Interactions of exercise and diet in health prevention

Dr Jason Gill
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University of Glasgow

- **Physical activity and health outcomes – does one size fit all?**

- **Physical activity and postprandial lipoprotein metabolism**

- **Physical activity, dietary intake and energy balance**

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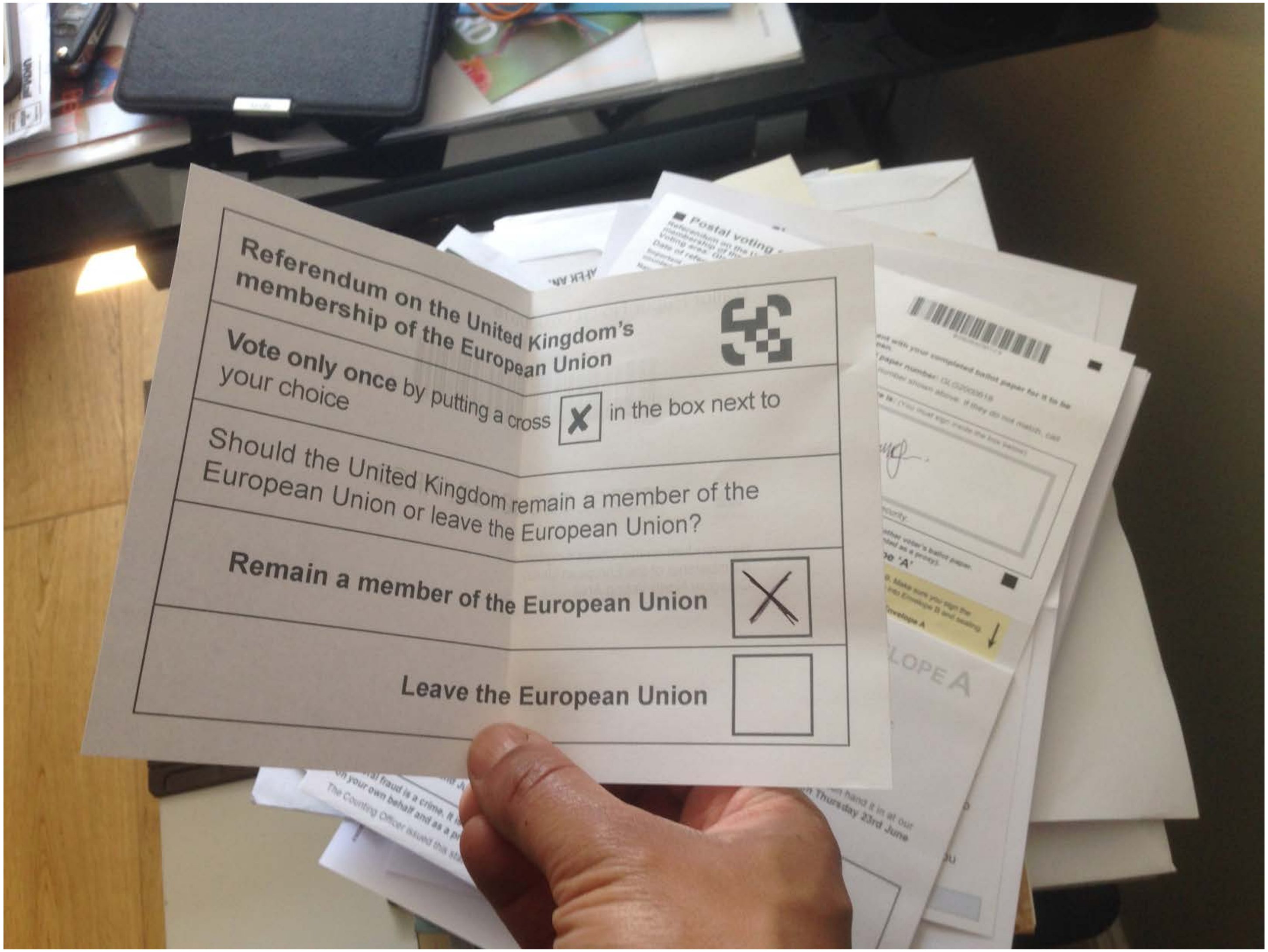


