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Randomised controlled trial evaluating lifestyle interventions in people with impaired glucose tolerance

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Abstract

Aim: To evaluate the effectiveness of lifestyle interventions in people with impaired glucose tolerance (IGT).
Methods: Participants with IGT ($n = 78$), diagnosed on two consecutive oral glucose tolerance tests (OGTTs), were randomly assigned to a 2-year lifestyle intervention or to a control group. Main outcome measures were changes from baseline in: nutrient intake; physical activity; anthropometry, glucose tolerance and insulin sensitivity. Measurements were repeated at 6, 12 and 24 months follow-up.
Results: After 24 months follow-up, there was a significant fall in total fat consumption (difference in change between groups (Δ intervention $-$ Δ control) = -17.9, 95% confidence interval (CI) -33.6 to -2.1 g/day) as a result of the intervention. Body mass was significantly lower in the intervention group compared with controls after 6 months (-1.6, 95% CI -2.9 to -0.4 kg) and 24 months (-3.3, 95% CI -5.7 to -0.89 kg). Whole body insulin sensitivity, assessed by the short insulin tolerance test (ITT), improved after 12 months in the intervention group (0.52, 95% CI 0.15–0.89%/min).
Conclusions: These findings complement the findings of the Finnish Diabetes Prevention Study and the American Diabetes Prevention Study, both of which tested intensive interventions, by showing that pragmatic lifestyle interventions result in improvements in obesity and whole body insulin sensitivity in individuals with IGT, without change in other cardiovascular risk factors.

Keywords: Impaired glucose tolerance; Diet; Physical activity; Type 2 diabetes; Coronary heart disease; Prevention

1. Introduction

Coronary heart disease (CHD) and Type 2 diabetes are major health problems and strategies are urgently needed to reduce cardiovascular risk in high risk individuals. It has recently been demonstrated that intensive behavioural interventions substantially lower the risk of diabetes in people with IGT [1–3], a high risk condition for the development of Type 2 diabetes and CHD [4]. However, these studies were resource intensive (e.g. providing one to one case managers) so that the effectiveness of pragmatic lifestyle interventions are not known. Additionally, it is unclear what

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effect lifestyle interventions have on whole body insulin sensitivity, measured directly, in people with IGT.

In this paper, we report the main outcomes after 24 months follow-up of a pragmatic randomised controlled trial (RCT) of diet and physical activity counselling for men and women with IGT, diagnosed using two consecutive oral glucose tolerance tests (OGTTs), conducted in Newcastle upon Tyne, UK. The study tested the null hypotheses that, in individuals with IGT: (i) counselling from a dietitian and physiotherapist over 24 months would result in no changes in nutrient intake and physical activity or CHD risk factors (including whole body insulin sensitivity) after 6 months follow-up; and (ii) any changes in nutrient intake and physical activity or CHD risk factors detected at 6 months would not be sustained for 24 months.

2. Patients and methods

2.1. Study design

We conducted an RCT with one intervention and one control arm at the Royal Victoria Infirmary, Newcastle upon Tyne, UK between 1994 and 1998. Men and women of European origin, aged 24–75 years, who had IGT identified on two consecutive OGTTs, the second within 2–12 weeks of the first, were eligible to participate. Individuals who were pregnant, on therapeutic diets or unable to undertake moderate physical activity were excluded. Medications likely to interfere with glucose metabolism were noted. Normal glucose tolerance (NGT), IGT and Type 2 diabetes were defined using World Health Organization (WHO) 1985 criteria [5]: NGT was defined as a fasting plasma glucose $<$7.8 mmol/l; IGT was defined as a 2 h post glucose load plasma glucose concentration $\geq$7.8 mmol/l and $<$11.1 mmol/l; Type 2 diabetes was defined as a fasting plasma glucose concentration $\geq$7.8 mmol/l or a 2 h plasma glucose $\geq$11.1 mmol/l. Ethical approval was obtained from the Joint Ethics Committee of Newcastle and North Tyneside Health Authority.

Eligible individuals who agreed to participate were randomly allocated to the intervention or control group at the first baseline appointment. Researchers performing the randomisation were blind to the group allocation.

Detailed descriptions of the follow-up measurements have been published elsewhere [6]. Participants attended the Clinical Research Centre after an overnight fast. All participants gave written informed consent. In addition to a WHO standard OGTT [5], lipid concentrations were measured on fasting blood samples on a DAX analyser (Bayer Plc, Basingstoke, UK). Non-esterified fatty acids (NEFA) were measured by an enzymatic colorimetric methods on a automated Cobas Bio analyser, using a Wako kit (Alpha Laboratories Limited, Eastleigh, UK). Weight was measured to the nearest 0.1 kg with the participants lightly clothed on SECA scales (Alpha Model 770 digital, SECA Limited, Birmingham, UK). Waist circumference was measured using a spring loaded tape measure at the midpoint between the lower costal margin and the iliac crest with the waist uncovered. Hip circumference was measured over the trochanters with the tape measure in the horizontal plain. Participants were given detailed instructions to complete a 4-day food diary comprising two weekdays and two weekend days. The amounts consumed were subsequently quantified using a food atlas [7]. Participants also completed a lifestyle questionnaire [6] which assessed physical activity. A shuttle walking test was used to measure fitness [6]. Whole body insulin sensitivity was assessed using the short ITT [8] from which a rate constant for glucose disposal was calculated (K_{ITT}). Measurements were repeated after 6, 12 and 24 months follow-up.

