular disease using standard methods of the WHS as described previously (6,15,16). Briefly, women reported incident type 2 diabetes and cardiovascular disease on annual follow-up questionnaires. Cases of type 2 diabetes were validated using the American Diabetic Association criteria through a telephone interview, supplemental questionnaire, and medical records. Ascertainment of self-reported type 2 diabetes mellitus using these methods has been shown to have a positive predictive value of 91% (5). Cases of cardiovascular disease were defined as confirmed cases of myocardial infarction, stroke, coronary artery bypass graft, angioplasty, or cardiovascular disease death. Study physicians reviewed medical records to confirm cases of cardiovascular disease. Women were followed from the date women returned the 96-month questionnaire through 2014 (≥99% complete).

**Statistical analyses.** Participant characteristics were described by minutes per week of strength training. For strength training and aerobic activities, we calculated hazard ratios (HR) and 95% confidence intervals (95% CI)

EPIDEMIOLOGY

comparing the rates of type 2 diabetes and cardiovascular disease across categories of time spent per week in each activity type using Cox proportional hazard models.

For all analyses, we used three nested analytical models:

1. *Multivariable adjusted model 1*: adjusted for age, smoking status, alcohol consumption, vegetable and fruit intake, saturated fat intake, total caloric intake, parental history of myocardial infarction, postmenopausal status, hormone therapy, randomization arm during the trial period
2. *Multivariable adjusted model 2*: multivariable adjusted model 1, additionally adjusting for time spent in other activities (lower-intensity activities and either strength training or aerobic activity)
3. *Multivariable adjusted model 3*: multivariable adjusted model 2, additionally adjusted for BMI, calculated as weight (kg) divided by height squared ($m^2$)

Nested models were used to examine the effects of different levels of potential confounder adjustment. Multivariable model 2 controlled for the overall physical activity volume to examine strength training independent of other physical activities, whereas model 3 examines the effects of controlling (or potentially overadjusting) for the potential intermediate of BMI. The proportional hazards assumption was tested and found to meet the assumptions.

To examine the joint association of strength training and aerobic activity, we compared the rates of type 2 diabetes and cardiovascular disease across the combinations of strength training (participation or no participation) and aerobic activities (no aerobic activities, ≥1 to <120 min·wk$^{-1}$, and ≥120 min·wk$^{-1}$). The joint association of strength training and aerobic activity was modeled using multivariable adjusted model 2. Because of the low number of cases among those who participated in strength training but no aerobic activities, we did not formally test for statistical interaction.

## RESULTS

Participant characteristics by categories of time spent strength training are displayed in Table 1. At the time of the 96-month questionnaire, 6742 (18.9%) women engaged in some strength training. On average, women were 62.6 yr old (SD = 6.9, range = 47.0–97.8) with a BMI of 27.0 kg·m$^{-2}$ (SD = 5.5). Women who reported participating in any amount of strength training were more likely to have a lower BMI, more likely to engage in healthy dietary patterns, and less likely to be a current smoker compared with women who did not participate in strength training.

From 2000 to 2014, 2120 women developed type 2 diabetes (average follow-up of 10.7 yr, SD = 3.7) and 1742 women developed cardiovascular disease (average follow-up of 11.2 yr, SD = 2.9). Participation in any strength training was associated with a 30% rate reduction of type 2 diabetes (HR = 0.70, 95% CI = 0.61–0.80, $P < 0.001$) compared with no participation, adjusting for time spent in lower-intensity and aerobic activities and model 1 covariates (age, smoking status, alcohol consumption, vegetable and fruit intake, saturated fat intake, total caloric intake, parental history of myocardial infarction, postmenopausal status, hormone therapy, and randomization arm during the trial period). Compared with women who did not participate in any strength training, women who engaged in 1 to <20, 20 to <60, 60 to <120, and ≥120 min·wk$^{-1}$ experienced multivariable adjusted type 2 diabetes rate reductions of 33% (HR = 0.67, 95% CI = 0.54–0.84), 22% (HR = 0.78, 95% CI = 0.62–0.98), 32% (HR = 0.68, 95% CI = 0.54–0.86), and 35% (HR = 0.65, 95% CI = 0.47–0.91) ($P$ trend < 0.001, Table 2).

