Impact of Intensive Lifestyle Intervention on Disability-Free Life Expectancy: The Look AHEAD Study

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OBJECTIVE

The impact of weight loss intervention on disability-free life expectancy in adults with diabetes is unknown. We examined the impact of a long-term weight loss intervention on years spent with and without physical disability.

RESEARCH DESIGN AND METHODS

Overweight or obese adults with type 2 diabetes age 45–76 years (n = 5,145) were randomly assigned to a 10-year intensive lifestyle intervention (ILI) or diabetes support and education (DSE). Physical function was assessed annually for 12 years using the 36-Item Short Form Health Survey. Annual incidence of physical disability, mortality, and disability remission were incorporated into a Markov model to quantify years of life spent active and physically disabled.

RESULTS

Physical disability incidence was lower in the ILI group (6.0% per year) than in the DSE group (6.8% per year) (incidence rate ratio 0.88 [95% CI 0.81–0.96]), whereas rates of disability remission and mortality did not differ between groups. ILI participants had a significant delay in moderate or severe disability onset and an increase in number of nondisabled years (P < 0.05) compared with DSE participants. For a 60-year-old, this effect translates to 0.9 more disability-free years (12.0 years [95% CI 11.5–12.4] vs. 11.1 years [95% CI 10.6–11.7]) but no difference in total years of life. In stratified analyses, ILI increased disability-free years of life in women and participants without cardiovascular disease (CVD) but not in men or participants with CVD.

CONCLUSIONS

Long-term lifestyle interventions among overweight or obese adults with type 2 diabetes may reduce long-term disability, leading to an effect on disability-free life expectancy but not on total life expectancy.

Type 2 diabetes increases the risk of microvascular and macrovascular morbidity, leading to a 60% increased risk of cardiovascular disease (CVD), 6 times the risk of end-stage kidney disease, and 10 times the risk of amputation relative to people without diabetes (1,2). Although rates of diabetes complications have declined in the U.S., accompanying increases in lifetime risk of diabetes and life span have increased the total number of years that the average American lives with the disease (2). Diabetes more than doubles the incidence of physical disability, hastens its onset by 6–7 years, and has a greater effect on disability-free years of life than total years of life

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**A complete list of the Look AHEAD Study Group can be found in the Supplementary Data online.*

(3,4). Disability affects quality of life, increases risk for further morbidity, and dramatically increases the need for subsequent health services (4–6). Furthermore, the lack of clear evidence of reductions in national disability prevalence levels over time among adults with diabetes raises the question of whether current clinical and public health approaches to reduce morbidity are effective (7,8).

Given the concern about the impact of diabetes and its complications in the older diabetic population, the Look AHEAD (Action for Health in Diabetes) trial found that overweight adults with type 2 diabetes assigned to an intensive lifestyle intervention (ILI) had a 48% reduced risk of mobility loss over 4 years compared with adults receiving the diabetes support and education (DSE) control condition (9). The large magnitude of this effect combined with the high absolute incidence of physical disability among adults with diabetes suggest that lifestyle interventions could have a substantial effect on the number of years spent in a disabled versus nondisabled state (3,6). A multifactorial behavioral intervention featuring caloric restriction and increased physical activity may affect mechanisms underlying functional decline and may have the greatest potential for affecting complex conditions such as disability. However, accurate estimation of the impact of an ILI on the remaining years of active and disabled life also depends on the concurrent associations of intervention with disability, remission from disability, and mortality risk.

As a 10-year lifestyle-based weight loss intervention, Look AHEAD is one of the longest lifestyle intervention trials to be conducted and presents a unique setting to examine the extended impact of lifestyle on healthy aging (10). In this study, we examine the impact of the Look AHEAD intervention on physical disability, remission from physical disability, and mortality. We then incorporate these findings into a lifetime progression model to estimate the impact of this ILI on the number of years spent with and without physical disability among adults with type 2 diabetes.

RESEARCH DESIGN AND METHODS

Study Design and Population

Look AHEAD is a multicenter randomized controlled trial that tested the impact of an ILI on CVD incidence and diabetes-related morbidity (11,12). The study enrolled 5,145 overweight and obese adults with type 2 diabetes age 45–76 years across 16 research centers. Participants were randomly assigned with equal probability to either an ILI designed to achieve sustained weight loss or DSE. Inclusion criteria included a BMI $\geq$25 kg/m^2 or $\geq$27 kg/m^2 among those receiving insulin therapy. Exclusion criteria included hemoglobin A_{1c} >11%, systolic blood pressure >160 mmHg, diastolic blood pressure >100 mmHg, plasma triglyceride levels >600 mg/dL, inability to complete a maximal graded exercise test, and inability to complete 2 weeks of diet and activity self-monitoring. Recruitment occurred during 2001–2004. All participants signed an informed consent approved by local institutional review boards. These analyses excluded eight individuals with missing data, leaving an analytic sample of 5,137 (99.8%) adults (Supplementary Fig. 1).