2.2. Interventions

The intervention consisted of regular motivational counselling from an National Health Service dietitian and physiotherapist based on the 'stages of change' model of behaviour change [9].

2.2.1. Dietary

The dietitian used motivational interviewing to develop an individual action plan for behaviour change [10]. Participants were encouraged to eat regular meals, eat more fruit and vegetables, reduce the fat content of foods, reduce sugar intake and eat adequate dietary fibre. The goal was to reduce BMI to $<$25 kg/m^2 in those who were overweight or obese, to achieve a dietary fat intake of $\leq$30% of total energy intake, a polyunsaturated to saturated fat ratio of $\geq$1.0, 50% of energy from carbohydrate and a dietary fibre intake of $\geq$20 g per 4.2 MJ [11]. All participants in the intervention group were given written nutrition education material.

2.2.2. Physical activity

The physiotherapist assessed participants' level of physical activity and readiness to change at baseline and provided a graded physical activity plan, tailored to the participant's lifestyle and designed to enable them to achieve 20–30 min of aerobic activity at least once a week. The type of exercise was tailored to the participant's interests, lifestyle and physical abilities. Exercises such as walking, cycling, swimming, dancing and playing golf were encouraged. Information leaflets about exercise facilities available in Newcastle were provided as appropriate. A CiTY CARD (a scheme offering up to 80% discount on use of all public leisure facilities in the city) was offered to all participants.

2.2.3. Review appointments

Intervention participants had twelve review appointments over 24 months follow-up. The review appointments were on an individual basis, each lasting 15–20 min, with the dietitian and physiotherapist. In the first 6 months there were three such appointments at two weekly intervals, followed by three at monthly intervals. There was one after 9 months and five at two monthly intervals between 12 and 24 months.

2.3. Control group

Participants in the control group were offered no dietary or physical activity advice for the duration of the study.

2.4. Sample size

We calculated that a sample size of 100 individuals (50 in each arm) was necessary to detect a 0.6 mmol/l difference in mean fasting plasma glucose and a 20% difference in the proportion with glucose intolerance, both with 90% power at the 5% significance level.

2.5. Statistical analysis

The Statistical Package for Social Scientists (SPSS Inc., Version 8.0, Chicago, USA) was used for all statistical analyses, which were performed on an intention-to-treat basis. The independent sample *t*-test was used for normally distributed variables to compare differences in mean change between the intervention and the control group.

Non-normally distributed variables were $\log_{10}$ transformed and geometric means (95% CI) were calculated. The medians (interquartile range) of the difference between baseline and follow-up values were computed for the intervention and control groups, respectively, and the Mann–Whitney test was used to compare differences in the medians between groups. The difference between groups in the proportion of participants who reported undertaking regular activity sufficient to get their heart thumping at least once a week was calculated from a method based on score intervals for the single proportion with continuity correction [12]. Logistic regression was used to obtain the odds of a change in serum insulin for a change in body mass. Analysis of covariance was used to determine the influence of sex and group allocation on change in hip circumference at follow-up.

3. Results

3.1. Recruitment

Fig. 1 shows the recruitment outcomes of the study. A total of 498 individuals with IGT were identified. Of these, 135 did not agree to be re-tested, 104 failed to reply and 51 were excluded. Of the remaining 208 who were re-tested 46 had diabetes, 80 were NGT and 82 were IGT. Of those with IGT, 78 were recruited and were randomised in equal numbers to the intervention group and to the control group.

3.2. Adherence to the intervention

On average, intervention participants attended 80% (range 67–95%) of review appointments in the first 6 months of the study. Fourteen participants (14/39, 36%) attended all 12 review appointments during the 24-month intervention period (Fig. 1).

3.3. Trial profile

Fourteen participants (five intervention, nine control) withdrew from the study over 24 months follow-up. Reasons for withdrawing were family problems, work commitments or ill health. The baseline characteristics of those who withdrew did not differ significantly in age, sex and major risk factors from those who remained in the study. Nine participants (three intervention, six control) failed to attend assessments over 24 months follow-up. In addition, one intervention participant died after a stroke between 12 and 24 months. Complete results are presented here for 69 participants after 6 months, 62 participants after 12 months and 54 participants after 24 months follow-up (Fig. 1).

3.4. Differences between intervention and control groups at baseline

As shown in Table 1, mean resting pulse was lower in the control compared with the intervention group (mean (S.D.) 71.6 (9.5) beats/min versus 78.0 (10.3) beats/min, $P = 0.011$). In addition, a significantly larger proportion of control participants reported engaging in regular physical activity sufficient to get their heart thumping at least once a week compared with intervention participants (53% versus 24%, $P = 0.017$). There was a higher proportion of women in the intervention group ($n = 20$) compared with the control group ($n = 10$) although this difference was not significant.

