Diabetes
Special Issue

Clinical Measures of Physical Fitness Predict Insulin Resistance in People at Risk for Diabetes

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Background and Purpose. Physical inactivity has been well documented as a risk factor for type 2 diabetes. Previous studies measured the level of physical activity either with questionnaires or with direct measurements of maximum oxygen uptake. However, questionnaires are patient-report measures, and methods for obtaining direct maximum oxygen uptake measurements often are not available clinically. The purpose of this study was to investigate whether clinical measurement of health-related physical fitness with a simple test battery can predict insulin resistance, a precursor of type 2 diabetes, in people at risk for diabetes.

Subjects and Methods. A total of 151 volunteers with at least one diabetes risk factor (overweight, hypertension, dyslipidemia, family history, impaired glucose tolerance, gestational diabetes, or delivering a baby weighing more than 4.0 kg) were recruited. Insulin resistance (as determined with the homeostasis model assessment of insulin resistance [HOMA-IR]), physical fitness (including body composition, as determined with the body mass index and waist circumference), muscle strength (handgrip strength [force-generating capacity]), muscle endurance (sit-up test), flexibility (sit-and-reach test), and cardiorespiratory endurance (step test) were measured, and a physical activity questionnaire was administered. Backward regression analysis was used to build the prediction models for insulin resistance from components of physical fitness and physical activity.

Results. Body mass index, muscle strength, and cardiorespiratory fitness predicted HOMA-IR in men (adjusted R^2=.264). In women, age, waist circumference, and cardiorespiratory fitness were the predictors of HOMA-IR (adjusted R^2=.438).

Discussion and Conclusion. Clinical measures of physical fitness can predict insulin resistance in people at risk for diabetes. The findings support the validity of clinical measures of physical fitness for predicting insulin resistance in people at risk for diabetes.

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The prevalence of type 2 diabetes is increasing worldwide in adults of all ages.[1,2] The disease and the associated complications, such as macrovascular disease (coronary artery disease, cerebrovascular accident, and peripheral arterial disease), microvascular disease (diabetic retinopathy and diabetic nephropathy), and neuropathy (of both peripheral and autonomic nervous systems), not only increase the burden of the economic costs of the disease but also decrease the quality of life of people and have a great effect on their families. Given the huge impact of type 2 diabetes, primary prevention efforts aimed toward people at risk for developing the disease are crucial.[3,4]

Insulin resistance (ie, reduced insulin sensitivity) has been recognized as a strong predictor of type 2 diabetes.[5] Studies have reported that insulin resistance can occur several years before the development of type 2 diabetes.[6] In the initial stage of insulin resistance, the normal level of plasma glucose is maintained by the increased secretion of insulin by pancreatic β cells (hyperinsulinemia). If insulin resistance keeps rising, the compensatory increased insulin secretion becomes insufficient, resulting in the elevation of the plasma glucose level and the development of type 2 diabetes.

At present, physical therapists are more involved in disease prevention and health promotion than they were in the past. The association between physical activity and the morbidity of type 2 diabetes has been reported in many epidemiological studies.[7–12] In addition, 3 randomized controlled trials revealed that intensive lifestyle interventions (diet and exercise) can effectively reduce the incidence of diabetes in people at risk.[13–15] Levels of physical activity are often determined with self-reported questionnaires in epidemiological studies and with maximal exercise testing in experimental studies. However, questionnaires are subjective measurements, and maximal exercise testing often is not available or desirable clinically. Measurement of health-related physical fitness, that is, fitness related to disease prevention and health promotion, typically includes body composition, muscle strength (force-generating capacity) and endurance, flexibility, and cardiopulmonary endurance.[16] The aim of this study was to investigate whether clinical measures of health-related physical fitness can predict insulin resistance in people at risk for type 2 diabetes.