Global burden of physical inactivity

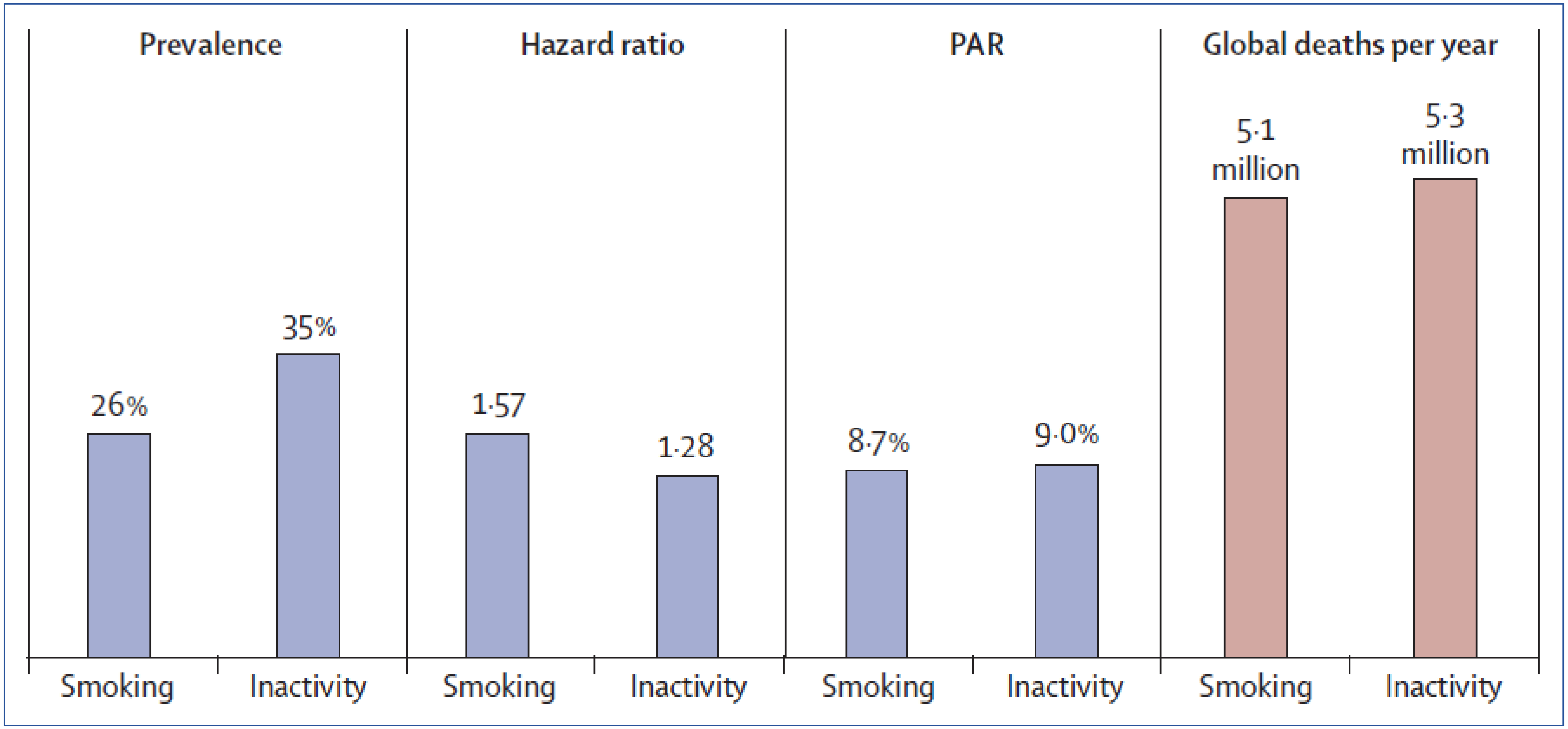
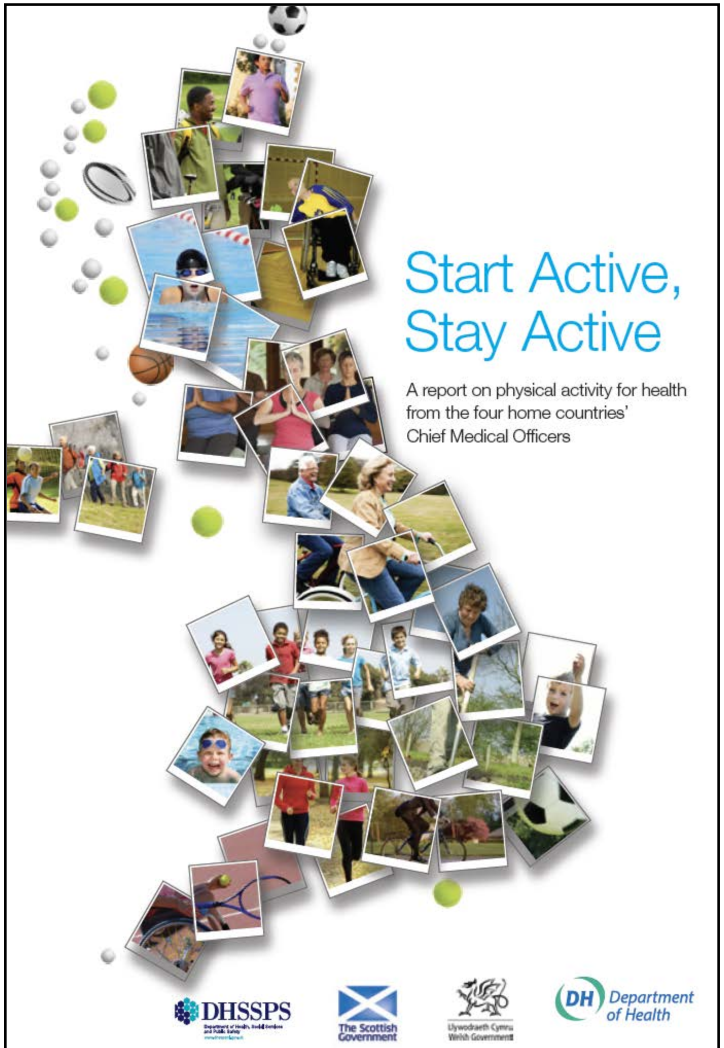


***Figure:* Comparison of global burden between smoking and physical inactivity**
Prevalence of smoking, population attributable risk (PAR), and global deaths for smoking were obtained from WHO.[7] Hazard ratio for all-cause mortality of smoking was obtained from meta-analysis studies.[8,9] All inactivity data were obtained from Lee and colleagues.[5]

Wen and Wu (2012) The Lancet http://dx.doi.org/10.1016/S0140-6736(12)60954-4

A brief history of physical activity guidelines (for adults)



2011

- **150 minutes of moderate or 75 minutes of vigorous physical activity per week in bouts of at least 10 minutes**
- **Muscle strengthening activities 2 x per week**
- **Minimise the amount of time spent sedentary (sitting)**