We observed an inverse dose response of aerobic activity and type 2 diabetes rates that persisted after controlling for lower-intensity activities, strength training, and model 1 covariates ($P$ trend < 0.001, Table 2). Among women who participated in 1 to <20, 20 to <60, 60 to <120, and ≥120 min·wk$^{-1}$, we observed type 2 diabetes HR of 0.86 (95%



TABLE 1. Participant characteristics by time spent/strength training, WHS.

| | Minutes per Week of Strength Training | | | | |
|---|---|---|---|---|---|
| | None | 1 to <20 | 20 to <60 | 60 to <120 | ≥120 |
| Characteristic | (*n* = 29,012) | (*n* = 1829) | (*n* = 1715) | (*n* = 2044) | (*n* = 1154) |
| Age, mean (SD), yr | 62.8 (7.0) | 61.8 (6.6) | 61.6 (6.3) | 61.5 (6.3) | 61.6 (6.3) |
| BMI, mean (SD), kg·m$^{-2}$ | 27.4 (5.6) | 25.9 (4.9) | 25.4 (4.3) | 25.5 (4.5) | 25.2 (4.5) |
| Postmenopausal, *n* (%) | 26,390 (91.0) | 1656 (90.5) | 1549 (90.3) | 1827 (89.4) | 1039 (90.0) |
| Current hormone replacement therapy, *n* (%) | 14,397 (49.6) | 963 (52.7) | 940 (54.8) | 1110 (54.3) | 628 (54.4) |
| Current smoking, *n* (%) | 2696 (9.3) | 80 (4.4) | 63 (3.7) | 89 (4.4) | 47 (4.1) |
| Parental history of MI, *n* (%) | 4131 (14.5) | 251 (13.9) | 232 (13.7) | 282 (14.0) | 173 (15.3) |
| Alcohol, never drinkers, *n* (%) | 13,100 (45.2) | 677 (37.0) | 557 (32.5) | 640 (31.3) | 375 (32.5) |
| Alcohol, among drinkers, mean (SD), g·d$^{-1}$ | 7.5 (10.1) | 7.4 (9.2) | 7.4 (8.6) | 7.8 (9.3) | 8 (9.4) |
| Total calories, mean (SD), kcal·d$^{-1}$ | 1724.8 (534.5) | 1768.0 (523.4) | 1758.5 (490.2) | 1739.3 (515.1) | 1735.7 (536.1) |
| Saturated fat, mean (SD), g·d$^{-1}$ | 20.0 (8.2) | 19.5 (7.7) | 18.9 (7.2) | 18.3 (7.5) | 17.8 (7.7) |
| Fiber, mean (SD), g·d$^{-1}$ | 18.6 (8.0) | 20.1 (8.2) | 20.2 (7.9) | 20.9 (8.7) | 21.4 (9.4) |
| Fruits and vegetables, mean (SD), servings per day | 6.0 (3.5) | 6.3 (3.7) | 6.5 (3.3) | 6.9 (3.4) | 7.2 (4.0) |
| Hypertension, *n* (%) | 14,218 (49.0) | 700 (38.3) | 618 (36.0) | 789 (38.6) | 416 (36.1) |
| High cholesterol, *n* (%) | 15,476 (53.3) | 901 (49.3) | 801 (46.7) | 963 (47.1) | 530 (45.9) |
| Physical activity, median (IQR), min·wk$^{-1}$ | | | | | |
| Strength training | 0 (0–0) | 10 (10–10) | 40 (40–40) | 60 (60–90) | 150 (150–300) |
| Aerobic activities | 102 (32–300) | 142 (57–272) | 192 (102–322) | 272 (154–429) | 367 (214–572) |
| Lower-intensity activities | 0 (0–0) | 10 (0–40) | 10 (0–40) | 40 (0–60) | 40 (0–150) |

IQR, interquartile range.