4. Main outcomes

4.1. Changes in nutrient intake

The proportion of individuals who had met the target for a dietary fat intake of <30% total energy was higher amongst the intervention group (40%) than amongst the controls (13%) after 24 months follow-up (Table 2). Tables 3–5 show that dietary fat intake decreased between baseline and 6, 12 and 24 months more in the intervention than the control group, respectively. The mean difference in change in total fat intake between groups was significant after 6 months (difference in change between groups (Δ intervention group $-$ Δ control group) = -17.4, 95% CI -33.7 to -1.1 g/day), 12 months (-16.3, -32.1 to -0.48 g/day) and 24 months follow-up (-17.9, -33.6 to -2.1 g/day).

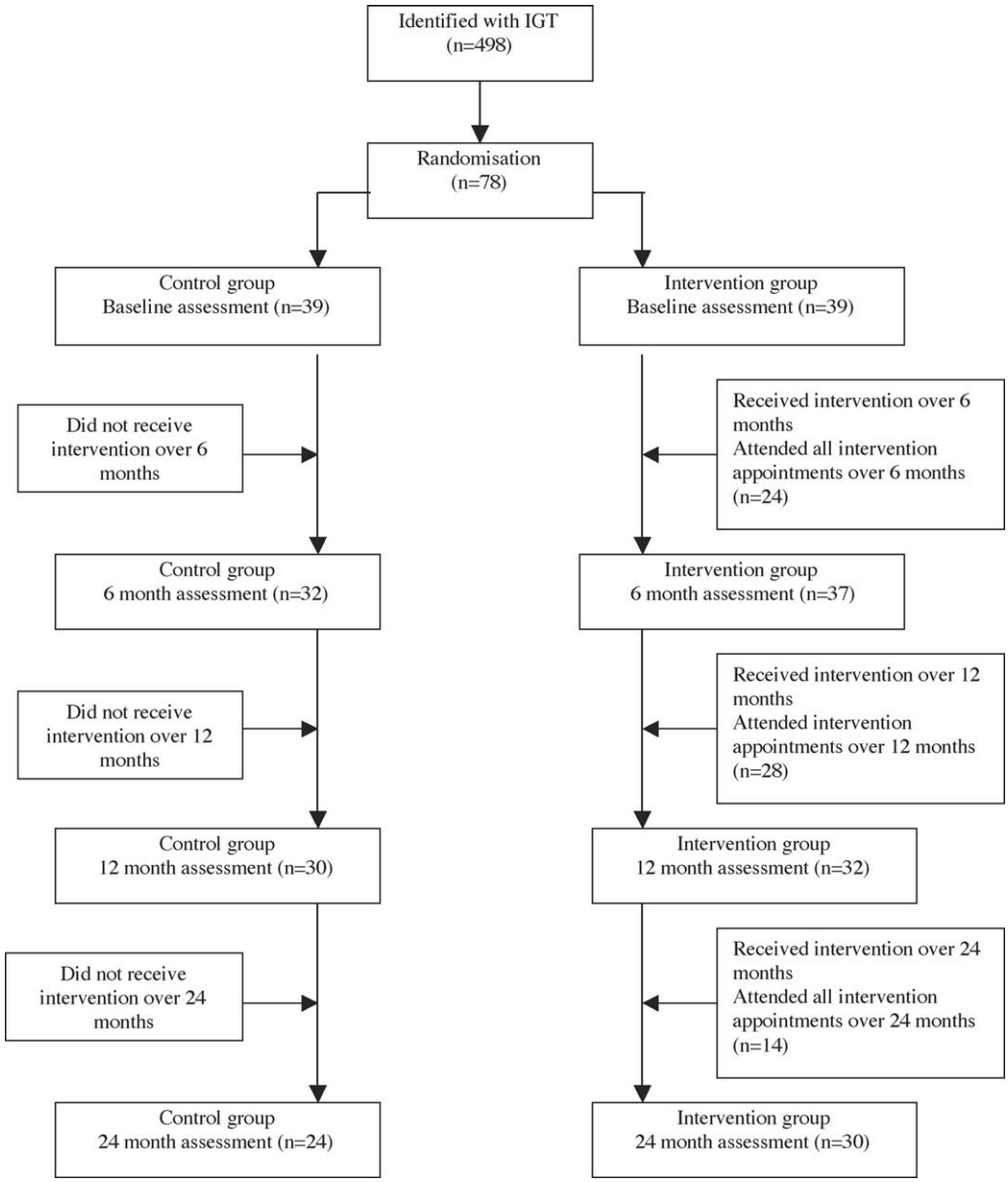

Fig. 1. Recruitment outcomes and trial profile.

4.2. Changes in resting pulse, shuttle walking test and self reported physical activity

The difference in change between groups in mean resting pulse was of borderline significance ($P = 0.051$) after 6 months (Table 3) and was significant after 24 months (−5.6, 95% CI −10.4 to −0.81 beats/min) (Table 5). The mean distance walked in the shuttle test was not significantly different at any time during follow-up (data not shown). The difference in change between groups in the proportion of participants who reported engaging in regular activity at least once a week was significantly higher in the intervention group after 6, 12 and 24 months follow-up (Tables 3–5).