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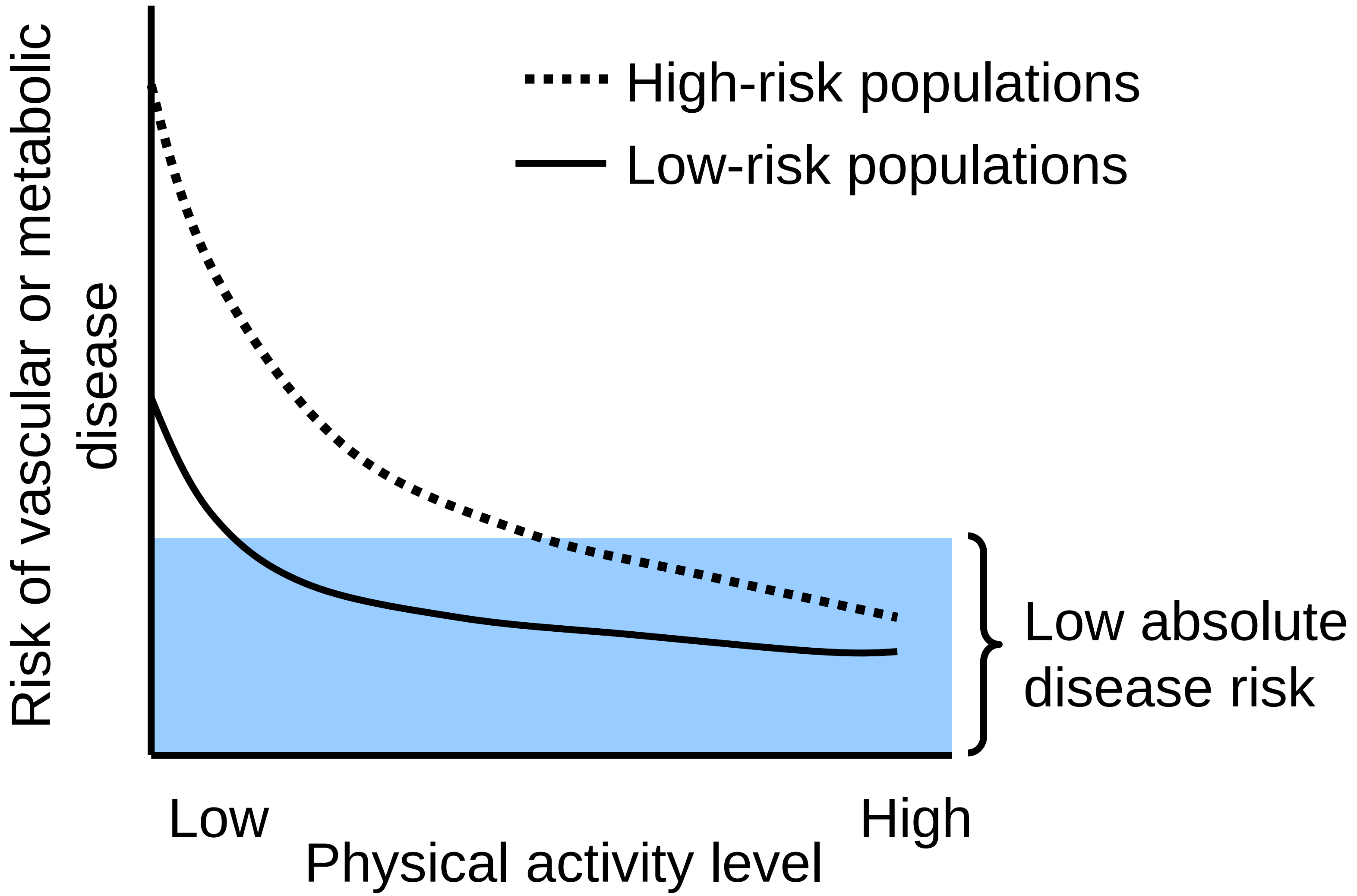
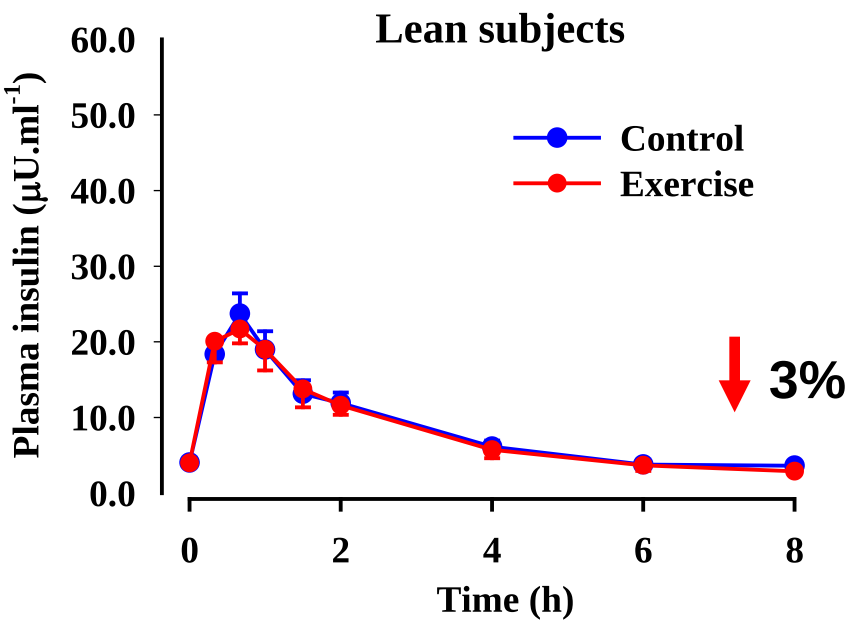
Physical activity and health outcomes: does one size fit all?

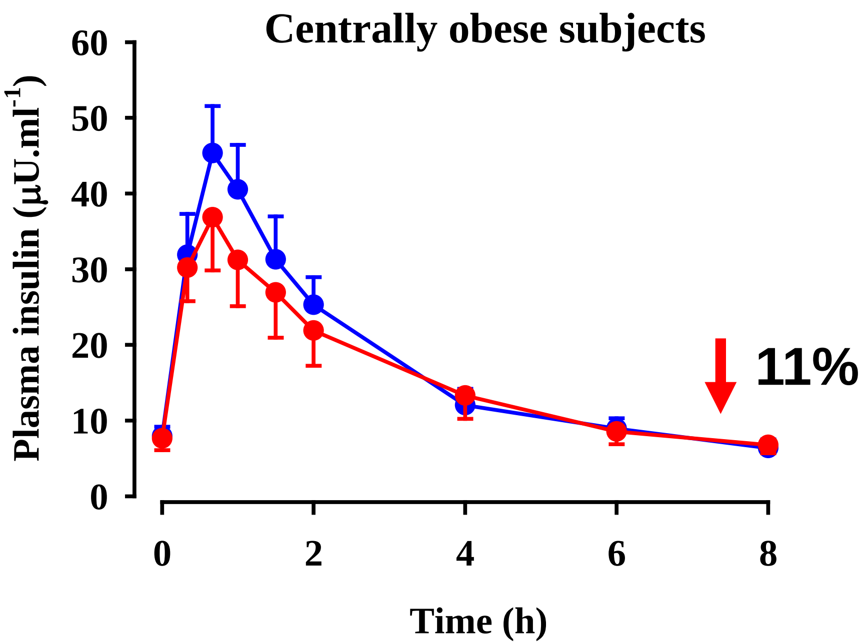
How much physical activity do people need to do?