Intervention

Details of the ILI have been published previously (12,13). The intervention included weekly group and individual sessions for 6 months followed by two group sessions and one individual session per month for the second 6 months, twice-monthly contact for years 2–4, and monthly contact for years 5 and beyond to prevent weight regain. The intervention also included refresher sessions throughout years 4–10. The ILI sought to reduce total caloric intake to 1,200–1,800 kcal/day on the basis of initial weight and to limit total fat and saturated fat content to <30% and 10% of the diet, respectively. Participants were counseled to achieve a goal of 175 min of physical activity per week using strategies such as brisk walking. Behavioral strategies included self-monitoring, goal setting, and problem solving. Dietary change was further supported through calorie counting and provision of meal replacements (12).

DSE participants were offered three group sessions each year that focused on diet, physical activity, and social support. Medical and pharmacological risk factor management for hyperglycemia, lipids, and blood pressure was provided by the participant's physician independent of the Look AHEAD trial for both groups. Interventions continued through 14 September 2012. The median intervention length was 9.9 years (interquartile range 9.2–10.4), and follow-up ranged from 0 to 11 years.

Assessments

Participants attended annual clinic visits for assessments conducted by centrally trained staff masked to intervention assignment. Body weight was measured with a digital scale. Physical function was assessed using items from the Medical Outcomes Study 36-Item Short Form Health Survey (SF-36) physical functioning subscale (14). The mobility items included activities such as pushing a vacuum cleaner or playing golf; climbing one flight of stairs; bending, kneeling, or stooping; walking more than a mile; and walking 100 yards.

Statistical Analysis and Modeling

The analyses involved three stages. First, we defined stages of physical disability using hidden Markov models. Second, we estimated incidence of physical disability, mortality, and remission after disability by intervention group. Finally, we incorporated incidence estimates into a five-stage Markov model to project the number of years spent with and without disability over the lifetime by intervention group.

Hidden Markov Models

Hidden Markov models were used to define states of physical disability and to classify individuals according to states over the duration of the study (15,16). These models used information from six variables of the SF-36 physical function items (vigorous activities; moderate activities; climbing one flight of stairs; bending, kneeling, or stooping; walking more than a mile; walking 100 yards) collected at each of the 11 visits to examine the dynamics and transitions of underlying latent states and to cluster participants according to these states. Participants were asked the following questions: "Does your health now limit you in these activities? If so, how much?" For each variable, responses were yes, limited a lot; limited a little; or not limited at all. The number and structure of states are determined by a goodness-of-fit index and are assumed to be constant over time. Participants were then classified in the state for which they had the greatest likelihood (15,16).

The hidden Markov models process led to 13 discrete states that were subsequently collapsed into three categories of no disability, moderate disability, and severe disability. Specific characteristics of each state are shown in Supplementary Fig. 2. In brief, participants classified as

having no disability generally had no limitations with walking 100 yards, climbing a flight of stairs, or doing moderate activities such as pushing a vacuum cleaner or playing golf. Those classified as moderately disabled generally had limitations across five or six activities and were unable to do vigorous activities. Participants classified as severely disabled had limitations for all moderate activities, including walking 100 yards and climbing one flight of stairs.

Incidence Estimation

Age- and sex-specific incidence of physical disability according to intervention assignment was parameterized using a Poisson model with a logarithmic link in longitudinal generalized estimating equations to account for repeated measures within individuals. Censoring occurred at the first incidence of physical disability, death, or final study contact. Analyses of disability incidence excluded individuals with disability at baseline. Similarly, we estimated yearly probability of remission from disability (i.e., transition from disability to nondisablement) according to intervention status, using incident cases of disability as the denominator. Age- and sex-specific mortality incidence was also estimated using Poisson regression, overall and separately by disability status and intervention group, using date of death to estimate person-years of follow-up. Time-varying regression models were examined to estimate mortality rates conditional upon disability status such that an individual could contribute person-time toward mortality estimation in a disabled or nondisabled state.

Calculation of Disability-Free Life Expectancy

Finally, the incidence of physical disability, remission from physical disability, and mortality were incorporated into a discrete-time Markov simulation model to estimate the number of remaining years of life spent with and without disability according to age (17). A 1-year transition cycle also was used to predict and compare lifetime disability-related outcomes between intervention groups (Supplementary Fig. 3). The definitions and the assumptions governing the model have been described in detail previously (3). At the end of each 1-year interval, individuals were classified among the five states: remaining not disabled, short-term disability, being not disabled but with a disability history, remaining disabled (termed long-term disability), and death. The two transitional states, short-term disability and being not disabled but with a disability history, were created because of the high remission rates observed in the data. Short-term disability was defined as being disabled $<$1 year before remission in contrast with long-term disability defined as remaining disabled until death. Thus, individuals with a short-term disability might revert to being not disabled, die, or continue to be disabled.