4.3. Changes in anthropometry and clinical variables

The difference in change in body mass between groups was progressive and significant at 6, 12 and 24 months follow-up (Tables 3–5). The decrease in body mass in intervention participants compared with

Table 1
Baseline characteristics of the control and intervention groups

Characteristic	Control ($n = 32$)	Intervention ($n = 37$)	P
Sex (number) men/women	22/10	17/20	0.057
Age (in years)	57.5 (41–73)	58.2 (41–75)	0.757
Physical activity			
Resting pulse (beats/min)	71.6 (9.5)[a]	78.0 (10.3)[b]	0.011
Percentage engaging in regular activity sufficient to get their heart thumping at least once a week (n)	53.1 (17)	24.2 (8)[c]	0.017
Anthropometry			
Weight (kg)	85.5 (14.2)	85.3 (17.9)	0.953
Waist circumference (cm)	99.6 (11.3)	99.0 (12.0)[b]	0.951
Hip circumference (cm)	104.0 (9.0)	107.6 (13.3)[b]	0.195
Glucose tolerance			
Fasting plasma glucose (mmol/l)	6.16 (0.89)	6.05 (0.89)	0.630
2 h plasma glucose (mmol/l)	9.22 (0.92)	9.15 (0.89)	0.731
Insulin sensitivity			
Fasting serum insulin (mU/l)*	11.9 (9.5–14.2)[d]	11.8 (9.8–14.1)[e]	0.826
K_{ITT}	2.0 (0.73)[a]	1.9 (0.71)[e]	0.489
Fasting C-peptide (nmol/l)*	0.76 (0.61–0.89)	0.75 (0.62–0.90)	0.888
2 h C-peptide (nmol/l)*	3.0 (2.5–3.8)	3.1 (2.6–3.8)	0.131
Serum lipids			
Total cholesterol (mmol/l)	5.7 (1.0)[f]	5.6 (1.1)[g]	0.759
LDL cholesterol (mmol/l)	3.6 (1.0)[a]	3.6 (1.1)[e]	0.960
Serum fasting NEFA (mmol/l)	0.64 (0.18)[h]	0.75 (0.21)[e]	0.061

Values are means (S.D.) except age, which is mean (range), percentage engaging in regular physical activity which is a percentage (number) and those indicated * which are geometric means (95% CI). LDL, low density lipoprotein; NEFA, non-esterified fatty acids.
[a] $n = 30$.
[b] $n = 36$.
[c] $n = 33$.
[d] $n = 25$.
[e] $n = 32$.
[f] $n = 31$.
[g] $n = 34$.
[h] $n = 26$.

controls after 6 months was −1.1 kg versus +0.54 kg, $P = 0.010$ and after 24 months was −1.8 kg versus +1.5 kg, $P = 0.008$. The proportion of intervention participants who lost at least 1.0 kg body weight after 6 months was 54% compared with 25% in the control group, a difference that persisted until 24 months follow-up (63% versus 17%). In multivariate linear regression analysis, change in weight was associated with decreases in fasting serum insulin after 6, 12 and 24 months after controlling for change in

Table 2
Number (%) of participants achieving intervention targets at 24 months follow-up

Intervention target	Control ($n = 24$)		Intervention ($n = 30$)	
	Baseline	24 months	Baseline	24 months
Met at least one nutrition target	3 (12.5)	4 (16.7)	6 (21.6)	15 (50.0)*
≤30% energy as fat	2 (8.3)	3 (12.5)	4 (14.3)	12 (40.0)*
P:S ratio > 1	2 (4.2)	1 (4.2)	2 (7.1)	1 (3.3)
≥50% E carbohydrate	2 (4.2)	0	2 (7.1)	9 (32.1)*
Dietary fibre ≥20 g per 4.2 MJ energy	2 (8.3)	3 (12.5)	4 (14.3)	12 (40.0)*
Percentage (n) engaging in regular activity at least once a week	12 (50.0)	11(45.8)	7 (25.0)	16 (57.1)*

* $P < 0.02$ for difference between baseline and 24 months; P:S, polyunsaturated:saturated fat.

Table 3
Changes between baseline and 6 months for selected variables in the control and intervention groups (adapted from [6] with permission)

Variable	Control ($n = 32$)	Intervention ($n = 37$)	P
Nutrient			
Change in total fat (g/day)	3.7 (30.4)	−13.6 (35.3)[a]	0.037
Change in P:S ratio	0.08 (0.32)	−0.002 (0.35)[a]	0.312
Change in dietary fibre (Southgate) (g/day)	−0.86 (5.8)	0.20 (6.0)[a]	0.471
Physical activity			
Change in resting pulse (beats/min)	1.7 (5.8)[b]	−1.7 (8.0)[c]	0.051
Change in percentage engaging in regular activity sufficient to get their heart thumping at least once a week	−3.1 (−14 to 8.5)	33.3 (13–50)[a]	0.030
Anthropometry			
Change in weight (kg)	0.54 (2.2)	−1.1 (2.9)	0.010
Change in waist circumference (cm)	0.06 (4.2)	−0.38 (5.5)[c]	0.710
Change in hip circumference (cm)	0.72 (4.4)	−1.3 (5.8)[c]	0.120
Glucose tolerance			
Change in fasting plasma glucose (mmol/l)	0.18 (1.1)	0.05 (0.60)	0.560
Change in 2 h plasma glucose (mmol/l)	−0.50 (1.7)	−0.55 (1.9)	0.910
Insulin sensitivity			
Change in fasting serum insulin (mU/l)*	0.60 (−2.6 to 3.9)[d]	−2.5 (−4.6 to −0.33)[e]	0.008
Change in K_{ITT}	−0.09 (0.57)[b]	0.05 (0.83)[f]	0.440
Serum lipids			
Change in total cholesterol (mmol/l)	−0.18 (0.59)[g]	−0.16 (0.55)[g]	0.860
Change LDL cholesterol (mmol/l)	−0.21 (0.61)[b]	−0.10 (0.54)[b]	0.440
Change in fasting serum NEFA (mmol/l)	0.04 (0.19)[h]	−0.14 (0.16)[i]	0.001

