Diabetes is a significant health problem worldwide and its prevalence is on the rise. Globally, it was estimated that there were 285 million adults living with diabetes in 2010 (26). In Australia, a national survey of diabetes in 2000 reported that 7.4% of the population had diabetes, and an additional 16.4% had precursors to diabetes (impaired fasting glucose [IFG] or impaired glucose tolerance [IGT]) (15). In the United States, the prevalence of diabetes in 2006 was 7.7%, and another 29.5% had IFG or IGT (12). Those with IFG or IGT not only are at an increased risk of developing type 2 diabetes but also have an elevated risk of cardiovascular complications and associated mortality (5).

Strength training (ST) is known to lead to improved glycemic control for those with or at risk of developing type 2 diabetes (13, 25, 29). Furthermore, ST assists in maintaining functional capacity and is beneficial in the prevention and management of sarcopenia, osteoporosis, blood pressure, cardiovascular risk, musculoskeletal disorders and injuries, and reduces susceptibility to falls (1, 6, 11, 28). The American College of Sports Medicine (ACSM), American Diabetes Association (ADA), and the American Heart Association (AHA) identify ST exercise as an integral component of a daily leisure time exercise routine for healthy adults (6, 11, 18, 24). These guidelines recommend that ST be undertaken at least twice per week by those with and without diabetes. While there are no explicit recommendations relating to ST duration, the AHA states that a 20-min period should be adequate to perform one set of 8 to 10 different resistance exercises (6). In the context of the recommended frequency (two or more times per week), this would be expected to yield a minimum of ≥40 min/wk in total (duration). Multiple logistic regression analyses examined associations of self-reported ST frequency and duration with IGM. Results: After adjustment for known confounding factors and total moderate- to vigorous-intensity leisure time exercise, the odds ratio (OR) of IGM was 0.73 (95% confidence interval [CI] = 0.59–0.91, P < 0.005) in those who met the ST frequency guideline (two or more times per week) and 0.69 (95% CI = 0.55–0.87, P < 0.01) in those who met the ST duration guideline (≥40 min/wk). Those who achieved both the recommended frequency and duration of ST had 24% lower odds of IGM. There was also evidence that a moderate frequency (once a week) and duration (10–39 min/wk) of ST reduced the odds of IGM (OR frequency = 0.53, 95% CI = 0.51–0.81, P < 0.01; OR duration = 0.72, 95% CI = 0.52–1.00, P < 0.05). Conclusions: These findings support the importance of including ST activity, at a frequency of at least once per week, within exercise management recommendations for the maintenance of favorable metabolic health, particularly as it may contribute to reducing the risk of developing type 2 diabetes mellitus.
guidelines interact at the population level, specifically when characterizing the association of ST and IGM. Indeed, one other population-based study has identified muscle-strengthening activity to be associated beneficially with insulin sensitivity; however, this study considered a different metabolic end point and did not stratify the study sample by the recommended guidelines, and only the associations with ST frequency were reported (10).

We examined the associations of achieving the current guideline relating to ST activity (both frequency and duration) with IGM in a large national population-based sample of Australian adults without clinically diagnosed diabetes.