The model permits an estimation of the remaining lifetime risk of becoming physically disabled, average age of disability onset, and remaining life-years with and without disability from age 50, 60, and 70 years. Remaining lifetime risk was calculated as the cumulative risk of experiencing either short-term or long-term physical disability over a lifetime. Because of the high frequency of multiple episodes of short-term disability, the average age of disability onset was defined as the difference between life expectancy and mean disabled life-years. The CIs of the lifetime estimates were based on Monte Carlo simulation in which we drew 5,000 age- and sex-specific estimates from the underlying parametric distributions of the regression models described above and calculated the outcomes.

The primary comparisons were the number of remaining years with and without physical disability between ILI and DSE over the course of the trial and over the entire predicted remaining life span. These analyses accounted for the time to disability and the differences in mortality rates between intervention groups and among disability states and followed an intention-to-treat approach to compare the ILI and DSE groups. The primary outcome combined participants with moderate and severe disability. A secondary outcome defined disability on the basis of the severe disability classification. In addition to the comparison of ILI versus DSE, we conducted stratified analyses on the basis of sex and CVD history. In sensitivity analysis, we also varied the duration of the continued effect; whereas in the primary analysis, the intervention effect was assumed to only last the duration of the intervention, in sensitivity analyses the effect of ILI was assumed to extend for 4 or 8 years or for the remainder of life. A two-tailed *P* value of 0.05 was used as the threshold for statistical significance.

RESULTS

Characteristics of the Sample

Among the 5,137 participants in the analytic sample, mean age at baseline was 59 years and ranged from 45 to 76 years; at the end of follow-up, it ranged from 57 to 88 years. Sixty-three percent self-identified as white, 16% as African American, 13% as Hispanic, 5% as Native American, and 3% as other or multiple races/ethnicities. Mean time since diabetes diagnosis at baseline was ~7 years, about one-fifth were taking insulin, and mean BMI was ~36 kg/m^2. Fourteen percent had a history of CVD, and 14% met the criteria for moderate or severe physical disability at baseline and were excluded from additional analyses. No significant differences were found in the baseline characteristics between the ILI and DSE groups except for prevalence of severe disability, which was higher in the DSE group (3.8%) than in the ILI group (2.8%; $P = 0.04$) (Supplementary Table 1). The mean percent weight changes in the ILI group at years 1 and 8 were 8.5% and 4.7%, respectively, compared with 0.6% and 2.1%, respectively, in the DSE group ($P < 0.0001$).

Incidence of Physical Disability

Incidence of moderate/severe physical disability was significantly lower among ILI participants (6.0% per year) than among DSE participants (6.8% per year) over the follow-up period (incidence rate ratio [IRR] 0.88 [95% CI 0.81–0.96]; $P < 0.01$) (Table 1). In stratified analyses, relative reductions in disability incidence associated with the ILI intervention were found among women (6.7% vs. 8.2% per year; IRR 0.81 [0.73–0.91]; $P < 0.01$) and those without prior CVD (7.1% vs. 8.2% per year; IRR 0.87 [0.79–0.95]; $P < 0.01$), but no significant association was found in men (IRR 0.99 [0.85–1.15]; $P = 0.91$) or among those with CVD (IRR 0.98 [0.78–1.24]; $P = 0.87$). Incidence of severe physical disability was less common and did not differ significantly between the DSE (2.5% per year) and ILI (2.2% per year) groups ($P = 0.07$) but was lower among ILI women (IRR 0.81 [0.67–0.99]; $P = 0.04$) and those without CVD (IRR 0.83 [0.71–0.98]; $P = 0.02$).

Incidence of moderate/severe disability for men ranged from 5.1% per year at age 60 years to 7.8% at age 75 years in the

Table 1—Incidence of disability and remission from physical disability according to intervention group: the Look AHEAD study