Method

Subjects

A total of 151 Asian volunteers (56 men and 95 women) with an age range of 22 to 70 years were recruited. Various advertising strategies, such as distributing pamphlets to university personnel and residents of nearby communities and posting recruiting posters in outpatient departments at university hospitals, were used to recruit volunteers. Volunteers were included in the study if they met at least one of the following criteria: body mass index (BMI) of $\geq$24 kg/m^2 (on the basis of the criteria of a national nutrition survey done in Taiwan), hypertension (blood pressure of $\geq$130/85 mm Hg), dyslipidemia (serum triglyceride level of $\geq$150 mg/dL or high-density lipoprotein level of <40 mg/dL in men and <50 mg/dL in women), first-degree relatives of parents with type 2 diabetes, impaired glucose tolerance (on the basis of oral glucose tolerance tests), gestational diabetes, and delivering a baby weighing $\geq$4.0 kg. The criteria were generated on the basis of the study of Helmrich et al[8] and components of metabolic syndrome as defined by the National Cholesterol Education Program Adult Treatment Panel III (NCEP ATP III).[17] Volunteers were excluded from the study if they had diagnosed diabetes, were currently receiving treatment with insulin or oral hypoglycemic agents, or could not undertake a fitness evaluation because of physical or psychological conditions. Written informed consent was obtained from each participant.

The anthropometric and metabolic profiles of the study population are shown in Table 1. Overall, 67% of the subjects had a BMI of greater than 24 kg/m^2, 52% had hypertension, 48% had dyslipidemia, 52% had a positive family history of type 2 diabetes, and 5 women had delivered a baby weighing more than 4.0 kg. Fifty-one percent of the subjects with hypertension were taking antihypertension medications. Specifically, men had higher values for BMI, waist circumference, blood pressure, and triglycerides and lower values for high-density lipoprotein than women. There were no sex differences in fasting plasma glucose levels.

Assessments

After providing written informed consent, each participant was interviewed to obtain a medical history and a list of current medications, if any.

Homeostasis model assessment of insulin resistance (HOMA-IR). Insulin resistance (as determined with the HOMA-IR) was calculated by use of a formula described by Matthews et al[18]: HOMA-IR=fasting plasma insulin level (μU/mL) $\times$ fasting plasma glucose level (mmol/L)/22.5. Subjects were asked to fast and to refrain from exercise for at least 8 hours before the blood test. Plasma glucose levels were determined by use of the glucose oxidase membrane/hydrogen peroxide electrode method with Antsense II.* Plasma in-

* Bayer-Sankyo Co, Marunouchi Kitaguchi Bldg 1-6-5, Marunouchi, Chiyoda-ku, Tokyo, Japan.

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sulin levels were measured by use of a microparticle enzyme immunoassay with an AxSYM system analyzer.[†]

Body composition. Body composition was determined with 2 indicators, BMI and waist circumference. Body mass index was calculated with the following formula: BMI=body weight (kg)/height squared (m^2). Body weight and height were measured to the nearest 0.2 kg and 0.5 cm, respectively. Waist circumference was measured to the nearest 1 mm with a flexible steel tape measure midway between the lowest rib and the iliac crest when subjects were in the standing position at the end of expiration. Each measurement was obtained twice, and the average was used in the analysis.[19]

Flexibility. Flexibility was measured with the sit-and-reach test. In this test, a yardstick was taped on a mat, and a strip was taped across the yardstick at a right angle. Subjects sat on the mat with their knees extended and the yardstick between their legs. The subjects' heels were put on the 2 ends of the taped strip, which was 30 cm long. The subjects were asked to reach forward slowly, as far as possible, with their hands overlapped and their fingers extended and to hold the end position for 2 seconds. The farthest point reached with the fingertips was the documented score. The best of 3 measurements was used in the analysis.[16]

Muscle strength and endurance. The grip strength of the dominant hand was measured with a Jamar handheld dynamometer[‡] while the subjects stood with their elbows extended.[20,21] The best score of 3 trials was recorded for analysis. Muscle endurance was measured with the sit-up test, with the subjects lying on their backs with their heels on the mat and their knees at 90 degrees of flexion; their arms were crossed over their chests, and their hands were placed lightly on their shoulders. Subjects were directed to lift the trunk until their elbows made contact with their knees and then to return to the supine position. The maximum number of sit-ups performed in 1 minute was used to represent muscle endurance.