Modified from Gill and Cooper (2008) Sports Med, 38: 807-824

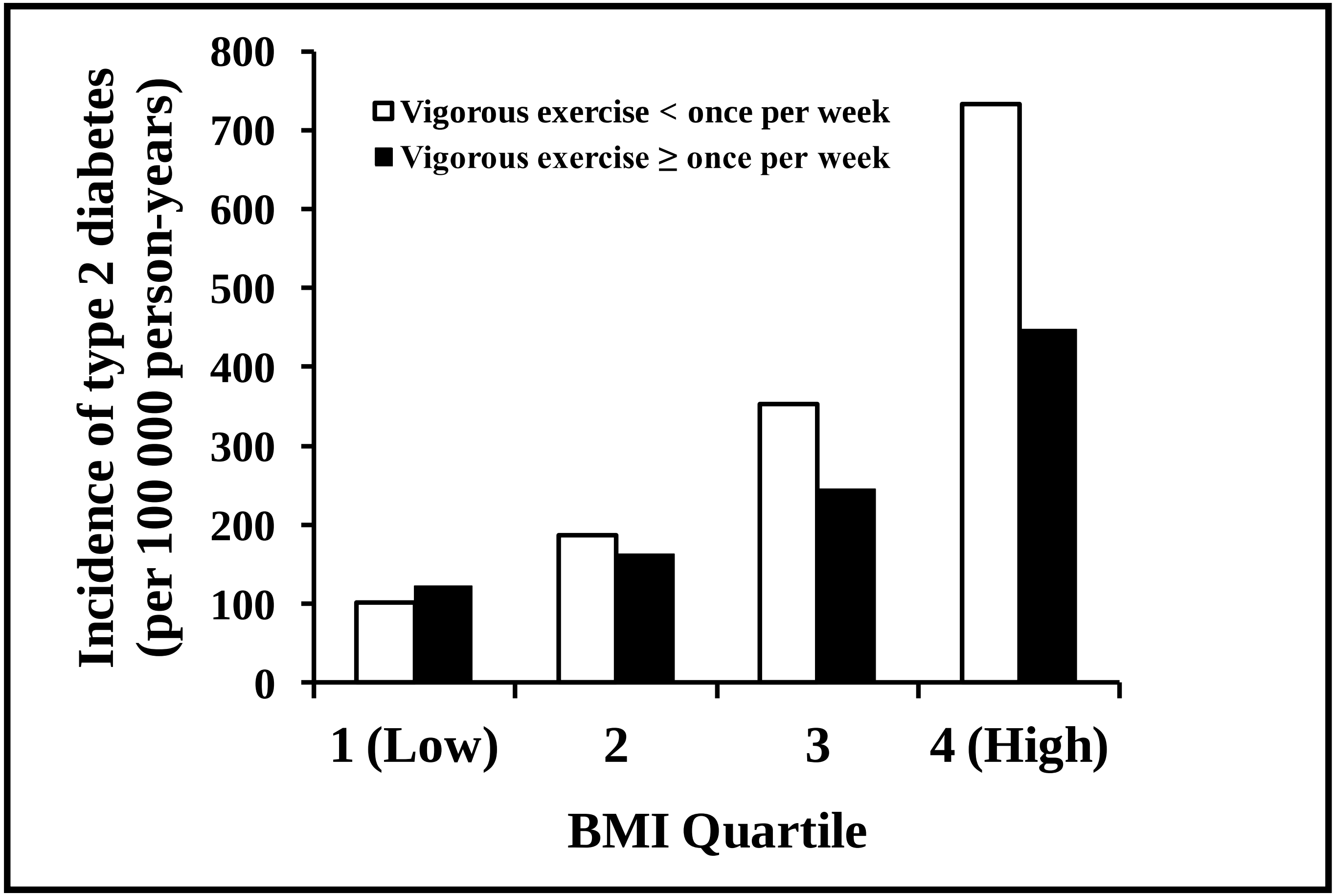
Moderate exercise and insulin responses in lean and obese men





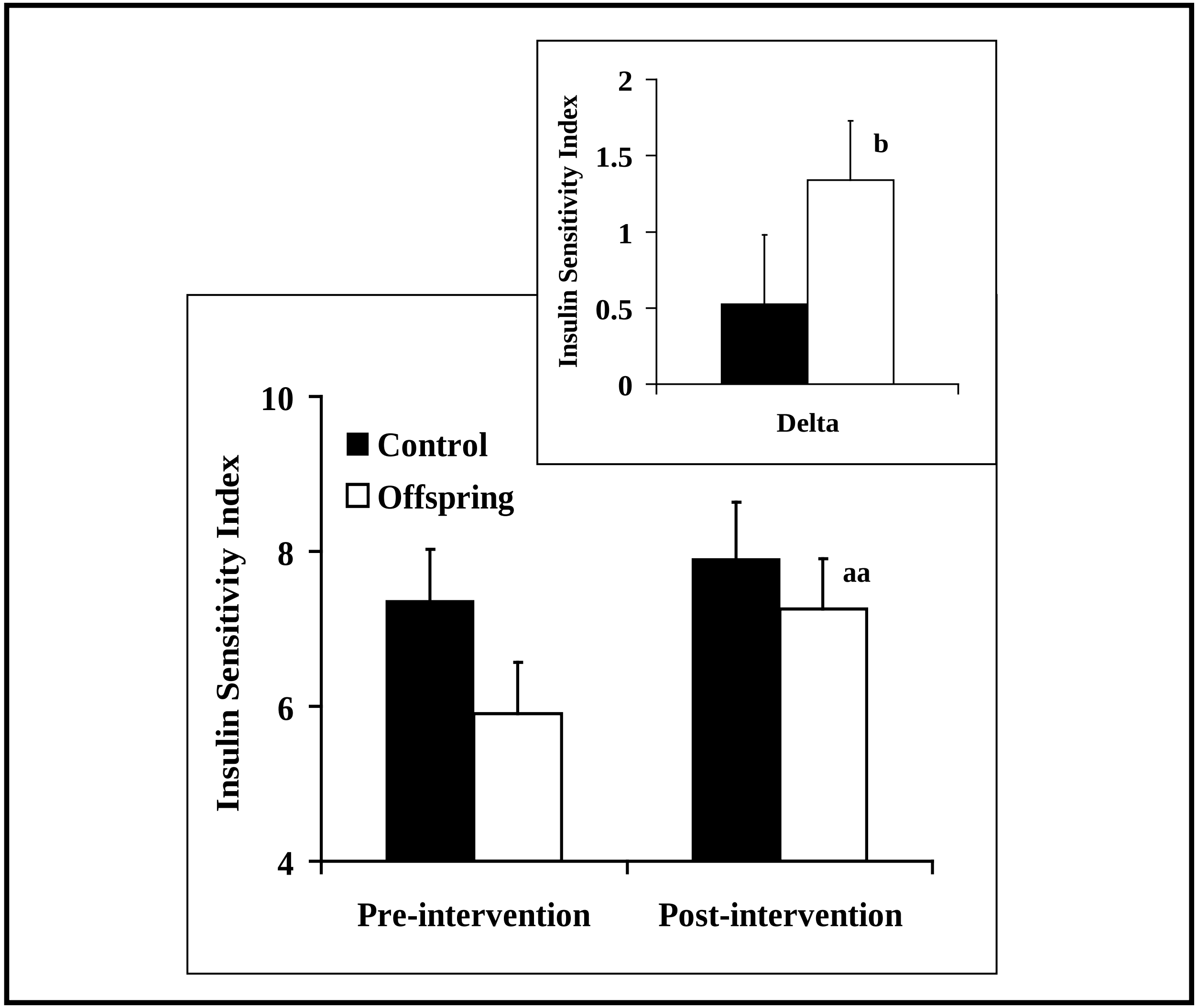
Gill et al (2004) J Am Coll Cardiol, 44:2375-82