TABLE 2. HR of type 2 diabetes by time spent in strength training and aerobic activities, WHS.

| | Minutes per Week in Strength Training or Aerobic Activities | | | | | *P* Value for Trend |
|---|---|---|---|---|---|---|
| | None | 1 to <20 | 20 to <60 | 60 to <120 | ≥120 | |
| Strength training | | | | | | |
| Cases (person-years) | 1870 (285,062) | 69 (19,824) | 67 (18,968) | 68 (22,548) | 46 (12,423) | |
| Multivariable model[a] | Reference | 0.62 (0.50–0.78) | 0.67 (0.53–0.84) | 0.55 (0.44–0.69) | 0.51 (0.37–0.70) | <0.001 |
| + Other activities[b] | Reference | 0.67 (0.54–0.84) | 0.78 (0.62–0.98) | 0.68 (0.54–0.86) | 0.65 (0.47–0.91) | <0.001 |
| + Other activities and BMI[c] | Reference | 0.74 (0.59–0.93) | 0.91 (0.72–1.14) | 0.76 (0.60–0.95) | 0.76 (0.54–1.05) | <0.001 |
| Aerobic activities[d] | | | | | | |
| Cases (person-years) | 164 (15,164) | 425 (45,173) | 325 (43,614) | 335 (56,769) | 871 (198,079) | |
| Multivariable model[a] | Reference | 0.86 (0.72–1.03) | 0.73 (0.61–0.89) | 0.63 (0.53–0.76) | 0.45 (0.38–0.53) | <0.001 |
| + Other activities[e] | Reference | 0.86 (0.72–1.03) | 0.75 (0.62–0.91) | 0.66 (0.55–0.79) | 0.49 (0.42–0.58) | <0.001 |
| + Other activities and BMI[c] | Reference | 1.08 (0.91–1.30) | 1.09 (0.90–1.33) | 1.01 (0.84–1.21) | 0.86 (0.72–1.01) | <0.001 |

[a]Multivariable model is adjusted for age, smoking status, dietary habits, alcohol intake, postmenopausal status, hormone use, parental history of myocardial infarction, and trial randomization.
[b]Further adjusted for time per week spent in lower-intensity activities and aerobic activities.
[c]Further adjusted for BMI.
[d]Aerobic activities included walking, jogging, running, bicycling, tennis, aerobic exercises, lap swimming, other aerobic activities, and stair climbing.
[e]Further adjusted for time per week spent in lower-intensity activities and weight lifting/strength training.

CI = 0.72–1.03), 0.75 (95% CI = 0.62–0.91), 0.66 (95% CI = 0.55–0.79), and 0.49 (95% CI = 0.42–0.58), compared with women who did not participate in aerobic activity. Further adjustment for BMI attenuated the associations of strength training or aerobic activity with type 2 diabetes.

Women who participated in strength training experienced a 17% rate reduction of cardiovascular disease (HR = 0.83, 95% CI = 0.72–0.96, $P$ = 0.01) compared with women who did not after adjusting for model 1 covariates and time spent in lower-intensity and aerobic activities. Compared with women who did not participate in any strength training, women who engaged in 1 to <20, 20 to <60, 60 to <120, and ≥120 $\text{min·wk}^{-1}$ experienced risk reductions of 20% (HR = 0.80, 95% CI = 0.62–1.03), 9% (HR = 0.91, 95% CI = 0.71–1.17), 26% (HR = 0.74, 95% CI = 0.57–0.96), and 6% (HR = 0.94, 95% CI = 0.68–1.29) ($P$ trend = 0.03, Table 3).