Table 1.
Anthropometric and Metabolic Profiles for the Study Sample

Variable	$\bar{X}$ (SD) for:		
	Men (n=56)	Women (n=95)	Total (N=151)
Age (y)	46.2 (13.7)	48.2 (10.8)	47.5 (11.9)
Height (cm)	171.4 (6.4)	156.8 (5.7)[a]	162.2 (9.2)
Weight (kg)	79.0 (9.7)	62.6 (13.6)[a]	68.7 (14.6)
Body mass index (kg/m^2)	26.9 (3.5)	25.4 (4.9)[a]	26.0 (4.5)
Waist circumference (cm)	88.3 (8.4)	77.9 (11.4)[a]	81.7 (11.6)
Systolic blood pressure (mm Hg)	127.9 (16.3)	121.2 (16.9)[a]	123.7 (16.9)
Diastolic blood pressure (mm Hg)	83.8 (10.3)	77.8 (11.1)[a]	80.0 (11.2)
Triglycerides (mg/dL)	172.4 (116.1)	119.4 (57.9)[a]	139.1 (87.8)
High-density lipoprotein (mg/dL)	43.1 (12.1)	57.1 (17.2)[a]	51.9 (16.9)
Fasting plasma glucose (mg/dL)	85.2 (12.0)	82.6 (11.5)	83.6 (11.7)
Fasting plasma insulin (μU/mL)	10.9 (8.3)	10.1 (8.2)	10.4 (8.2)

[a] $P<.05$ compared with the value in men.

Cardiorespiratory fitness. The standardized 3-minute step test (step height of 35 cm and frequency of 24 steps per minute) was used to evaluate cardiorespiratory fitness. The cardiorespiratory endurance index was derived from heart rate recovery after the test with the following formula: cardiorespiratory endurance index= duration of exercise (seconds) × 100/sum of heart beats during the recovery period/2. The sum of heart beats during the recovery period was the sum of the heart rates during 3 periods after the test: 1 to 1.5 minutes, 2 to 2.5 minutes, and 3 to 3.5 minutes. The test was terminated if a subject lost balance, missed the stepping rhythm for 3 steps, or reported any discomfort during the test.[22]

Level of physical activity. The level of physical activity was evaluated with an interviewer-administered questionnaire, the 7-day recall physical activity questionnaire. This questionnaire records all physical activities (occupational work as well as leisure activities) during the preceding week. Subjects reported the time (with one unit being 0.5 hour) spent in vigorous activities (greater than 6 metabolic equivalents [1 MET=3.5 mL $O_2 \cdot kg^{-1} \cdot min^{-1}$]), moderate activities (3–5 METs), and sleep during the preceding 7 days. Energy expenditure (kJ/d) was calculated on the basis of the reported duration and intensity of activities. This questionnaire has been shown to have good reliability and validity.[23]

Data Analysis

The data were analyzed with the SPSS statistical program (version 10.0 for Windows).[§] The HOMA-IR was logarithmically transformed because of the skewed distribution of nontransformed values. An independent sample *t* test and a chi-square test were used to examine sex-related differences as well as differ-

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[‡] JA Preston Corp, 60 Page Rd, Clifton, NJ 07012.
[§] SPSS Inc, 233 S Wacker Dr, Chicago, IL 60606.

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ences between subjects with and subjects without metabolic syndrome.

The Pearson correlation coefficient was used to determine associations between variables. We performed backward regression analysis to construct sex-specific models that predict insulin resistance. We initiated the regression with a full model that included age, physical activity, and the 5 components of physical fitness as the possible predictors. Subsequently, the predictor with the largest *P* value was dropped, and the model was refitted. Once a variable was eliminated, it was not used in the model again. The final model included only factors that explained the variance of HOMA-IR significantly.