Vigorous exercise, BMI and diabetes incidence in the Physicians' Health Study



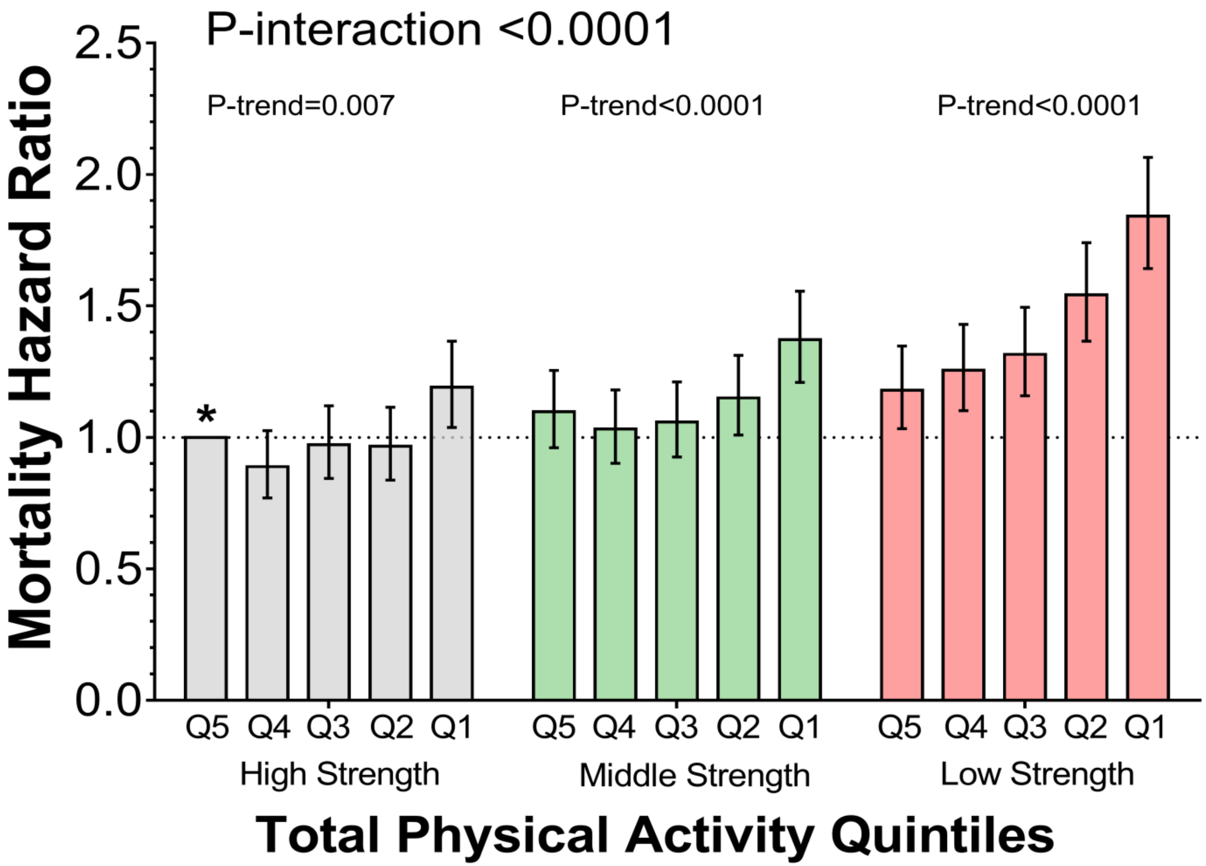
Manson et al (2002) JAMA, 268:63-67

Change in insulin sensitivity following a 7-week exercise intervention in women with and without a family history of diabetes