We observed an inverse dose response of aerobic activity and cardiovascular disease, adjusting for model 1 covariates and time spent in lower-intensity activities and strength training ($P$ trend < 0.001, Table 3). Among women who participated in 1 to <20, 20 to <60, 60 to <120, and ≥120 $\text{min·wk}^{-1}$, we observed cardiovascular disease HR of 0.81 (95% CI = 0.66–1.01), 0.91 (95% CI = 0.73–1.13), 0.72 (95% CI = 0.58–0.89), and 0.66 (95% CI = 0.55–0.79) compared with women who did not participate in aerobic activity. In addition, adjusting for BMI did not substantially alter the associations of strength training or aerobic activity with cardiovascular disease.

Engaging in both strength training and aerobic activity was associated with a greater rate reduction of type 2 diabetes and cardiovascular disease compared with aerobic activity alone (Table 4). Compared with women who participated in neither strength training nor aerobic activity, women who participated in both strength training and ≥120 min of aerobic activity experienced a type 2 diabetes rate reduction of 65% (HR = 0.35, 95% CI = 0.28–0.44), whereas women participating in ≥120 min of aerobic activity alone (but no strength training) experienced a 48% reduction (HR = 0.52, 95% CI = 0.43–0.62). This additional reduction associated with strength training persisted when adjusting for the total physical activity time among women participating in ≥120 min of aerobic activity ($P$ < 0.05). Similar trends were observed when examining cardiovascular disease (Table 4). Women participating in both strength training and ≥120 min of aerobic activity had the largest cardiovascular rate reduction of 39% (HR = 0.61, 95% CI = 0.48–0.78), whereas women participating

EPIDEMIOLOGY

TABLE 3. HR of cardiovascular disease by time spent in strength training and aerobic activities, WHS.

| | Minutes per Week in Strength Training or Aerobic Activities | | | | | *P* Value for Trend |
|---|---|---|---|---|---|---|
| | None | 1 to <20 | 20 to <60 | 60 to <120 | ≥120 | |
| Strength training | | | | | | |
| Cases (person-years) | 1506 (315,394) | 64 (20,927) | 64 (19,528) | 66 (23,405) | 42 (13,016) | |
| Multivariable model[a] | Reference | 0.78 (0.60–1.00) | 0.85 (0.66–1.09) | 0.68 (0.53–0.87) | 0.85 (0.63–1.16) | 0.002 |
| + Other activities[b] | Reference | 0.80 (0.62–1.03) | 0.91 (0.71–1.17) | 0.74 (0.57–0.96) | 0.94 (0.68–1.29) | 0.03 |
| + Other activities and BMI[c] | Reference | 0.82 (0.64–1.06) | 0.94 (0.73–1.21) | 0.76 (0.59–0.98) | 0.97 (0.70–1.33) | 0.08 |
| Aerobic activities[d] | | | | | | |
| Cases (person-years) | 132 (18,357) | 306 (51,559) | 196 (48,676) | 259 (61,927) | 849 (211,751) | |
| Multivariable model[a] | Reference | 0.81 (0.66–1.00) | 0.90 (0.73–1.12) | 0.71 (0.57–0.88) | 0.64 (0.53–0.76) | <0.001 |
| + Other activities[e] | Reference | 0.81 (0.66–1.01) | 0.91 (0.73–1.13) | 0.72 (0.58–0.89) | 0.66 (0.55–0.79) | <0.001 |
| + Other activities and BMI[c] | Reference | 0.83 (0.67–1.03) | 0.97 (0.78–1.20) | 0.78 (0.63–0.96) | 0.73 (0.60–0.88) | <0.001 |

[a]Multivariable model is adjusted for age, smoking status, dietary habits, alcohol intake, postmenopausal status, hormone use, parental history of myocardial infarction, and trial randomization.
[b]Further adjusted for time per week spent in lower-intensity activities and aerobic activities.
[c]Further adjusted for BMI.
[d]Aerobic activities included walking, jogging, running, bicycling, tennis, aerobic exercises, lap swimming, other aerobic activities, and stair climbing.
[e]Further adjusted for time per week spent in lower-intensity activities and weight lifting/strength training.