Values are mean (S.D.) differences except change in % engaging in regular activity which is a % (95% CI); those indicated * which are the median (interquartile range) of the differences between baseline and 6 months values for the control and intervention groups, respectively. P:S, polyunsaturated to saturated fat; LDL, low density lipoproteins; NEFA, non-esterified fatty acids.

[a] $n = 33$.
[b] $n = 30$.
[c] $n = 36$.
[d] $n = 25$.
[e] $n = 32$.
[f] $n = 34$.
[g] $n = 31$.
[h] $n = 26$.
[i] $n = 24$.

leisure time physical activity and change in total dietary fat intake. The odds ratio for a 10% decrease in fasting serum insulin among those who lost at least 1.0 kg of their initial body weight after 6 months follow-up was 3.3 (95% CI 1.03–10.7).

Hip circumference was significantly reduced in the intervention participants compared with controls after 12 and 24 months follow-up as a result of the intervention.

4.4. Changes in glucose tolerance

There were no significant differences in change between groups in fasting or 2 h plasma glucose at follow-up. More participants from the intervention than the control group reverted to NGT at 12 and 24 months follow-up but these differences were not significant (22% versus 17% after 12 months; 20% versus 13% after 24 months). In total, 15/69 participants (7 intervention, 8 control) developed diabetes over the 24-month trial.

4.5. Changes in insulin sensitivity, C-peptide and intact pro-insulin concentrations

The difference in change between groups for K_{ITT} was not statistically significant after 6 months, became significant after 12 months and remained so to 24 months follow-up (Tables 3–5) with those in the intervention groups showing improved insulin sensi-

Table 4
Changes between baseline and 12 months for selected variables in the control and intervention groups

Variable	Control ($n = 30$)	Intervention ($n = 32$)	P
Nutrient			
Change in total fat (g/day)	−0.43 (33.5)[a]	−16.7 (26.5)	0.044
Change in P:S ratio	0.031 (0.33)[a]	0.006 (0.36)	0.777
Change in dietary fibre (Southgate) (g/day)	−0.02 (6.6)[a]	1.9 (8.6)	0.335
Physical activity			
Change in resting pulse (beats/min)	−1.4 (9.4)[b]	−3.0 (8.7)	0.525
Change in percentage engaging in regular activity sufficient to get their heart thumping at least once a week	7.1 (−8 to 21)	34.3 (16–49)	0.020
Anthropometry			
Change in weight (kg)	1.5 (2.6)	−1.1 (3.4)	0.001
Change in waist circumference (cm)	0.45 (4.8)	−0.23 (5.5)[c]	0.610
Change in hip circumference (cm)	1.2 (4.7)	−2.0 (4.8)[c]	0.010
Glucose tolerance			
Change in fasting plasma glucose (mmol/l)	0.08 (0.97)	0.03 (0.60)	0.789
Change in 2 h plasma glucose (mmol/l)	0.22 (1.9)	−0.63 (1.6)	0.534
Insulin sensitivity			
Change in fasting serum insulin (mU/l)*	−0.1 (−1.2 to 4.2)[d]	−1.6 (−4.6 to 0.20)[a]	0.012
Change in K_{ITT}	−0.14 (0.6)[e]	0.38 (0.7)[f]	0.007
Serum lipids			
Change in total cholesterol (mmol/l)	−0.12 (0.63)[f]	−0.12 (0.62)[c]	0.961
Change in LDL cholesterol (mmol/l)	−0.13 (0.69)[g]	−0.11 (0.58)[g]	0.947
Change in fasting serum NEFA (mmol/l)	0.02 (0.17)[h]	−0.07 (0.16)[i]	0.131

Values are mean (S.D.) differences except change in % engaging in regular activity which is a % (95% CI); those indicated * which are the median (interquartile range) of the differences between baseline and 12 months values for the control and intervention groups, respectively. P:S, polyunsaturated to saturated fat; LDL, low density lipoproteins; NEFA, non-esterified fatty acids.

[a] $n = 28$.
[b] $n = 24$.
[c] $n = 31$.
[d] $n = 27$.
[e] $n = 22$.
[f] $n = 29$.
[g] $n = 30$.
[h] $n = 20$.
[i] $n = 23$.

tivity relative to controls. The difference in change between groups in fasting serum insulin concentration was significant after 6 months but this was not sustained over 24 months follow-up. Two-hour serum insulin concentration was significantly improved by the intervention after 6 months but not thereafter ($P = 0.008$). Two hours, but not fasting, serum C-peptide concentration decreased significantly in the intervention group after 6 months only (2 h C-peptide −0.63, 95% CI −1.3 to −0.15 nmol/l). Both fasting intact pro-insulin and 2 h intact pro-insulin concentrations decreased in the intervention group after 12 months only (fasting intact pro-insulin −0.90, 95% CI −1.6 to −0.2 pmol/l; 2 h intact pro-insulin −3.8, 95% CI −13.6 to −0.90 pmol/l, respectively).