Barwell et al (2008) Diabetologia 51:1912-9

Grip-strength, physical activity and risk of mortality in UK Biobank



(n = 495,786) Celis-Morales et al (2016) European Heart Journal

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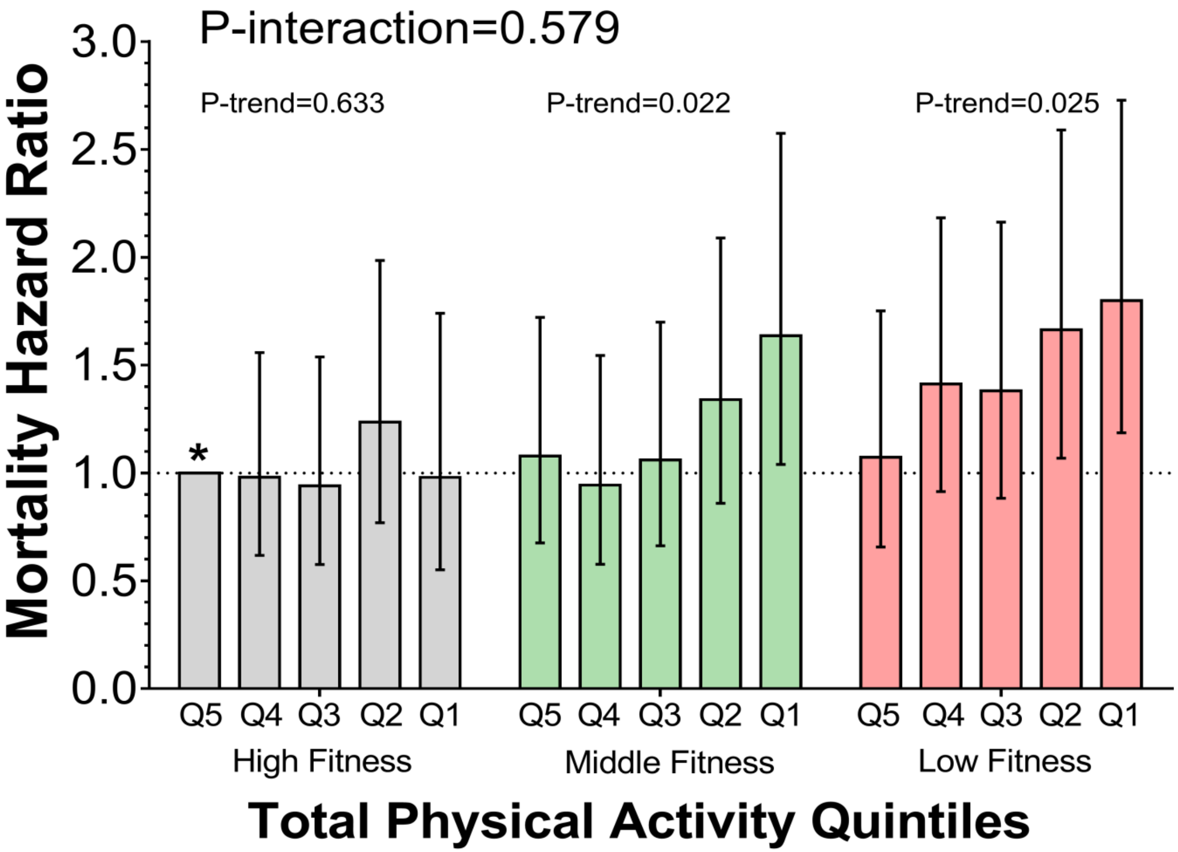
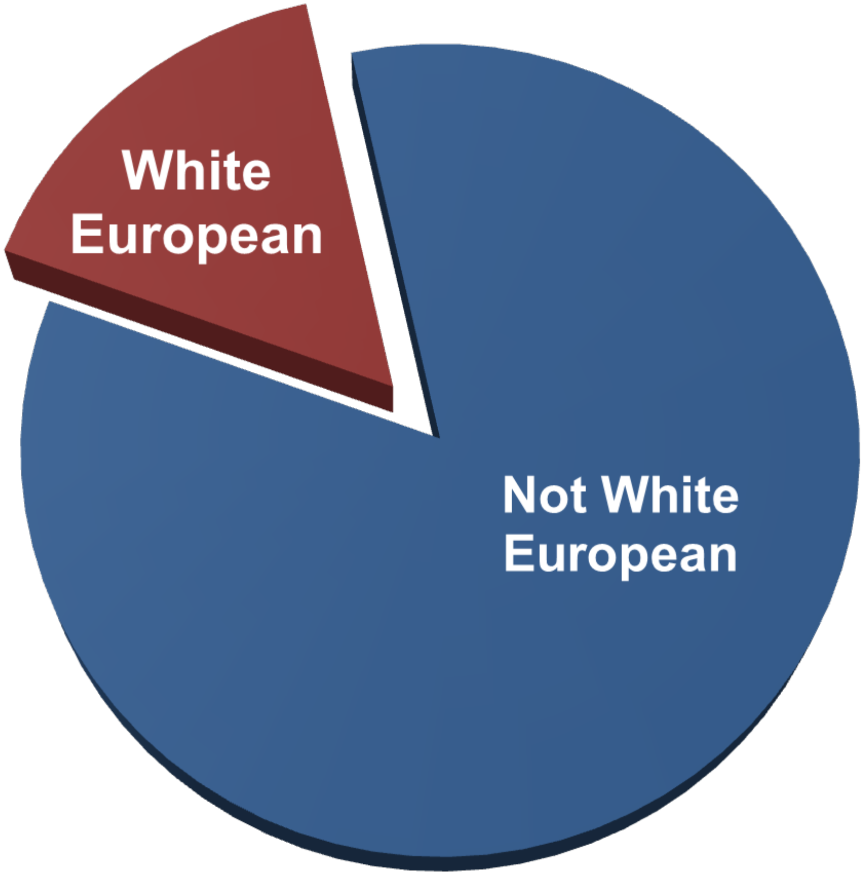
Fitness, physical activity and risk of mortality in UK Biobank



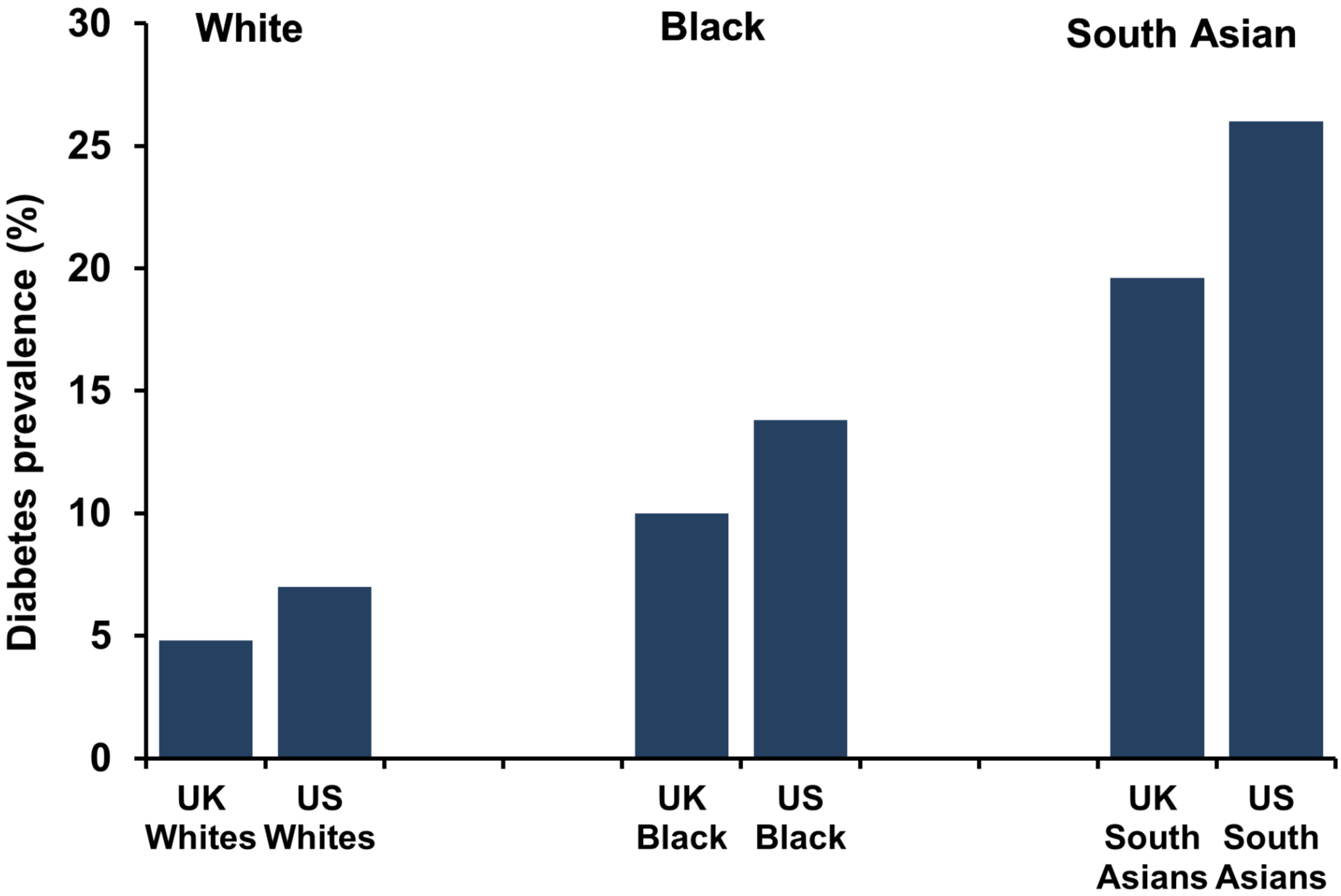
(n = 76,702)