TABLE 4. HR (95% CI) of the joint association of time spent in strength training and aerobic activities on type 2 diabetes and cardiovascular disease, WHS.

| | | Aerobic Activity | | |
|---|---|---|---|---|
| Strength Training | | None | 1 to <120 | ≥120 |
| Type 2 diabetes | | | | |
| None | Cases (person-years) | 163 (14,593) | 1006 (128,065) | 701 (142,403) |
| | HR (95% CI) | Reference | 0.77 (0.65–0.92) | 0.52 (0.43–0.62) |
| ≥1 min | Cases (person-years) | 1 (570) | 79 (17,517) | 170 (55,675) |
| | HR (95% CI) | 0.21 (0.03–1.50) | 0.46 (0.34–0.60)* | 0.35 (0.28–0.44)* |
| Cardiovascular disease | | | | |
| None | Cases (person-years) | 126 (17,808) | 693 (143,481) | 687 (154,105) |
| | HR (95% CI) | Reference | 0.88 (0.72–1.07) | 0.79 (0.65–0.96) |
| ≥1 min | Cases (person-years) | 6 (549) | 68 (18,681) | 162 (57,646) |
| | HR (95% CI) | 1.06 (0.39–2.9) | 0.74 (0.55–1.00) | 0.61 (0.48–0.78)* |

Adjusted for age, smoking status, dietary habits, alcohol intake, postmenopausal status, hormone use, parental history of myocardial infarction, trial randomization, and time spent in lower-intensity and conditioning activities.
*$P < 0.05$ comparing participation in weight lifting/strength training to no participation within levels of aerobic activity controlling for total physical activity time.

in aerobic activity alone experienced a reduction of 21% (HR = 0.79, 95% CI = 0.65–0.96).

## DISCUSSION

Consistent evidence has shown that aerobic physical activity is associated with decreased rates of type 2 diabetes and cardiovascular disease (10,18,20,21). However, limited data exist examining the associations of strength training with type 2 diabetes and cardiovascular disease (2,8,9,18). This study is one of the first studies to specifically examine the longitudinal effects of strength training with incident type 2 diabetes or cardiovascular disease. In a large cohort of older women, we observed that participating in strength training was associated with a significant reduction in both type 2 diabetes and cardiovascular disease compared with not participating in strength training when adjusting for time spent in other activities.

These findings are similar to studies conducted in a cohort of men and women from the Health Professionals Follow-up Study and Nurses' Health Study, which reported that weight lifting was associated with reduced rates of type 2 diabetes (8,9). Grontved et al. (9) observed an inverse dose response of time spent weight lifting and incident type 2 diabetes in men, ranging from a 12% to 34% rate reduction. Women in the present study also had a risk reduction for any participation in strength training of 22% to 35%, but we did not observe a clear dose response. A recent report from the Nurses' Health Study noted that women engaging in muscle-strengthening exercises had a reduced risk of type 2 diabetes ranging from 7% to 40% (8). In a cohort of male and female Japanese workers, participation in strength training was associated with a 34% decrease in risk of type 2 diabetes (12). In the Health Professionals Follow-up Study, Tanasescu et al. (25) observed that weight lifting was also associated with reductions in coronary heart disease. To our knowledge, there is no comparable study examining weight lifting and incident cardiovascular disease in women.

However, in cross-sectional data, Drenowatz et al. showed that women ($n$ = 7321) reporting resistance exercise had fewer cardiovascular disease risk factors, including lower body fat, fasting glucose, and total cholesterol (7). In addition, studies examining measured muscle strength and cardiovascular disease have shown that grip strength is associated with fewer cardiovascular risk factors as well as a lower risk of cardiovascular events (13,22).