	Intervention condition			
	DSE	ILI	IRR (95% CI)	*P* value
Overall population (*n* = 5,137)	2,570	2,567	—	
Moderate/severe disability cases	980	930	—	
Moderate/severe per 100 person-years	6.8 (5.8–7.9)	6.0 (5.6–6.4)	0.88 (0.81–0.96)	< 0.01
Severe per 100 person-years	2.5 (1.9–3.2)	2.2 (2.0–2.4)	0.87 (0.75–1.01)	0.07
Disability remission per 100 disabled persons/year*	30.1 (23.6–38.5)	34.8 (31.4–38.5)	1.06 (0.92–1.23)	0.42
Deaths (*n*, %)	199 (7.7)	171 (6.7)	—	
Yearly mortality rate per 100 person-years	0.96 (0.67–1.36)	0.81 (0.69–0.94)	0.86 (0.70–1.06)	0.15
Men (*n* = 2,079)	1,037	1,042		
Moderate/severe disability cases	345	346	—	
Moderate/severe per 100 person-years	5.2 (4.0–6.6)	5.1 (4.6–5.7)	0.99 (0.85–1.15)	0.91
Severe per 100 person-years	2.1 (1.4–3.2)	1.9 (1.6–2.3)	0.96 (0.75–1.21)	0.70
Disability remission per 100 disabled persons/year	24.1 (16.0–36.3)	32.5 (27.5–38.4)	1.23 (0.96–1.56)	0.10
Deaths (*n*, %)	117 (11.3)	93 (8.9)	—	
Yearly mortality rate per 100 person-years	1.4 (0.9–2.3)	1.1 (0.9–1.4)	0.79 (0.60–1.03)	0.08
Women (*n* = 3,058)	1,533	1,525		
Moderate/severe disability cases	635	584	—	
Moderate/severe per 100 person-years	8.2 (6.7–9.9)	6.7 (6.2–7.3)	0.81 (0.73–0.91)	< 0.01
Severe per 100 person-years	2.8 (2.0–3.9)	2.3 (2.0–2.7)	0.81 (0.67–0.99)	0.04
Disability remission per 100 disabled persons/year	34.4 (25.3–46.6)	36.3 (31.9–41.2)	0.98 (0.82–1.17)	0.81
Deaths (*n*, %)	82 (5.4)	78 (5.1)	—	
Yearly mortality rate per 100 person-years	0.6 (0.4–1.0)	0.6 (0.5–0.8)	0.96 (0.70–1.30)	0.77
No CVD (*n* = 4,424)	2,223	2,201		
Moderate/severe disability cases	842	786	—	
Moderate/severe per 100 person-years	8.2 (6.9–9.6)	7.1 (6.6–7.6)	0.87 (0.79–0.95)	< 0.01
Severe per 100 person-years	2.4 (1.8–3.2)	2.0 (1.8–2.3)	0.83 (0.71–0.98)	0.02
Disability remission per 100 disabled persons/year	34.2 (26.4–44.3)	37.9 (34.1–42.2)	1.05 (0.90–1.22)	0.56
Deaths (*n*, %)	138 (6.2)	116 (5.3)	—	
Yearly mortality rate per 100 person-years	0.8 (0.5–1.2)	0.6 (0.5–0.8)	0.84 (0.66–1.08)	0.17
CVD (*n* = 713)	347	366		
Moderate/severe disability cases	138	144	—	
Moderate/severe per 100 person-years	9.9 (6.7–14.7)	9.8 (8.4–11.5)	0.98 (0.78–1.24)	0.87
Severe per 100 person-years	2.9 (1.6–5.5)	3.2 (2.5–4.1)	1.14 (0.78–1.65)	0.50
Disability remission per 100 disabled persons/year	15.3 (7.3–31.7)	21.0 (15.5–28.4)	1.17 (0.75–1.82)	0.49
Deaths (*n*, %)	61 (17.6)	55 (15.0)	—	
Yearly mortality rate per 100 person-years	2.4 (1.3–4.6)	2.0 (1.6–2.6)	0.86 (0.60–1.25)	0.43

Data are *n* or *n* (95% CIs) unless otherwise indicated. *Analyses of disability incidence excluded persons with disability at baseline.

ILI group and ranged from 5.8% at age 60 to 8.8% at age 75 in the DSE group (Supplementary Fig. 4). For women, incidence ranged from 7.6% per year at age 60 to 11.5% at age 75 in the ILI group and from 8.7% at age 60 to 13.0% at age 75 in the DSE group. Incidence of remission for men ranged from 25.7% per year at age 60, declining to 15.0% at age 75 in the ILI group (vs. 23.1% and 13.4% for ages 60 and 75, respectively, in the DSE group) (Supplementary Fig. 5). For women, incidence of remission ranged from 23.1% per year at age 60, declining to 13.4% at age 75 in the ILI group (vs. 22.1% and 12.7% for ages 60 and 75, respectively, in the DSE group). However, the overall differences in rates of remission between ILI and DSE were not statistically significant. Similarly, no significant differences were found in rates of mortality between ILI and DSE participants overall or in any strata.

Disability-Free Life Expectancy

Across all ages, ILI participants were estimated to have a 0.8–0.9-year delay in the age of onset of moderate/severe physical disability and an equivalent increase in the number of nondisabled years of life (Table 2) while having no significant difference in the total years of life. The impact on active years of life was significant from age 50 and 60 years, but not from age 70 years. For example, from age 50, the average ILI participant had 15.3 nondisabled years, became disabled at age 65.3, and then spent 20.7 years disabled before death. The same-aged counterparts in the DSE group had 14.4 nondisabled years, became disabled at age 64.4, and spent 21.5 years disabled before death. In stratified analyses, the ILI intervention was associated with an increase in the number of nondisabled years in women and those without CVD but not in men or those with CVD. Age of disability onset was younger for women than for men and for those with CVD than for those without CVD.

When disability-free life expectancy was estimated using the severe disability definition instead of the moderate/severe definition (Table 3), the difference in disability onset and years of life spent with disability between ILI and DSE participants was ~30% less than in the primary analysis and was no longer statistically significant. A 60-year-old in the ILI group had 16.7 nondisabled years of life (vs. 16.1 in the DSE group), became severely disabled at age 76.7 years (vs. 76.1 in DSE), and spent 10.4 years with disability before death (vs. 10.7 in the DSE group).