4.6. Changes in serum lipid concentrations

The intervention resulted in no significant change in total serum cholesterol or triglycerides (data not shown). Fasting serum non-esterified fatty acids (NEFA) decreased in intervention but not control participants after 6 months (−0.18, 95% CI −0.28 to −0.08 mmol/l) and 24 months follow-up (−0.19, 95% CI −0.32 to −0.05 mmol/l).

5. Discussion

5.1. Interpretation

We have shown that counseling from a dietitian and physiotherapist results in important changes in CHD

Table 5
Changes between baseline and 24 months for selected variables in the control and intervention groups

Variable	Control ($n = 24$)	Intervention ($n = 30$)	P
Nutrient			
Change in total fat (g/day)	−6.5 (30.9)	−24.4 (24.5)[a]	0.027
Change in P:S ratio	0.03 (0.29)	−0.06 (0.38)[a]	0.389
Change in dietary fibre (Southgate) (g/day)	0.60 (7.4)	1.2 (7.6)[a]	0.760
Physical activity			
Change in resting pulse (beats/min)	1.2 (8.5)	−4.4 (8.5)[b]	0.023
Change in percentage engaging in regular activity sufficient to get their heart thumping at least once a week	−4.2 (−23 to 14)	32.1 (12–48)[a]	0.030
Anthropometry			
Change in weight (kg)	1.5 (2.6)	−1.8 (5.9)	0.008
Change in waist circumference (cm)	2.5 (4.5)	−0.35 (6.9)[c]	0.073
Change in hip circumference (cm)	1.8 (2.2)	−2.1 (3.4)[c]	0.001
Glucose tolerance			
Change in fasting plasma glucose (mmol/l)	0.12 (1.0)	0.25 (0.77)	0.593
Change in 2 h plasma glucose (mmol/l)	−0.52 (1.9)	0.23 (1.6)	0.564
Insulin sensitivity			
Change in fasting serum insulin (mU/l)*	−0.80 (−2.2 to 0.50)[d]	0.10 (−1.9 to 2.8)[e]	0.506
Change in K_{ITT}	−0.29 (0.71)[f]	0.21 (0.98)[e]	0.047
Serum lipids			
Change in total cholesterol (mmol/l)	−0.06 (0.59)	0.04 (0.79)[c]	0.587
Change in LDL cholesterol (mmol/l)	−0.14 (0.56)	−0.09 (0.71)[e]	0.768
Change in fasting serum NEFA (mmol/l)	0.06 (0.17)[g]	−0.13 (0.22)[d]	0.009

Values are means (S.D.) differences except change in % engaging in regular activity which is a % (95% CI); those indicated * which are the median (interquartile range) of the differences between baseline and 24 months values for the control and intervention groups, respectively. P:S, polyunsaturated to saturated fat; LDL, low density lipoproteins; NEFA, non-esterified fatty acids.

[a] $n = 28$.
[b] $n = 31$.
[c] $n = 29$.
[d] $n = 22$.
[e] $n = 27$.
[f] $n = 21$.
[g] $n = 17$.

risk factors in people with IGT. Since starting this investigation, 'gold standard' diabetes prevention studies namely, the American Diabetes Prevention Study [1], Da Qing study [2], the Finnish Diabetes Prevention Study (FDPS) [3] have been conducted which tested intensive interventions in ethnically diverse groups with IGT. Our findings complement these studies because our interventions were pragmatic using advice to increase everyday physical activity and offering simple cooking instructions. Additionally, participants in our study had IGT measured on two consecutive OGTTs in which the average risk of diabetes is greater than those with IGT identified on a single OGTT. We found significant changes in dietary fat intake, self-reported leisure time physical activity as well as body mass and fasting serum insulin after 6 months follow-up. Further, the changes in dietary fat intake, physical activity and body mass persisted until 24 months. Whole body insulin sensitivity (measured by the short ITT) improved significantly after 12 and 24 months. In a UK population we have shown that obesity, insulin sensitivity can be improved by less intensive, pragmatic lifestyle interventions.

5.2. Changes in nutrient intake

The proportion of individuals who had met the target for a dietary fat intake of $\leq$30% total energy was higher amongst the intervention group than amongst the controls after 24 months follow-up. In addition, we observed a significant decrease in total dietary fat intake in intervention participants after 6 and 24 months follow-up. Total dietary fat intake has been shown to be a risk factor for diabetes and IGT

[13], although recently greater attention has been paid to the role of specific types of fat (e.g. polyunsaturated fats) rather than total fat per se [14]. Our results are consistent with a meta-analysis of dietary interventions that found that lifestyle interventions resulted in a net decrease of −2.5% (95% CI −3.9% to −1.1%) of energy as dietary fat [15]. The larger decrease that we have found is likely to be due to dietary under-reporting [16] since validation of the diet diaries by a comparison of reported dietary energy intakes relative with predicted basal metabolic rate [17] showed significant under-reporting of energy intake in study participants at baseline. However, the effect of the intervention was strengthened when suspected under-reporters were excluded. Due to relatively small numbers of participants in the study, all individuals were included in the final analysis.