Women who participated in higher amounts of both strength training and aerobic activity had a greater reduction in type 2 diabetes than those who engaged in higher levels of strength training or aerobic activity alone. These data give evidence that the benefits of strength training and aerobic activity are independent and additional benefit may be conferred by participation in both even after controlling for total minutes spent in physical activity. Similar findings of larger magnitude of risk reduction with the combination of both types of activity also were observed in the Nurses' Health Study (8). In a trial of 262 adults with diabetes, Church et al. (3) observed that a combination of resistance and aerobic training improved HbA1c, whereas aerobic or resistance training individually did not. However, the combination group lost nearly twice the body weight compared with the individual treatment arms (−1.5 kg in the combination group compared with −0.8 kg in aerobic group and −0.3 kg in the resistance group). This significantly larger weight loss may account for the lack of effect within the individual arms. A similar effect of body weight was also seen in the WHS data where the association of strength training and type 2 diabetes was attenuated and became statistically nonsignificant after controlling for BMI. It is also possible that adjusting for BMI when examining strength training and diabetes may be overadjustment, removing part of the causal pathway.

Previous studies examining biomarkers and risk factors may provide a mechanistic explanation of the independent benefit of strength training. Resistance training has been shown to increase muscle mass and reduce BMI, potentially leading to greater insulin sensitivity (30). Randomized controlled trials of resistance exercise either by itself or in combination with aerobic activity have shown resistance exercise can improve glycemic control among diabetics (26). This increase in muscle mass may lower future risk of type 2 diabetes as hypertrophy is associated with increased glucose transport and insulin sensitivity (17). Although endurance training has also been shown to improve glucose metabolism (23,24), the larger gains in hypertrophy from strength training may explain the greater risk reduction for type 2 diabetes than cardiovascular disease among those participating in both strength training and aerobic activities. Yang et al. (30) in a recent meta-analysis of randomized control trials, reported that resistance exercise conferred no additional reduction in cardiovascular disease risk factors, such as lipid profile, compared with aerobic activity.

Strengths of this study include the large sample of older women in the WHS with nearly complete follow-up over an average of greater than 10 yr. However, several limitations are worth noting. Although detailed, physical activity was self-reported. Information on strength training was limited to the time spent per week and did not include data on intensity or specific strength training exercises. Thus, these data cannot determine an ideal dose or intensity of strength training for reduced rates of type 2 diabetes or cardiovascular disease. In addition, the WHS questionnaire did not ask about the frequency of training sessions, and thus we were unable to directly examine the guideline recommendation of at least twice a week of muscle-strengthening exercises. Although women who decide to participate in muscle-strengthening activities may be a self-selected group, we observed that nearly one-fifth of WHS women participate in some strength training. This is a similar proportion to other large US cohorts such as National Health Interview Survey (16.2%) and Behavioral Risk Factor Surveillance Survey (19.1%) (11). In these analyses, we carefully controlled for both demographic and health characteristics to reduce this potential selection bias. Future randomized controlled trials may further help reduce the potential of selection bias and reverse causation.

Type 2 diabetes and cardiovascular disease were self-reported and confirmed by medical report. However, the potential "screening bias" for diabetes is likely small as analyses limited to those women who reported glucose screenings did not alter the associations. Although coronary revascularization as an outcome may be susceptible to biases because of referral or disease severity, sensitivity analyses eliminating revascularization from the outcome definition did not show substantial differences from the current analyses. Although information of confounders was collected in detail and updated over time, residual confounding remains a potential limitation. Sensitivity analyses were conducted by adding hypertension and high cholesterol to the BMI model but showed no differences. Furthermore, it is possible because of the high correlation between aerobic activity and strength training (Table 1), that despite adjusting for time spent in aerobic activity and lower-intensity activities in Model 2, residual confounding may remain. Lastly, women in WHS are older, primarily white, and of high education and socioeconomic status, which may limit the generalizability of our findings.

In conclusion, we observed a substantial decrease in type 2 diabetes and cardiovascular disease rates among those who participated in strength training compared with those who did not engage in any strength training, independent of participation in other activities. These data suggest that including strength training in a physical activity regimen, as recommended by the federal guidelines, may result in decreased rates of type 2 diabetes and cardiovascular disease. Further research is needed to determine an optimum dose and intensity of muscle-strengthening activities for the reduction of type 2 diabetes and cardiovascular disease rates.