RESEARCH DESIGN AND METHODS

Details of the Australian Diabetes, Obesity and Lifestyle (AusDiab) study methods have been described in greater detail elsewhere (14,23). In brief, the AusDiab study is a national, longitudinal survey designed to examine the prevalence of diabetes and obesity across Australia. The stratified, clustered, population-based study sample was drawn from 42 randomly selected Census Collector Districts across Australia. The study was approved by the Baker IDI Heart and Diabetes Institute Ethics Committee, and written informed consent was obtained from all participants. The baseline 1999/2000 survey included 11,247 adults (5049 men) age ≥25 yr who represented 55.3% of those completing the initial household interview. In 2004/2005, 6400 adults attended the follow-up survey (response rate = 58%), with the primary aim of estimating the incidence of diabetes. The present analyses use data from the follow-up survey where ST measures were first implemented. Weight, height, hip, and waist circumference were measured as previously described (7,14). A fasting blood sample was taken, and a 75-g oral glucose tolerance test was performed. From the cohort of 6400, we excluded those who were pregnant, had clinically diagnosed type 2 diabetes, or had an unclassified diabetes status (n = 544). We also excluded those with implausibly high ST values (>24 h per frequency of once per week, n = 5) or with no leisure time exercise data provided (n = 20); the remaining 5831 participants were included in these analyses. Impaired glucose metabolism (IGM) was defined as having IFG (fasting plasma glucose [PG] = 6.1–6.9 mmol L⁻¹ and 2-h PG < 7.8 mmol L⁻¹), IGT (fasting PG < 7.0 mmol L⁻¹ and 2-h PG = 7.8–11.1 mmol L⁻¹), or undiagnosed diabetes mellitus (fasting PG ≥ 7.0 mmol L⁻¹ and/or 2-h PG ≥ 11.1 mmol L⁻¹) (31). Participants who reported ≥2.5 h of leisure time exercise per week were classified as meeting the public health guidelines for physical activity (2).

ST activity was assessed using questions adapted from the Behavioral Risk Factor Surveillance System Survey (9). ST frequency was determined by asking participants to report separately for the last week, “How many times have you done any activities designed to increase muscle strength or tone, such as lifting weights, pull-ups, push-ups, or sit-ups?” In a separate question, ST duration was evaluated by asking, “What do you estimate was the total time that you spent in these activities in the last week?”

In accordance with the 2010 ACSM/ADA and the AHA physical activity guidelines (6,11), we categorized self-reported ST frequency into three groups: those meeting the recommended guidelines (two or more times per week), those reporting a ST frequency of once per week, and those who did not participate in ST exercise (less than once per week). In addition, we categorized self-reported ST duration into three groups: <10, 10–39, and ≥40 min wk⁻¹. To reduce possible inconsistencies with self-reported frequency and duration, we further stratified the analyses by those participants who fulfilled both ST elements (frequency, duration; two or more times per week and ≥40 min wk⁻¹) versus those who did not.

Analyses used STATA version 11.0 (STATA, College Station, TX), using multiple logistic regression models adjusting for potential confounding factors. Model A adjusted for age and gender. Model B included model A plus education (never attended/primary/some education or high school/university graduate), family history of diabetes (parents/siblings), and smoking (current/former/nonsmoker). Model C included model B plus total leisure time exercise (those meeting the public health physical activity guidelines of ≥2.5 h wk⁻¹ versus those who did not). Model D included model C plus waist circumference. Waist circumference is a widely used indirect measure of central adiposity that has previously been shown to be an independent predictor of mortality risk (32). Furthermore, waist circumference is considered to be a better predictor of diabetes than body mass index in the AusDiab sample (23). There were no significant interactions between age or gender and ST frequency/duration (P > 0.05); thus, the analyses were not stratified by age or gender.

RESULTS

The mean ± SD age of the participants (2622 men and 3209 women) was 56.0 ± 12.7 yr. In this sample, 1055 participants (18.1%) were identified as having IGM. Of those, 28.1% had IFG, 53.5% had IGT, and 18.5% had undiagnosed type 2 diabetes. The proportion of the sample reporting participation in ST two or more times per week was similar to the proportion reporting duration of ST ≥ 40 min wk⁻¹ in men (16.5% and 14.1%, respectively) and in women (14.8% and 13.9%, respectively). Furthermore, 11.8% of all of the participants met both frequency and duration guidelines. A total of 5.0% and 6.1% of all participants reported undertaking ST once a week or for a duration of 10–39 min wk⁻¹, respectively. Of those with IGM, 11.6% achieved the frequency guideline of two or more times in the previous week and 9.5% achieved ≥40 min of ST in the previous week compared with 16.4% and 15.0% of those without IGM, respectively.