To examine the ability of the constructed model to predict insulin resistance, we calculated sensitivity (proportion of cases correctly identified as having an abnormal HOMA-IR [≥2.61]), specificity (proportion of cases correctly identified as having a normal HOMA-IR), positive likelihood ratio [sensitivity/(1−specificity)], and negative likelihood ratio [(1−sensitivity)/specificity].

Results

The HOMA-IR in our subjects was 2.2 (SD=1.8), and there was no differences between the sexes ($\overline{X}$ [SD]: 2.3 [1.7] for men and 2.1 [1.9] for women). The level of HOMA-IR in our study population was higher than that in people who were healthy ($\overline{X}$ [SD]: 1.22 [1.16])[24] but lower than that in people with type 2 diabetes (2.21 [1.55] and 5.98 [3.49] in the studies of Yokoyama et al[24] and Bonora et al,[25] respectively). When a HOMA-IR of 2.61 was used as the cutoff point and a HOMA-IR of ≥2.61 was defined as abnormal,[18,26] 38 subjects (25%; 15 men and 23 women) had abnormal HOMA-IR levels. Table 2 shows the components of metabolic syndrome. Men had a higher prevalence of high blood pressure and high triglyceride levels than women. Thirty-six subjects (24%; 16 men and 20 women) met at least 3 of the 5 criteria for metabolic syndrome as defined by the NCEP ATP III.

Physical fitness and activity levels in the study population are shown in Table 3. Men had higher values for handgrip strength and muscle endurance (sit-up test) but lower values for flexibility (sit and reach test) than women. No sex-related differences were noted in cardiorespiratory fitness values and physical activity levels.

Both men and women who met the criteria for metabolic syndrome had higher HOMA-IR levels, higher BMI values, and larger waist circumference values. Eighteen percent of subjects without metabolic syndrome and 47% of subjects with metabolic syndrome had elevated HOMA-IR

Table 2.
Prevalence of Elevated Values for Components of Metabolic Syndrome

Variable	No. (%) of:		
	Men (n=56)	Women (n=95)	Total (N=151)
High waist circumference[a]	24 (43)	35 (37)	59 (39)
High blood pressure[b]	37 (66)	42 (44)[c]	79 (52)
Triglycerides[d]	26 (46)	25 (26)[c]	51 (34)
High-density lipoprotein[e]	22 (39)	33 (35)	55 (36)
Fasting plasma glucose[f]	2 (4)	3 (3)	5 (3)
Criteria for MS[g]			
0 criterion met for MS	5 (9)	24 (25)	29 (19)
1 criterion met for MS	12 (21)	35 (37)	47 (31)
2 criteria met for MS	23 (41)	16 (17)	39 (26)
3 criteria met for MS	11 (20)	9 (9)	20 (13)
4 criteria met for MS	5 (9)	11 (12)	16 (11)

[a] For women, ≥88 cm; for men, ≥102 cm.
[b] Systolic blood pressure, ≥130 mm Hg; or diastolic blood pressure, ≥85 mm Hg; or taking antihypertension medications.
[c] $P<.05$ compared with the value in men.
[d] ≥150 mg/dL.
[e] For women, <50 mg/dL; for men, <40 mg/dL.
[f] ≥100 mg/dL.
[g] MS=metabolic syndrome (as defined by National Cholesterol Education Program Adult Treatment Panel III as having any 3 of the following 5 features: high waist circumference, high blood pressure, elevated triglyceride levels, lower levels of high-density lipoprotein, and elevated fasting plasma glucose).

Table 3.
Physical Fitness and Activity Levels in the Study Sample

Variable	$\overline{X}$ (SD) for:			Range
	Men (n=56)	Women (n=95)	Total (N=151)	
Handgrip strength (kg)	42.9 (7.8)	24.9 (5.2)[a]	31.6 (10.7)	13.0–61.0
Sit-up test (no. of sit-ups/min)	20.6 (11.4)	11.2 (8.5)[a]	14.7 (10.7)	0–40
Sit-and-reach test (cm)	18.8 (11.1)	24.4 (11.2)[a]	22.3 (11.5)	−6.5–48
Cardiorespiratory endurance index	57.8 (12.4)	53.2 (16.1)	54.9 (15.0)	19.0–90.0
Physical activity (kJ/kg/d)	139.2 (7.9)	140.0 (7.8)	139.7 (7.8)	93.5–162.8

[a] $P<.05$ compared with the value in men.