Celis-Morales et al (2016) European Heart Journal

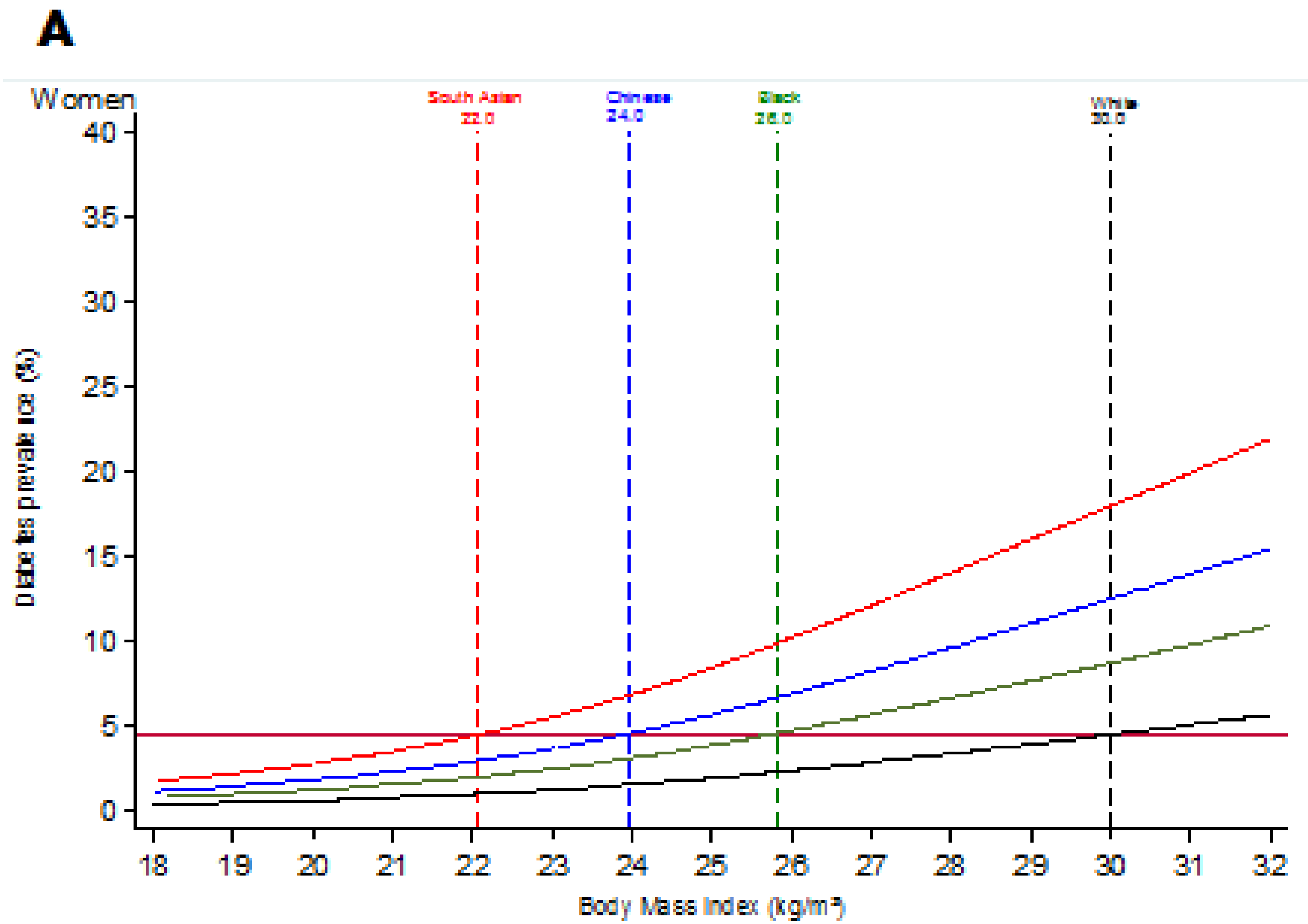


Five-sixths of the World’s population is not of White European origin.