The authors are grateful to the staff of the Women's Health Study (Brigham and Women's Hospital), particularly Jane Jones, MEd. None of the persons named in the acknowledgments were compensated for manuscript preparation.

This research was supported by the National Institutes of Health (research grant nos. CA154647, CA047988, HL043851, HL080467, HL099355, and HL007575). The National Institutes of Health played no role in the design and conduct of the study; the collection, management, analysis, and interpretation of the data; or the preparation, review, or approval of the manuscript. EJS was supported in part by and the Intramural Research Program of the National Institutes of Health, National Institute on Aging.

The authors report no conflicts of interest. The results of the present study do not constitute endorsement by the American College of Sports Medicine.

E. J. Shiroma and I-M. Lee designed and conducted the study, including collecting data, conducting analyses, and preparing the manuscript. J. E. Buring, N. R. Cook, J. E. Manson, M. V. Moorthy, and E. B. Rimm provided substantial feedback on analyses, including shaping the analysis plan, as well as providing critical input during the manuscript preparation.

E. J. Shiroma and I-M. Lee had full access to the all of the data and take full responsibility for the integrity of the data and the accuracy of the data analysis.



## REFERENCES

1. Ainsworth BE, Leon AS, Richardson MT, Jacobs DR, Paffenbarger RS Jr. Accuracy of the College Alumnus Physical Activity Questionnaire. *J Clin Epidemiol*. 1993;46(12):1403–11.
2. Chomistek AK, Cook NR, Flint AJ, Rimm EB. Vigorous-intensity leisure-time physical activity and risk of major chronic disease in men. *Med Sci Sports Exerc*. 2012;44(10):1898–905.
3. Church TS, Blair SN, Cocreham S, et al. Effects of aerobic and resistance training on hemoglobin A1c levels in patients with type 2 diabetes: a randomized controlled trial. *JAMA*. 2010;304(20):2253–62.
4. Cook NR, Lee IM, Gaziano JM, et al. Low-dose aspirin in the primary prevention of cancer: the Women's Health Study: a randomized controlled trial. *JAMA*. 2005;294(1):47–55.
5. Ding EL, Song Y, Manson JE, Pradhan AD, Buring JE, Liu S. Accuracy of administrative coding for type 2 diabetes in children, adolescents, and young adults. *Diabetes Care*. 2007;30(9):e98; author reply e99.
6. Djousse L, Lee IM, Buring JE, Gaziano JM. Alcohol consumption and risk of cardiovascular disease and death in women: potential mediating mechanisms. *Circulation*. 2009;120(3):237–44.
7. Drenowatz C, Sui X, Fritz S, et al. The association between resistance exercise and cardiovascular disease risk in women. *J Sci Med Sport*. 2015;18(6):632–6.
8. Grontved A, Pan A, Mekary RA, et al. Muscle-strengthening and conditioning activities and risk of type 2 diabetes: a prospective study in two cohorts of US women. *PLoS Med*. 2014;11(1):e1001587.