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Table 4.
Homeostasis Model Assessment of Insulin Resistance (HOMA-IR), Physical Fitness, and Physical Activity Levels in the Study Sample According to the Presence or Absence of Metabolic Syndrome (MS)[a]

Variable	$\bar{X}$ (SD):			
	Without MS		With MS	
	Men (n=40)	Women (n=75)	Men (n=16)	Women (n=20)
HOMA-IR	1.8 (1.1)	1.8 (1.3)	3.4 (2.3)[b]	3.3 (2.9)[b]
Age (y)	45.0 (13.2)	47.9 (10.4)	49.0 (14.9)	49.5 (12.5)
Body composition				
Body mass index (kg/m²)	26.0 (3.0)	24.3 (4.1)	29.3 (3.6)[b]	29.7 (5.4)[b]
Waist circumference (cm)	85.4 (6.7)	75.1 (10.0)	95.6 (7.7)[b]	88.2 (10.7)[b]
Handgrip strength (kg)	44.0 (7.7)	24.5 (4.6)	40.2 (7.7)	26.7 (7.1)
Sit-up test (no. of sit-ups/min)	22.7 (10.8)	11.8 (8.3)	15.4 (11.7)[b]	8.9 (9.2)
Sit-and-reach test (cm)	20.7 (11.3)	24.6 (11.1)	14.2 (9.4)[b]	23.6 (11.9)
Cardiorespiratory endurance index	59.8 (12.9)	54.8 (15.6)	52.4 (9.5)[b]	46.8 (16.9)
Physical activity (kJ/kg/d)	139.1 (8.4)	140.2 (8.4)	139.4 (6.8)	139.5 (4.9)

[a] As defined by National Cholesterol Education Program Adult Treatment Panel III criteria.
[b] $P<.05$ compared with the value in people of the same sex without MS.

levels. Men with metabolic syndrome had lower cardiorespiratory fitness, flexibility, and muscle endurance values than men without metabolic syndrome. However, differences in physical fitness between subjects with and subjects without metabolic syndrome were not seen in women (Tab. 4).

Associations Among HOMA-IR, Physical Fitness, Age, and Activity Level

Correlations between measurements in men and women are shown in Table 5. In men, insulin resistance was correlated positively with BMI ($r=.40$, $P=.003$) and waist circumference ($r=.39$, $P=.003$) and negatively with cardiorespiratory endurance index ($r=-.30$, $P=.03$). In women, insulin resistance was correlated positively with BMI ($r=.60$, $P<.0005$), waist circumference ($r=.64$, $P<.0005$), and handgrip strength ($r=.31$, $P=.003$) and negatively with flexibility ($r=-.26$, $P<.013$), cardiorespiratory endurance index ($r=-.45$, $P<.0005$), and age ($r=-.20$, $P<.047$).

Contributions of Age and Physical Fitness and Activity Levels to HOMA-IR

Table 6 shows a summary of the backward regression analysis for HOMA-IR. The final prediction models for insulin resistance for men and women were different. In men, BMI, muscle strength, and cardiorespiratory fitness were significant predictors of HOMA-IR. In women, age, waist circumference, and cardiorespiratory fitness were significant predictors of HOMA-IR. About 26% and 44% of the variances in HOMA-IR were explained by the final models for men and women, respectively.

The sensitivities of the generated models for men and women were .27 and .42, respectively. The specificity for both men and women was .93. Because sensitivity and specificity are influenced by prevalence (27% and 24% in men and women, respectively), positive and negative likelihood ratios were calculated. The positive likelihood ratios in men and women were 3.64 and 6.00, respectively. The negative likelihood ratios in men and women were 0.79 and 0.63, respectively.