Table 2—Number of years with and without physical disability (moderate or severe), according to intervention group: the Look AHEAD study

	DSE				ILI			
Age (years)	Age at disability onset (years)	Nondisabled years (*n*)	Disabled years (*n*)	Total years (*n*)	Age at disability onset (years)	Nondisabled years (*n*)	Disabled years (*n*)	Total years (*n*)
Total								
50	64.4 (63.7–65.1)	14.4 (13.7–15.1)	21.5 (19.3–23.7)	35.8 (33.8–38.1)	65.3 (64.8–65.8)§	15.3 (14.8–15.8)§	20.7 (18.7–22.9)	36.0 (34.1–38.2)
60	71.1 (70.6–71.7)	11.1 (10.6–11.7)	15.7 (13.7–18.0)	26.9 (24.8–29.2)	72.0 (71.5–72.4)§	12.0 (11.5–12.4)§	15.2 (13.2–17.3)	26.8 (24.8–29.0)
70	78.4 (77.8–79.0)	8.4 (7.8–9.0)	10.2 (8.0–12.5)	18.6 (16.4–21.0)	79.2 (78.6–79.8)	9.2 (8.8–9.8)	9.9 (7.8–12.2)	18.7 (16.5–21.1)
Men								
50	67.0 (66.0–67.9)	17.0 (16.0–17.8)	16.8 (14.5–19.3)	33.7 (31.5–36.2)	67.9 (67.1–68.6)	17.9 (17.3–18.5)	16.1 (14.0–18.5)	34.0 (31.8–36.3)
60	72.8 (72.0–73.5)	12.8 (8.7–10.1)	12.3 (10.3–14.7)	25.1 (23.0–27.4)	73.7 (73.0–74.3)	13.7 (13.3–14.5)	11.8 (9.8–14.0)	25.5 (23.4–27.8)
70	79.4 (78.7–80.1)	9.4 (8.7–10.1)	7.8 (5.9–11.1)	17.2 (15.1–19.7)	80.2 (79.5–80.9)	10.2 (9.5–10.8)	7.6 (5.7–9.8)	17.8 (15.6–20.3)
Women								
50	63.0 (62.3–63.6)	13.0 (12.3–13.6)	25.6 (22.7–28.2)	38.5 (35.8–41.1)	63.9 (63.3–64.4)	13.9 (13.3–14.4)§	24.8 (22.0–27.4)	38.7 (35.9–41.4)
60	69.8 (69.2–70.4)	9.8 (9.2–10.4)	19.7 (17.0–22.3)	29.4 (26.7–32.1)	70.6 (70.1–71.1)	10.6 (10.1–11.1)§	19.1 (16.5–21.6)	29.7 (27.0–32.3)
70	77.3 (76.7–77.9)	7.3 (6.7–7.9)	13.6 (10.9–16.3)	20.9 (18.2–23.6)	78.0 (77.5–78.7)	8.0 (7.5–8.7)	13.3 (10.6–15.9)	21.4 (18.7–24.0)
No CVD								
50	64.7 (64.0–65.4)	14.7 (14.0–15.4)	23.7 (21.0–26.2)	38.0 (35.6–40.3)	65.6 (65.1–66.2)*	15.6 (15.1–16.2)*	22.9 (20.3–25.3)	38.5 (35.8–41.0)
60	71.5 (70.9–72.1)	11.5 (10.9–12.1)	17.8 (15.3–20.3)	29.0 (26.6–31.3)	72.4 (71.9–72.9)‡	12.4 (11.9–12.9)‡	17.3 (14.7–19.7)	29.7 (27.1–32.1)
70	78.9 (78.3–79.6)	8.9 (8.3–9.6)	12.1 (9.4–14.6)	20.7 (18.1–23.1)	79.7 (79.1–80.4)§	9.7 (9.1–10.4)§	11.7 (8.2–14.3)	21.5 (18.7–24.0)
CVD								
50	62.0 (60.9–63.2)	12.0 (10.9–13.2)	18.2 (15.6–20.9)	30.2 (27.7–32.9)	63.0 (61.9–64.1)	13.0 (11.9–14.1)	17.7 (15.3–20.2)	30.6 (28.3–33.1)
60	69.3 (68.4–70.1)	9.3 (8.4–10.1)	12.8 (10.7–15.3)	22.1 (19.9–24.5)	70.1 (69.3–70.9)	10.1 (9.3–10.9)	12.5 (10.5–14.8)	22.6 (20.7–24.9)
70	77.0 (76.4–77.7)	7.0 (6.4–7.7)	7.9 (6.0–10.3)	14.9 (12.9–17.6)	77.7 (77.1–78.5)	7.7 (7.1–8.5)	7.9 (6.0–10.2)	15.6 (13.7–18.1)

Data are *n* in years (95% CIs). *$P < 0.001$, ‡$P < 0.01$, §$P < 0.05$ for comparison between the ILI and DSE groups.