9. Grontved A, Rimm EB, Willett WC, Andersen LB, Hu FB. A prospective study of weight training and risk of type 2 diabetes mellitus in men. *Arch Intern Med*. 2012;172(17):1306–12.
10. Jeon CY, Lokken RP, Hu FB, van Dam RM. Physical activity of moderate intensity and risk of type 2 diabetes: a systematic review. *Diabetes Care*. 2007;30(3):744–52.
11. Keadle SK, McKinnon R, Graubard BI, Troiano RP. Prevalence and trends in physical activity among older adults in the United States: a comparison across three national surveys. *Prev Med*. 2016;89:37–43.
12. Kuwahara K, Honda T, Nakagawa T, et al. Strength training and risk of type 2 diabetes in a Japanese working population: a cohort study. *J Diabetes Investig*. 2015;6(6):655–61.
13. Lawman HG, Troiano RP, Perna FM, Wang CY, Fryar CD, Ogden CL. Associations of relative handgrip strength and cardiovascular disease biomarkers in U.S. adults, 2011–2012. *Am J Prev Med*. 2016;50(6):677–83.
14. Lee IM, Cook NR, Gaziano JM, et al. Vitamin E in the primary prevention of cardiovascular disease and cancer: the Women's Health Study: a randomized controlled trial. *JAMA*. 2005;294(1):56–65.
15. Lee IM, Cook NR, Manson JE, Buring JE, Hennekens CH. Beta-carotene supplementation and incidence of cancer and cardiovascular disease: the Women's Health Study. *J Natl Cancer Inst*. 1999;91(24):2102–6.
16. Lee IM, Rexrode KM, Cook NR, Manson JE, Buring JE. Physical activity and coronary heart disease in women: is "no pain, no gain" passe? *JAMA*. 2001;285(11):1447–54.
17. Pereira LO, Lancha AH Jr. Effect of insulin and contraction up on glucose transport in skeletal muscle. *Prog Biophys Mol Biol*. 2004;84(1):1–27.
18. Physical Activity Guidelines Committee. *Physical Activity Guidelines Advisory Committee Report*. [Internet]. Washington (DC): Department of Health and Human Services. Available from: http://health.gov/paguidelines/guidelines/report.aspx.
19. Ridker PM, Cook NR, Lee IM, et al. A randomized trial of low-dose aspirin in the primary prevention of cardiovascular disease in women. *N Engl J Med*. 2005;352(13):1293–304.
20. Sattelmair J, Pertman J, Ding EL, Kohl HW 3rd, Haskell W, Lee IM. Dose response between physical activity and risk of coronary heart disease: a meta-analysis. *Circulation*. 2011;124(7):789–95.
21. Shiroma EJ, Lee IM. Physical activity and cardiovascular health: lessons learned from epidemiological studies across age, gender, and race/ethnicity. *Circulation*. 2010;122(7):743–52.
22. Silventoinen K, Magnusson PK, Tynelius P, Batty GD, Rasmussen F. 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. *Int J Epidemiol*. 2009;38(1):110–8.
23. Stanford KI, Goodyear LJ. Exercise and type 2 diabetes: molecular mechanisms regulating glucose uptake in skeletal muscle. *Adv Physiol Educ*. 2014;38(4):308–14.
24. Suh SH, Paik IY, Jacobs K. Regulation of blood glucose homeostasis during prolonged exercise. *Mol Cells*. 2007;23(3):272–9.
25. Tanasescu M, Leitzmann MF, Rimm EB, Willett WC, Stampfer MJ, Hu FB. Exercise type and intensity in relation to coronary heart disease in men. *JAMA*. 2002;288(16):1994–2000.
26. Umpierre D, Ribeiro PA, Schaan BD, Ribeiro JP. Volume of supervised exercise training impacts glycaemic control in patients with type 2 diabetes: a systematic review with meta-regression analysis. *Diabetologia*. 2013;56(2):242–51.
27. United States Department of Health and Human Services. *2008 Physical Activity Guidelines for Americans*. [Internet]. Available from: http://www.health.gov/paguidelines/.
28. Willett WC, Sampson L, Stampfer MJ, et al. Reproducibility and validity of a semiquantitative food frequency questionnaire. *Am J Epidemiol*. 1985;122(1):51–65.
29. Wolf AM, Hunter DJ, Colditz GA, et al. Reproducibility and validity of a self-administered physical activity questionnaire. *Int J Epidemiol*. 1994;23(5):991–9.
30. Yang Z, Scott CA, Mao C, Tang J, Farmer AJ. Resistance exercise versus aerobic exercise for type 2 diabetes: a systematic review and meta-analysis. *Sports Med*. 2014;44(4):487–99.