Discussion

The purpose of this study was to investigate whether clinical measures of health-related physical fitness can predict insulin resistance in people at risk for diabetes. The results demonstrated that statistical models based on physical fitness can predict abnormal HOMA-IR levels in people at risk for diabetes. Specifically, we found that BMI, muscle strength, and cardiorespiratory fitness were predictors of insulin resistance in men. In women, age, waist circumference, and cardiorespiratory fitness were predictors of insulin resistance.

With regard to the predictive values of our generated models, the probability of a man with an abnormal HOMA-IR of being predicted to have an abnormal HOMA-IR was 3.64 times higher than that of a man who did not have an abnormal HOMA-IR. In addition, the probability of a man who had an abnormal HOMA-IR of being predicted to have a normal

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Table 5.
Correlation Coefficients for Measurements in Men and Women[a]

Parameter	Correlation Coefficient for: Log HOMA-IR	Body Mass Index	Waist Circumference	Handgrip Strength	Sit-up Test	Sit-and-Reach Test	Cardiorespiratory Endurance Index	Age	Physical Activity
Log HOMA-IR									
Men	1.00	.40[b]	.39[b]	.04	−.14	−.17	−.30[b]	−.06	−.24
Women	1.00	.60[b]	.64[b]	.31[b]	−.03	−.26[b]	−.45[b]	−.20[b]	−.01
Body mass index									
Men		1.00	.86[b]	−.59[b]	−.46[b]	−.34[b]	−.40[b]	.25	.12
Women		1.00	.91[b]	.34[b]	−.03	−.23[b]	−.46[b]	−.14	.07
Waist circumference									
Men			1.00	−.48[b]	−.46[b]	−.35[b]	−.46[b]	.24	.09
Women			1.00	.34[b]	−.03	−.27[b]	−.48[b]	−.12	.12
Handgrip strength									
Men				1.00	.63[b]	.23	.32[b]	−.55[b]	−.28[b]
Women				1.00	.36[b]	−.06	.02	−.36[b]	−.03
Sit-up test									
Men					1.00	.41[b]	.35[b]	−.66[b]	−.11
Women					1.00	.12	.24[b]	−.31[b]	−.14
Sit-and-reach test									
Men						1.00	.35[b]	−.39[b]	.01
Women						1.00	.25[b]	.32[b]	.14
Cardiorespiratory endurance index									
Men							1.00	−.24	.04
Women							1.00	−.02	.07
Age									
Men								1.00	.25
Women								1.00	.20[b]
Physical activity									
Men									1.00
Women									1.00

[a] HOMA-IR=homeostasis model assessment of insulin resistance.
[b] $P<.05$ (as determined by Pearson correlation).

HOMA-IR was 0.79 times lower than that of a man who did not have an abnormal HOMA-IR. Similarly, the probability of a woman with an abnormal HOMA-IR of being predicted to have an abnormal HOMA-IR was 6 times higher than that of a woman who did not have an abnormal HOMA-IR. The probability of a woman who had an abnormal HOMA-IR of being predicted to have a normal HOMA-IR was 0.63 times lower than that of a woman who did not have an abnormal HOMA-IR.

HOMA-IR Is a Valid Surrogate of Insulin Resistance

The gold standard technique for insulin resistance determination is the euglycemic-hyperinsulinemic clamp (clamp-IR). However, the clamp-IR is invasive, expensive, laborious, and rarely performed in clinical settings. The HOMA-IR was developed to be a surrogate of insulin resistance. The validity of the HOMA-IR has been established for different populations. For example, significant correlations between the HOMA-IR and the clamp-IR have been reported for healthy people without diabetes ($r=-.4$ to $-.7$),[24,25] for people with type 2 diabetes ($r=-.5$ to $-.75$),[24,25] and for people with hypertension and type 2 diabetes ($r=-.57$).[27]

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Cardiorespiratory Fitness Evaluated by the Step Test Was an Independent Predictor of Insulin Resistance in Both Sexes