The odds ratios (ORs) and 95% confidence intervals (95% CIs) for having IGM in those meeting the guidelines for ST
frequency and/or duration are shown in Table 1. Those who undertook ST once per week or achieved the recommended frequency of two or more times per week had 52% and 33% lower odds of having IGM (model A). Similarly, those who participated in 10–39 min wk⁻¹ or the recommended duration of ≥40 min wk⁻¹ of ST had 34% and 37% lower odds of having IGM (model A). When educational attainment, family history of diabetes, smoking, and leisure time exercise were included in the models, the beneficial influence of ST frequency and duration remained, with the exception of ST duration of 10–39 min wk⁻¹ (model C). However, after adjusting for waist circumference, only the associations of moderate frequency (once per week) (OR = 0.58, 95% CI = 0.38–0.80, P = 0.016) and high duration (≥40 min wk⁻¹) remained statistically significant (OR = 0.78, 95% CI = 0.61–0.99, P = 0.038).

**DISCUSSION**

In this population-based study of Australian adults, achieving the current the ACSM/ADA and AHA recommended guideline of two or more times of ST per week or ≥40 min of ST weekly was associated with a reduced risk of having IGM. There were no additional benefits for those who achieved both the ST frequency and duration guidelines. The study also demonstrated that undertaking ST once a week or training for 10–39 min weekly was associated with a significantly reduced risk for IGM relative to those who undertook ST < 10 min wk⁻¹ even after controlling for age, gender, educational attainment, family history of diabetes, smoking, and leisure time exercise. This suggests that ST undertaken at least once weekly may provide benefit in terms of minimizing the risk of developing diabetes, although this will need to be confirmed in experimental intervention studies.

Only one other population-based study has evaluated the associations of muscle-strengthening activities, or ST, and glucose tolerance. In a sample of 4504 US adults involved in the 1999–2004 National Health and Nutrition Examination Survey, the associations of muscle-strengthening activities with insulin sensitivity, fasting insulin, and fasting glucose were examined (10). After adjustment for major confounders including, age, leisure time non–muscle-strengthening activities, race/ethnicity, body mass index, smoking status, alcohol consumption, and daily total caloric intake, muscle-strengthening activities levels were positively associated with insulin sensitivity and fasting insulin but not fasting glucose. Statistically significant associations were generally observed for the group participating in ST three or more times per week compared with the referent group (less than one muscle-strengthening activity per week). Our findings provide additional evidence to indicate that ST activity is inversely associated with the presence of IGM in adults and that this favorable association is present even with a modest frequency of ST activities—as little as once per week.

Clinical trials show that ST, particularly high-intensity progressive ST, improves insulin sensitivity, glycemic control, and blood glucose control in those with type 2 diabetes (8,15,17,21,27), largely as a result of gains in muscle mass. Furthermore, previous studies have demonstrated significant reductions in central obesity (waist circumference) after ST in individuals with or at risk of type 2 diabetes (4,20,30). In our previous randomized controlled trial of older adults with type 2 diabetes, we reported that the combination of a modest weight loss diet with high-intensity ST led to a 6.9-cm decrease in waist circumference compared with baseline measurements, which coincided with a significant 0.8 percentage point net reduction in glycated hemoglobin (HbA₁c) relative to the controls (13). It is plausible that through improving insulin sensitivity, ST may be an important

**TABLE 1. ORs for the presence of IGM according to achieving the recommended ST frequency, duration, and both frequency and duration.**