In sensitivity analyses of the primary outcome (moderate/severe disability), if the relative effect of ILI on disability and remission was assumed to be maintained after the completion of the intervention for the remainder of life (i.e., instead of return to no difference between groups as in the primary analyses), the difference in disabled and nondisabled life-years between ILI and DSE is ~50% greater than in primary analyses. There is a 1.6-year difference between ILI and DSE in estimated nondisabled years from age 50 years and a 1.0-year difference from age 70 years (Table 4). If the intervention effect was assumed to last 4 or 8 years beyond the period of intervention, the estimated benefits are intermediate between the primary analyses and those assuming a lifetime continued effect.

CONCLUSIONS

The combination of high rates of diabetes prevalence, increasing longevity of adults with type 2 diabetes, and high incidence of disability has increased the need for interventions that reduce morbidity and increase the number of years spent in an active, healthy state (2,3). In these analyses of adults with type 2 diabetes, ILI for weight loss resulted in significant delays in the onset of physical disability and significant increases in disability-free life expectancy in the overall population and in stratified analyses among women and those without CVD. Given the large increases in life span observed and the continued high national prevalence of type 2 diabetes in older adults, these findings indicate that lifestyle interventions can play an important role in compressing population morbidity.

Obesity and diabetes have each been consistently associated with an increased risk of physical disability, including mobility loss and loss of independence in instrumental and basic activities of daily living (5,18,19). Disability is a core element of morbidity, affects quality of life, and is a potent predictor of subsequent use of health services and mortality. However, few studies have examined the impact of lifestyle interventions on disability incidence. In prior analyses from Look AHEAD, participants randomly assigned to ILI had reduced disability prevalence after 4 and 8 years (9,20), consistent with other studies showing that exercise and weight loss programs reduce mobility loss in older adults with osteoarthritis (21,22). The

present analyses extend those findings to 12 years and incorporate data on remission from disability and mortality risk to provide the first estimates, to our knowledge, of the long-term impact of a lifestyle intervention on disability.

The multicomponent, lifestyle-based Look AHEAD intervention could have affected disability-free life expectancy in several ways. First, intervention participants had significant improvements in physical fitness as measured by treadmill walking capacity after 4 years, likely resulting from a combination of improved muscle strength, cardiorespiratory fitness, and reduced fat mass (23,24). Studies of the specific domains of quality of life in Look AHEAD have shown that the primary benefits have been in the areas of mobility and ambulation as well as global feelings of health on the basis of the Feeling Thermometer Scale (25). An improved lean-to-fat mass ratio associated with the intervention was further confirmed at 8 years (24). Second, other analyses from Look AHEAD have demonstrated benefits on depressive symptoms and sleep apnea that also could have translated into improved physical functioning (26,27). Finally, other observed benefits on health reported for the Look AHEAD ILI, including reduced chronic kidney disease, inflammation, and overall hospitalizations, possibly have indirect effects on daily functioning (28–30).

We observed variation in the effects by age, sex, and CVD history. First, the effects of ILI on disability-free life expectancy were significant from age 50 and 60 years but not from age 70 years, which was not due to an observed difference in the ILI effect on disability incidence but, rather, because the number of years of expected life remaining (18 years) for a 70-year-old was only one-half that of a 50-year-old (36 years) (3). Second, ILI was associated with a significant reduction in physical disability incidence in women and those without prior CVD but not among men or those with CVD. The more robust effect among women may be because they become disabled earlier and live longer than men, providing a greater potential for benefit of lifestyle intervention. Similarly, people without CVD may be more apt to benefit from lifestyle intervention as a result of a better physical capacity to maintain changes in physical activity habits. We note, however, that the magnitude of difference between ILI and DSE did

Table 3—Number of years with and without physical disability (severe) according to intervention group: the Look AHEAD study