Few studies have examined potential exercise-related predictors of insulin resistance. Maximal exercise testing is a sophisticated measure of cardiorespiratory fitness; however, it is not often feasible or desirable clinically. Step tests, in contrast, are submaximal exercise tests and require minimal equipment. A wide variety of step tests (different step heights and different stepping rates) have been developed to estimate peak oxygen consumption and have been shown to be reliable and valid measures of cardiopulmonary fitness.[28,29] The 3-minute step test used in the present study was adapted from the Harvard step test, which assesses cardiorespiratory fitness on the basis of the speed of heart rate recovery from submaximal exercise. The index of the 3-minute step test has been shown to be correlated positively (r=.5) with peak oxygen consumption in Taiwanese adults who were healthy.[30]

The results of the present study showed that the 3-minute step test was a significant predictor for insulin resistance in both men and women at risk for diabetes. This finding is consistent with previous research. Endurance exercise that positively affects cardiorespiratory fitness has been shown to increase insulin sensitivity in people who were healthy[31–33] as well as in people with type 2 diabetes.[31] The improvement in insulin resistance resulting from endurance exercise is mainly associated with the exercise-induced adaptations of intramuscular enzymes and signaling proteins that are involved in glucose and fat metabolism.[34,35] For additional details on the effects of exercise on insulin sensitivity, see the articles by Turcotte and Fisher[36] and Gulve[37] in this issue.

Table 6.
Summary of Backward Regression Analysis for Homeostasis Model Assessment of Insulin Resistance (HOMA-IR)[a]

Group	Step	Variable Removed	No. of Remaining Variables in the Model	Model-Adjusted R^2	P Value of the Model
Men	1	Flexibility	7	.243	.004
	2	Waist circumference	6	.258	.002
	3	Age	5	.266	.001
	4	Muscle endurance	4	.278	<.0005
	5	Physical activity	3	.264	<.0005
Women	1	Physical activity	7	.424	<.0005
	2	Flexibility	6	.431	<.0005
	3	Body mass index	5	.437	<.0005
	4	Muscle endurance	4	.441	<.0005
	5	Muscle strength	3	.438	<.0005

[a] Final models: for men (adjusted R^2=.264), log HOMA-IR=−1.28+0.042 BMI+0.016 muscle strength−0.005 cardiorespiratory fitness; for women (adjusted R^2=.438), log HOMA-IR=−0.42−0.004 age+0.013 waist circumference−0.004 cardiorespiratory fitness.

BMI and Waist Circumference Predict Insulin Resistance in Men and Women, Respectively

Body fat mass and percentage can be determined directly or indirectly. Techniques such as dual-energy x-ray absorptiometry scanning, bioelectrical impedance analysis, and air displacement plethysmography (densitometry) provide direct measurements of body fat mass, whereas anthropometric methods such as BMI and waist circumference measurements estimate body fat indirectly. With regard to indexes of adiposity derived from anthropometric measurements, BMI is an index of general adiposity, and waist circumference is a marker of central adiposity. Studies comparing the predictive values of direct measures and indirect indexes of adiposity revealed that indirect indexes of adiposity are better predictors of metabolic risk factors.[26,38] The World Health Organization recommended using BMI and waist-to-hip ratio as criteria for metabolic syndrome, and the National Cholesterol Education Program (NCEP) suggested using waist circumference as a criterion for metabolic syndrome.[17]

The results of the present study showed that BMI and waist circumference were independent predictors of insulin resistance in people at risk for diabetes. This finding is consistent with previous research reporting an association between body composition and metabolic risk factors.[8,26,39] An interesting finding from the present study is that the association between indexes of adiposity and insulin resistance was sex related. In men, BMI, but not waist circumference, was the independent predictor of insulin resistance. On the contrary, waist circumference, but not BMI, was the independent predictor of insulin resistance in women. The mechanisms for explaining the sex-related association between adiposity indexes and insulin resistance are unknown; however, the association is likely attributable to sex variations in body composition.[6]