5.3. Changes in physical activity

We observed a significant increase in the proportion of participants who self-reported undertaking regular activity physical activity sufficient to get their heart thumping at least once a week, after 6, 12 and 24 months. Despite such large increases in self-reported physical activity the intervention resulted in no improvement in fitness as assessed by the shuttle walking test, an objective measure of fitness. There was a relatively small decrease in resting pulse ($P = 0.023$) suggesting an increase in fitness, the onset of which was delayed until 24 months follow-up. Caution is needed in interpreting these results since changes in medication that may have affected pulse rate were not recorded. In addition, self-reported physical activity and physical fitness are generally poorly correlated due to over-reporting of physical activity [18], and this cannot be excluded in this study.

5.4. Changes in anthropometry

We found a small but significant decrease in body mass in intervention participants (−1.1 kg) after 6 months which was greater at 24 months (−1.8 kg). These changes were less than those reported in the FDPS in which a decrease of −4.6 kg in body mass in intervention participants was observed after 12 months follow-up [3]. The differences in effect size may have been due to the greater intensity of the interventions used in the FDPS. For example, supervised resistance training sessions were organized for participants in the FDPS. The weight loss in our study, although smaller than that found in other studies, appeared to be central to the improvements in CHD risk factors that were observed. In an adjusted multivariate regression model, the reduction in body mass was associated with decreases in fasting serum insulin after 6, 12 and 24 months. This has implications for the weight loss targets that are frequently set in primary health care which encourage a return to an ideal BMI. Our results suggest that more modest decreases in body mass bring measurable health benefit.

5.5. Changes in cardiovascular risk factors

The intervention was associated with significant decreases in fasting serum insulin at 6 and 12 months follow-up, but this effect was not detectable at 24 months. In contrast, whole body insulin sensitivity estimated by the short ITT (coefficient of variation 9% [8]) was significantly greater in intervention participants at 12 and 24 months follow-up. Taken together, these results suggest a maximal improvement in insulin sensitivity after 12 months, which reverted towards control levels by 24 months follow-up.

Despite the improvements in insulin sensitivity observed, there were no improvements in glucose tolerance during follow-up. This may be because there was a tendency to declining insulin secretion in intervention subjects (e.g. C-peptide as well as fasting intact and 2 h intact pro-insulin decreased at 6 and 12 months).

We found that fasting serum NEFA concentration decreased in the intervention group after 6 months and persisted to 24 months follow-up. In contrast to fasting serum insulin, fasting serum NEFA concentrations were highest after 12 months when insulin sensitivity was greatest. This is inconsistent with the large body of evidence which suggests that high circulating NEFA concentrations impair insulin action [19]. This apparent anomaly may be a chance finding resulting from the relatively small study sample size. The ability of exogenous insulin to suppress lipolysis in adipose tissue and/or clear blood NEFA was assessed by calculating the rate constant for change in NEFA concentration following insulin injection during the ITT (K_{ITT} NEFA) [20]. Although differences in change were not significant between control and intervention groups, there was a tendency to increased K_{ITT} NEFA sensitivity in those in the intervention arm of the study. Our results imply that several factors, in addition to NEFA metabolism, are likely to contribute to insulin resistance.

Attendance is likely to have been influenced by the acceptability of the intervention to the participants.

There were more dropouts in the control group than in the intervention group suggesting that the intervention was acceptable to them.

6. Limitations

Recent diabetes prevention studies [1–3] have provided strong evidence for the effectiveness of lifestyle interventions for the prevention of diabetes in people with IGT. The present study was not designed to assess the impact of counseling on health outcomes but rather on risk factors for CHD and Type 2 diabetes.

Other comparable lifestyle studies have had more intensive interventions such as 24 review appointments in the first 6 months [21] in contrast to the six appointments offered during this period in our pragmatic study. It is possible that the intensity of our intervention was insufficient to bring about changes in CHD risk factors.

Due to difficulties with recruitment the present study was underpowered but, despite this, we were able to detect statistically significant changes in several cardiovascular risk factors, notably body weight and whole body insulin sensitivity assessed by the short ITT.

7. Implications

The results of this study imply that less intensive, pragmatic interventions can reduce risk factors for CHD and Type 2 diabetes such as overweight and insulin resistance in individuals with IGT. These are evident after 6 months and are sustained at 24 months. This is important since obesity has been identified as a public health challenge in a recent White Paper in the UK [22]. However, more research is needed to determine practical ways to identify people with IGT in Primary Health Care, such as in the FINRISK study in Finland [23]. In the UK this currently requires OGTTs (on two separate occasions to be confident of the diagnosis) which is resource intensive. Finally, further research is needed into the development of interventions for people with IGT in Primary Health Care who are most susceptible to Type 2 diabetes.

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References

[1] W.C. Knowler, E. Barrett-Connor, S.E. Fowler, R.F. Hamman, J.M. Lachin, E.A. Walker, et al., Reduction in the incidence of type 2 diabetes with lifestyle intervention or metformin, New Engl. J. Med. 346 (2002) 393–403.