	DSE				ILI			
Age (years)	Age at disability onset (years)	Nondisabled years (*n*)	Disabled years (*n*)	Total years (*n*)	Age at disability onset (years)	Nondisabled years (*n*)	Disabled years (*n*)	Total years (*n*)
Total								
50	71.4 (70.5–72.3)	21.4 (20.5–22.3)	14.4 (12.4–16.6)	35.8 (33.7–38.0)	72.0 (71.3–72.6)	22.0 (21.3–22.6)	14.1 (12.2–16.1)	36.0 (34.0–38.2)
60	76.1 (75.3–77.0)	16.1 (15.3–17.0)	10.7 (8.8–12.9)	26.9 (24.8–29.2)	76.7 (76.0–77.5)	16.7 (16.0–17.5)	10.4 (8.7–12.5)	27.2 (25.2–29.4)
70	81.6 (80.7–82.6)	11.6 (10.7–12.6)	6.9 (5.1–9.1)	18.6 (16.3–21.0)	82.3 (81.4–83.1)	12.3 (11.4–13.1)	6.8 (5.0–8.9)	19.1 (16.9–21.4)
Men								
50	73.4 (72.1–74.6)	23.4 (22.1–24.6)	10.4 (8.5–12.6)	33.7 (31.5–36.2)	73.9 (72.8–75.0)	24.2 (23.0–25.3)	9.3 (7.7–11.4)	33.6 (31.5–35.9)
60	77.3 (76.2–78.4)	17.3 (16.2–18.4)	7.8 (6.1–9.9)	25.1 (22.9–27.5)	77.9 (76.9–78.9)	18.2 (17.2–19.3)	6.8 (5.3–8.7)	25.0 (23.0–27.3)
70	82.2 (81.2–83.3)	12.2 (11.2–13.3)	5.0 (3.5–7.0)	17.2 (15.0–19.7)	82.8 (81.8–83.9)	13.0 (11.9–14.1)	4.3 (3.0–6.1)	17.3 (15.2–19.8)
Women								
50	70.2 (69.2–71.1)	20.2 (19.2–21.1)	18.4 (15.7–21.1)	38.5 (35.7–41.2)	70.8 (69.2–71.1)	20.8 (20.0–21.5)	18.0 (15.4–20.5)	38.7 (36.0–41.3)
60	75.1 (74.2–76.0)	15.1 (14.2–16.0)	14.3 (11.7–16.9)	29.4 (26.7–32.0)	75.7 (75.0–76.5)	15.7 (15.1–16.8)	14.0 (11.4–16.5)	29.7 (27.0–32.3)
70	81.0 (80.0–81.9)	11.0 (10.0–11.9)	11.0 (10.0–11.9)	20.9 (18.1–23.7)	81.6 (80.7–82.5)	11.6 (10.7–12.5)	9.8 (7.3–12.3)	21.4 (18.6–24.0)
No CVD								
50	72.4 (71.3–73.4)	22.4 (21.3–23.4)	15.6 (13.3–18.0)	38.0 (35.6–40.3)	72.9 (72.1–73.6)	22.9 (22.1–23.6)	15.7 (13.3–18.0)	38.5 (35.8–41.0)
60	77.3 (76.3–78.3)	17.3 (16.3–18.3)	11.7 (9.5–14.0)	29.0 (26.6–31.3)	77.8 (76.9–78.6)	17.8 (16.9–18.6)	11.9 (9.6–14.2)	29.7 (27.1–32.1)
70	82.9 (81.9–84.0)	12.9 (11.9–14.0)	7.8 (5.6–10.1)	20.7 (18.1–23.1)	83.4 (82.4–84.3)	13.4 (12.4–14.3)	8.1 (5.8–10.3)	21.5 (18.7–24.0)
CVD								
50	67.6 (66.1–69.0)	17.6 (16.1–19.0)	12.6 (10.3–15.3)	30.2 (27.7–32.9)	68.3 (66.9–69.6)	18.3 (16.9–19.6)	12.4 (10.2–14.8)	30.6 (28.3–33.1)
60	73.1 (72.0–74.2)	13.1 (12.0–14.2)	9.0 (7.1–11.2)	22.1 (19.9–24.5)	73.8 (72.8–74.9)	13.8 (12.8–14.9)	8.8 (7.0–11.0)	22.6 (20.7–24.9)
70	79.4 (78.5–80.3)	9.4 (8.5–10.3)	5.5 (4.0–7.8)	14.9 (12.9–17.6)	80.1 (79.1–81.0)	10.1 (9.1–11.0)	5.5 (4.0–7.7)	15.6 (13.7–18.1)

Data are *n* in years (95% CIs).

Table 4—Number of disabled and nondisabled years (moderate or severe) according to intervention group and duration of effect after end of intervention: the Look AHEAD study