Muscle Strength Evaluated by Handgrip Strength Was an Independent Predictor of Insulin Resistance in Men

Handgrip strength was used to represent the general muscle strength of

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subjects in the present study. Although the measurement of muscle strength is muscle group specific, studies have shown that grip strength has a moderate correlation with the muscle strength of larger muscle groups, such as trunk flexor, trunk extensor, and knee extensor muscles.[40–42]

We found that handgrip strength was an independent predictor of insulin resistance in men. This finding was similar to that of Lazarus et al,[43] who reported that handgrip strength was an independent predictor of the fasting insulin concentration in a population of healthy men. Skeletal muscle is the major site of glucose disposal in the euglycemic state, and muscle strength is related to muscle size. Interventional studies have shown that resistance exercise, a type of exercise that increases skeletal muscle mass, can improve insulin resistance.[34,44,45]

Interestingly, handgrip strength was not a significant predictor of insulin resistance for women. Further studies are needed to explain the possible mechanisms for the sex-dependent predictive value of handgrip strength for insulin resistance.

Age Was an Independent Predictor of Insulin Resistance in Women

The independent contribution of age to insulin resistance was sex specific. We found that age was not an independent predictor of insulin resistance after adjustment for physical fitness and physical activity in men. This finding is consistent with those of previous studies showing that age was not associated with insulin resistance after controlling for BMI[46] and abdominal fat.[47] In contrast, we found that age was an independent predictor of insulin resistance in women. The unbalanced numbers of women in different age groups (14% of women were 21–35 years of age, 37% were 36–50 years of age, and 49% were 51–67 years of age) may be associated with the inconsistent findings.

Flexibility, Muscle Endurance, and Physical Activity Were Not Independently Associated With Insulin Resistance

As expected, flexibility and muscle endurance determined with a commonly used physical fitness battery were not independent predictors of insulin resistance. Flexibility measured with the sit-and-reach test assesses hamstring muscle flexibility, which is important for activities of daily living. The sit-up test assesses abdominal muscle endurance, which is thought to be related to muscular low back pain. Our findings imply that exercise that specifically improves hamstring muscle flexibility and abdominal muscle endurance may not effectively influence insulin resistance.

Levels of physical activity are often assessed with physical activity questionnaires in clinics and in field tests. We found that physical activity levels assessed with the 7-day recall physical activity questionnaire were not associated with levels of insulin resistance. This finding suggests that simple, clinically available physiological assessments of physical fitness provide better predictions of insulin resistance than subject-reported physical activity levels.

Clinical Implications and Limitations of the Study

The findings of the present study provide physical therapists with another viewpoint for considering insulin resistance—from the perspectives of physical activity and physical fitness. For example, physical therapists can apply the results of clinical measures of physical fitness to models and predict insulin resistance levels. More intensive exercise interventions and lifestyle modifications can therefore be provided to people who are predicted to have elevated insulin resistance. In addition, our results imply that interventions that improve body composition, muscle strength, and cardiorespiratory fitness may be more effective in terms of improving insulin resistance in people at risk for diabetes.

The main limitation of the present study is that our findings may not be applicable to people who cannot perform the 3-minute step test, such as those who have severe arthritis or poor coordination or those who are dependent on walking devices. In addition, our results may not be generalizable to people of different races. For example, the step height and stepping rate of the 3-minute step test used in the present study may need to be modified to validate the assessment of the cardiorespiratory fitness of white people, who are usually of higher stature. Last but not least, randomized controlled trials are needed to provide more evidence about interventions that can effectively improve insulin resistance in people at risk for diabetes.

Conclusion

Our results showed that the level of insulin resistance in people at risk for diabetes can be predicted by physical fitness. Body mass index, muscle strength, and cardiorespiratory fitness were predictors of insulin resistance for men. Age, waist circumference, and cardiorespiratory fitness were significant predictors of insulin resistance for women. The findings support the validity of using measures that are feasible in the physical therapist practice setting to help predict insulin resistance in people at risk for diabetes.

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