<table>
<thead>
<tr>
<th>Frequency, sessions per week</th>
<th>Models</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4634 (79.5)</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>1</td>
<td>290 (5.0)</td>
<td>0.48 (0.32–0.73)*</td>
<td>0.51 (0.33–0.77)**</td>
<td>0.53 (0.34–0.81)**</td>
<td>0.58 (0.38–0.90)**</td>
</tr>
<tr>
<td>≥2</td>
<td>907 (15.5)</td>
<td>0.67 (0.54–0.82)*</td>
<td>0.71 (0.58–0.87)*</td>
<td>0.73 (0.59–0.91)**</td>
<td>0.82 (0.66–1.02)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Duration, min wk⁻¹</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0–9</td>
<td>4659 (79.9)</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>10–39</td>
<td>357 (6.1)</td>
<td>0.66 (0.48–0.90)**</td>
<td>0.70 (0.51–0.97)**</td>
<td>0.72 (0.52–1.00)**</td>
<td>0.80 (0.57–1.13)</td>
</tr>
<tr>
<td>≥40</td>
<td>815 (14.0)</td>
<td>0.63 (0.50–0.79)*</td>
<td>0.66 (0.53–0.84)*</td>
<td>0.69 (0.55–0.87)**</td>
<td>0.78 (0.61–0.99)**</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Frequency two or more times per week and duration ≥40 min wk⁻¹</th>
<th>Models</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>5143 (88.2)</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Yes</td>
<td>688 (11.8)</td>
<td>0.70 (0.55–0.88)**</td>
<td>0.73 (0.57–0.93)**</td>
<td>0.76 (0.60–0.98)**</td>
<td>0.85 (0.68–1.09)</td>
</tr>
</tbody>
</table>

Data are presented as ORs (95% CI).
ST frequency (times per week) and duration (min wk⁻¹) coefficients are based on self-report data using the timeframe of the previous 7 d.
Model A: adjusted for age and gender only.
Model B: adjusted for model A plus education (never attended/primary/some education or high school/university graduate), family history of diabetes (parents/siblings), and smoking (current/former/nonsmoker).
Model C: adjusted for model B plus total leisure time physical activity (those meeting the public health physical activity guidelines of ≥2.5 h wk⁻¹ versus those who did not).
Model D: adjusted for model C plus waist circumference (cm).
* P < 0.001.
** P < 0.01.
*** P < 0.05.
contributor to diabetes risk reduction and could potentially be given stronger endorsement as an integral component of a daily exercise program for both healthy individuals and those who are at risk of developing prediabetes or diabetes (16,29).

While the numerous health benefits of ST are now well established (30), our findings indicate that the prevalence of ST in the community is low, with only 20.5% of the study sample participating in ST one or more times per week. These findings are comparable with other studies that have assessed the prevalence of ST within populations. For example, a study in regional Australia reported that 13.7% of participants completed one or more sessions of ST in the previous week (19), whereas a 2004 study in the United States established a national prevalence of 21.9% among men and 17.5% among women participating in ST two or more times per week (22). The lowest participation rates are evident in the older adults (3,22), with 7% of Australian adults age 55 or greater participating in ST activities (19). Importantly, older adults are a population group who would be expected to derive the greatest benefits from ST. It is well documented that advancing age coincides with substantial losses in muscle mass and strength, which invariably affects physical function and well-being (30).

Although our study has several strengths, including the large sample size, objective measurement of glucose tolerance, and observation of the role of habitual resistance exercise at the population level, limitations do exist. The cross-sectional nature of our study limits our ability to make causal inferences about the association of ST and IGM and thereby emphasizes the importance for prospective studies to assess the ST and IGM relationship longitudinally. The nature of the ST question used and the inherent biases of a self-report measure may have misrepresented the actual ST frequency and duration values. Furthermore, we lacked information about the intensity of ST, which might have resulted in an underestimate of the observed relationship. Also, the relatively small number of individuals reporting a moderate frequency (n = 290, 5.0% of the sample) and duration (n = 357, 6.1% of the sample) of ST may overestimate the magnitude of the associations of ST with IGM. Nevertheless, because high-intensity ST can lead to favorable changes in glucose metabolism in those with or at risk of type 2 diabetes (8,13), it is plausible that performing ST only once a week, specifically high-intensity ST, may produce benefits typically consistent with more frequent, but less intense, ST regimens.

In conclusion, our findings indicate that ST, even for a frequency of once per week, may have favorable effects on metabolic health and thereby could contribute to reducing the risk of developing type 2 diabetes. In addition, these findings provide further evidence that diabetes prevention strategies should give greater emphasis to approaches that incorporate ST, consistent with existing physical activity guidelines for healthy adults and those with type 2 diabetes.

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There is no conflict of interest to report for any author listed on this article. The results of the present study do not constitute endorsement by the American College of Sports Medicine.

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