	DSE				ILI			
	Age at disability onset (years)	Nondisabled years (*n*)	Disabled years (*n*)	Total years (*n*)	Age at disability onset (years)	Nondisabled years (*n*)	Disabled years (*n*)	Total years (*n*)
0 years								
50	64.4 (63.7–65.1)	14.4 (13.7–15.1)	21.5 (19.3–23.7)	35.8 (33.8–38.1)	65.3 (64.8–65.8)§	15.3 (14.8–15.8)§	20.7 (18.7–22.9)	36.0 (34.1–38.2)
60	71.1 (70.6–71.7)	11.1 (10.6–11.7)	15.7 (13.7–18.0)	26.9 (24.8–29.2)	72.0 (71.5–72.4)§	12.0 (11.5–12.4)§	15.2 (13.2–17.3)	26.8 (24.8–29.0)
70	78.4 (77.8–79.0)	8.4 (7.8–9.0)	10.2 (8.0–12.5)	18.6 (16.4–21.0)	79.2 (78.6–79.8)	9.2 (8.8–9.8)	9.9 (7.8–12.2)	18.7 (16.5–21.1)
4 years								
50	64.4 (63.7–65.1)	14.4 (13.7–15.1)	21.5 (19.3–23.8)	35.8 (33.8–38.1)	65.4 (64.9–65.9)§	15.4 (14.9–15.9)§	20.7 (18.6–22.9)‡	36.1 (34.0–38.2)
60	71.1 (70.6–71.7)	11.1 (10.7–11.7)	15.7 (13.7–18.0)	26.9 (24.8–29.1)	72.0 (71.6–72.5)§	12.0 (11.6–12.5)§	15.2 (13.2–17.4)*	27.2 (25.2–29.4)
70	78.4 (77.9–79.1)	8.4 (7.9–9.1)	10.2 (8.0–12.6)	18.6 (16.3–21.1)	79.2 (78.6–79.8)	9.2 (8.6–9.8)	9.9 (7.8–12.3)	19.1 (17.0–21.6)
8 years								
50	64.4 (63.7–65.1)	14.4 (13.7–15.1)	21.5 (19.4–23.7)	35.8 (33.8–38.1)	65.5 (64.9–66.0)§	15.5 (15.0–16.1)§	20.6 (18.6–22.8)‡	36.1 (34.1–38.2)
60	71.1 (70.6–71.7)	11.1 (10.6–11.7)	15.7 (13.7–18.0)	26.9 (24.8–29.1)	72.1 (71.6–72.6)§	12.1 (11.6–12.6)§	15.2 (13.2–17.4)	27.3 (25.3–29.5)
70	78.4 (77.9–79.0)	8.4 (7.9–9.0)	10.2 (8.0–12.5)	18.6 (16.3–21.1)	79.3 (78.7–79.9)	9.3 (8.7–9.9)	10.0 (7.9–12.3)	19.2 (17.1–21.6)
Lifetime								
50	64.4 (63.7–65.1)	14.4 (13.7–15.1)	21.5 (19.4–23.7)	35.8 (33.8–38.0)	66.0 (65.3–66.7)*	16.0 (15.3–16.7)*	21.2 (18.9–23.6)	37.2 (35.0–39.6)
60	71.1 (70.6–71.7)	11.1 (10.6–11.7)	15.7 (13.7–18.0)	26.9 (24.8–29.1)	72.4 (71.8–73.0)‡	12.4 (11.8–13.0)‡	15.7 (13.5–18.2)	28.1 (25.8–30.5)
70	78.4 (77.9–79.1)	8.4 (7.9–9.1)	10.2 (8.0–12.6)	18.6 (16.3–21.0)	79.4 (78.8–80.1)§	9.4 (8.8–10.1)§	10.3 (8.0–12.7)	19.7 (17.3–22.2)

Data are *n* in years (95% CIs). *$P < 0.001$, ‡$P < 0.01$, §$P < 0.05$ for comparison between the ILI and DSE groups.

not differ appreciably across the strata and that the sample sizes and number of events were considerably smaller among men and those with CVD. Thus, variation in statistical power was likely the primary factor driving different conclusions across strata. Significant benefits also were limited to moderate/severe disability because disability-adjusted life-years defined by the more severe threshold were not significant. Although this finding may be a function of less statistical power for the less frequent outcome, severe disability possibly is affected by different mechanisms that are less influenced by ILI.

The current study differs from prior intervention studies in terms of the metric under investigation. Whereas prior studies evaluated changes in physical function, our analyses incorporate effects on remission from disability as well as mortality and take a lifetime perspective. In general, lower incidence of disability, higher remission from disability, and a more favorable mortality rate in adults without versus with disabilities will contribute to a delay in disability and a greater disability-free life expectancy. The large reductions in mortality and macrovascular complications of diabetes in the U.S. during the 1990s and 2000s is likely to place a greater emphasis on this and similar metrics that capture the impact of diabetes on quality of life (2,3).

This analysis had several limitations. First, our definition of disabled and nondisabled life-years ultimately depends on a subjective selection of a threshold for physical disability. However, we used an objective, data-driven approach to select the most appropriate threshold by using all the information available in the SF-36 items before calculating incidence or testing primary comparisons. Second, our physical function assessments are based on self-report and not validated by objective, physical performance measures. However, the SF-36 has strong psychometric properties, has been extensively validated, and is well-accepted for quality-of-life measurements in clinical trials (14). Third, the analyses modeled life expectancy beyond the trial time frame and years of age. However, our primary analysis used a conservative assumption that there was no intervention effect beyond the period of intervention. Finally, the analysis did not permit a determination of factors influencing the association between lifestyle intervention and years of

life with and without disability. Nevertheless, this study is the first we are aware of to directly estimate the impact of a long-term lifestyle intervention on active and disabled life expectancy in overweight and obese adults with type 2 diabetes.

In summary, these findings indicate that an ILI that focuses on caloric restriction and increased physical activity can reduce long-term physical disability and has an impact on disability-free life expectancy despite not affecting total life expectancy. Given the continued high prevalence of diabetes in the U.S. and the increasing life spans of adults with diabetes, these findings have important implications for the compression of morbidity and improvement of quality of life among overweight and obese adults with type 2 diabetes.

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