[2] X.R. Pan, G.W. Li, Y.H. Hu, J.X. Wang, W.Y. Yang, Z.X. An, et al., Effects of diet and exercise in preventing NIDDM in people with impaired glucose tolerance. The Da Qing IGT and Diabetes Study, Diabetes Care 20 (1997) 537–544.

[3] J. Tuomilehto, J. Lindstrom, J.G. Eriksson, T.T. Valle, H. Hamalainen, P. Ilanne-Parikka, et al., Prevention of type 2 diabetes mellitus by changes in lifestyle among subjects with impaired glucose tolerance, New Engl. J. Med. 344 (2001) 1343–1350.

[4] N. Unwin, J. Shaw, P. Zimmet, K.G.M.M. Alberti, Impaired glucose tolerance and impaired fasting glycaemia: the current status on definition and intervention, Diabet. Med. 19 (2002) 708–723.

[5] WHO Study Group on Diabetes, WHO Technical Report Series 727, World Health Organization, Geneva, 1985.

[6] J.C. Oldroyd, N.C. Unwin, M. White, K. Imrie, J.C. Mathers, K.G.M.M. Alberti, Randomised controlled trial evaluating the effectiveness of behavioural interventions to modify cardiovascular risk factors in men and women with impaired glucose tolerance: outcomes at 6 months, Diabetes Res. Clin. Pract. 52 (2001) 29–43.

[7] M. Nelson, M. Atkinson, J. Meyer, A Photographic Atlas of Food Portion Series on Behalf of Nutritional Epidemiology Group UK. Ministry of Agriculture Fisheries and Food, 1997.

[8] K.G.M.M. Alberti, M.E. Daly, A. Robinson, S.M. Marshall, J.C. Mathers, The short insulin tolerance test is safe and reproducible, Diabet. Med. 16 (1999) 352–353.

[9] J.O. Prochaska, C.C. DiClemente, Transtheoretical therapy: towards a more intregrative model of change, Psychotherapy: Theory Res. Pract. 19 (1982) 276–288.

[10] R. Lamb, M.S. Joshi, The stages model and processes of change in dietary fat reduction, J. Nutr. Diet 9 (1996) 43–53.

[11] British Diabetic Association, Guidelines for diabetics for the 1990s, Nutrition Subcommittee, British Diabetic Association, 1989.

[12] R.G. Newcombe, Interval estimation for the difference between independent proportions: comparison of eleven methods, Stat. Med. 17 (1998) 873–890.

[13] E.J. Feskens, S.M. Virtanen, L. Rasanen, J. Tuomilehto, J. Stengard, J. Pekkanen, et al., Dietary factors determining diabetes and impaired glucose tolerance. A 20-year follow-up of the Finnish and Dutch cohorts of the Seven Countries Study, Diabetes Care 18 (1995) 1104–1112.

[14] F.B. Hu, R.M. van Dam, S. Liu, Diet and risk of Type II diabetes: the role of types of fat and carbohydrate, Diabetologia 44 (2001) 805–817.

[15] E. Brunner, I. White, M. Thorogood, A. Bristow, D. Curle, M. Marmot, Can dietary interventions change diet and cardiovascular risk factors? A meta-analysis of randomized controlled trials, Am. J. Public Health 87 (1997) 1415–1422.
[16] S.W. Lichtman, K. Pisarska, E.R. Berman, M. Pestone, H. Dowling, E. Offenbacher, et al., Discrepancy between self-reported and actual caloric intake and exercise in obese subjects, New Engl. J. Med. 327 (1992) 1893–1898.
[17] Department of Health, Dietary reference values for food energy and nutrients for the UK, Report of the panel on dietary reference values of the Committee on Medical Aspects of Food Policy No. 41, HMSO, 1991.
[18] R.E. LaPorte, H.J. Montoye, C.J. Caspersen, Assessment of physical activity in epidemiologic research: problems and prospects, Public Health Rep. 100 (1985) 131–146.
[19] K.N. Frayn, C.M. Williams, P. Arner, Are increased plasma non-esterified fatty acid concentrations a risk marker for coronary heart disease and other chronic diseases? Clin. Sci. (Lond.) 90 (1996) 243–253.
[20] M.E. Daly, C. Vale, M. Walker, A. Littlefield, K.G.M.M. Alberti, J.C. Mathers, Acute effects on insulin sensitivity and diurnal metabolic profiles of a high-sucrose compared with a high-starch diet, Am. J. Clin. Nutr. 67 (1998) 1186–1196.
[21] R.R. Wing, E. Venditti, J.M. Jakicic, B.A. Polley, W. Lang, Lifestyle intervention in overweight individuals with a family history of diabetes, Diabetes Care 21 (1998) 350–359.
[22] R. Raine, G. Walt, I. Basnett, The White Paper on Public Health, BMJ 329 (2004) 1247–1248.
[23] P. Ilanne-Parikka, J.G. Eriksson, J. Lindstrom, H. Hamalainen, S. Keinanen-Kiukaanniemi, M. Laakso, et al., Prevalence of the metabolic syndrome and its components: findings from a Finnish general population sample and the Diabetes Prevention Study cohort, Diabetes Care 27 (2004) 2135–2140.