Ethnicity and diabetes risk



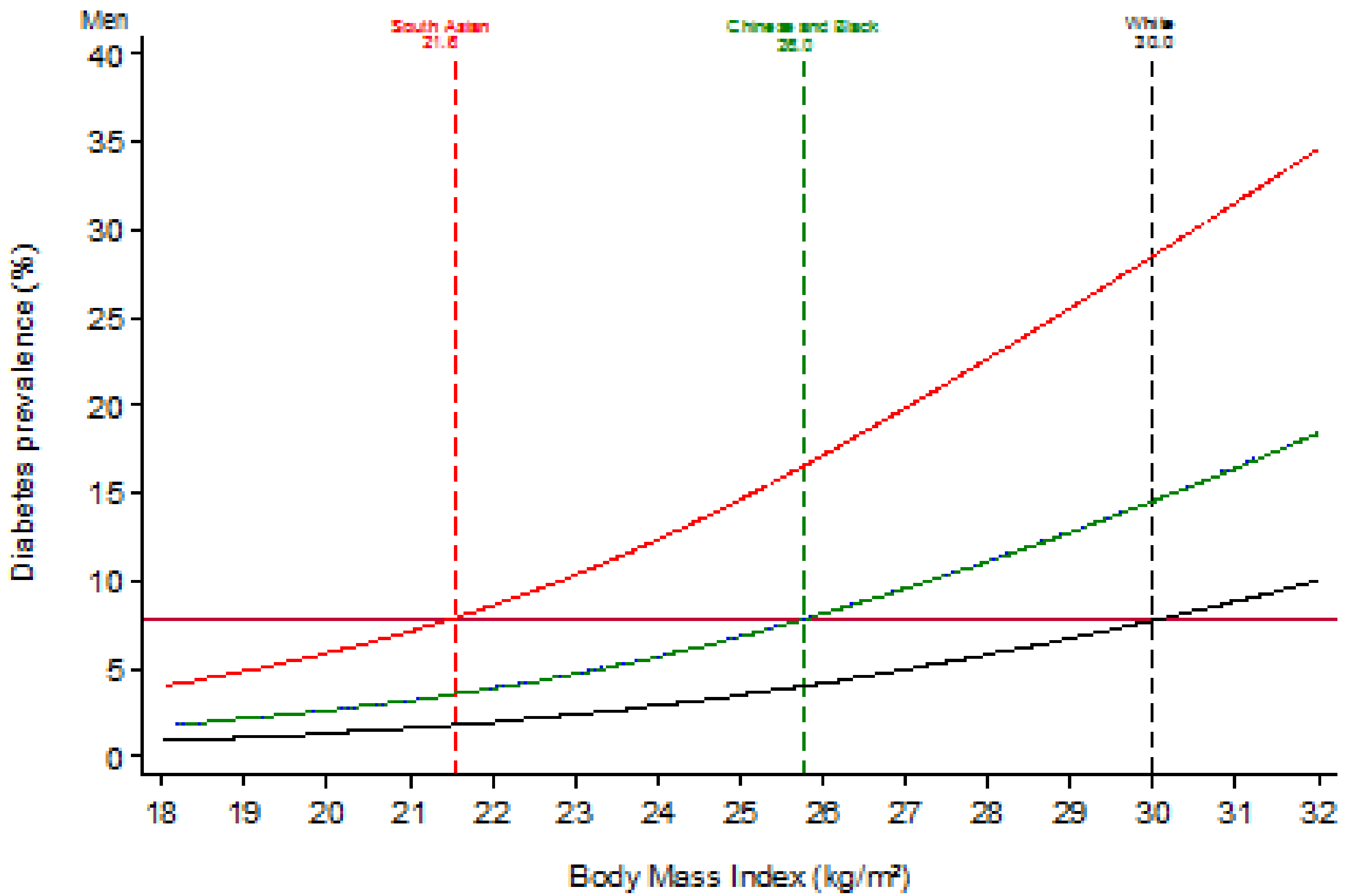
Ethnicity, BMI and diabetes prevalence in UK Biobank



Ntuk et al (2014) Diabetes Care 37:2500-7

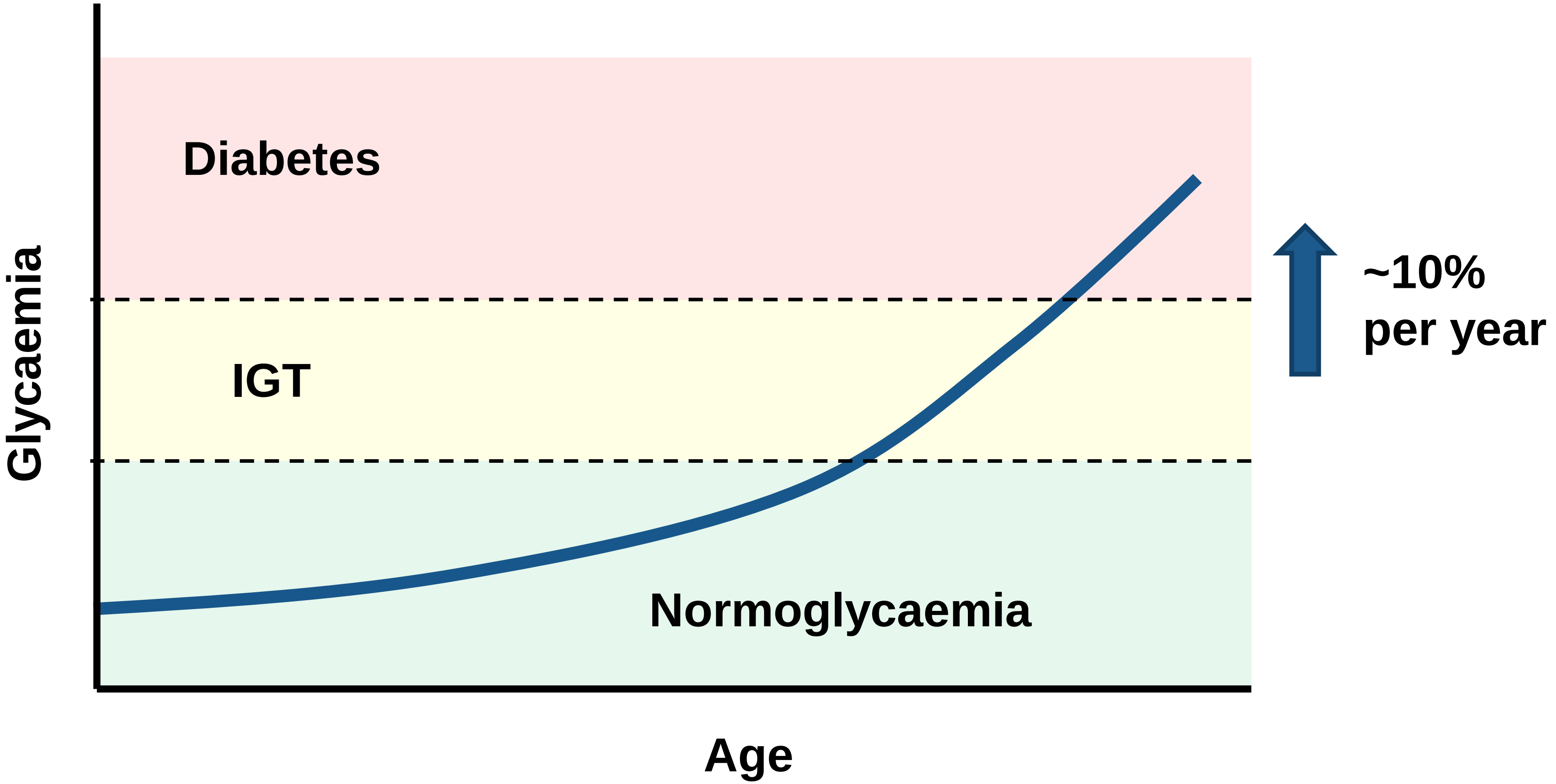
Ethnicity, BMI and diabetes prevalence in UK Biobank

B



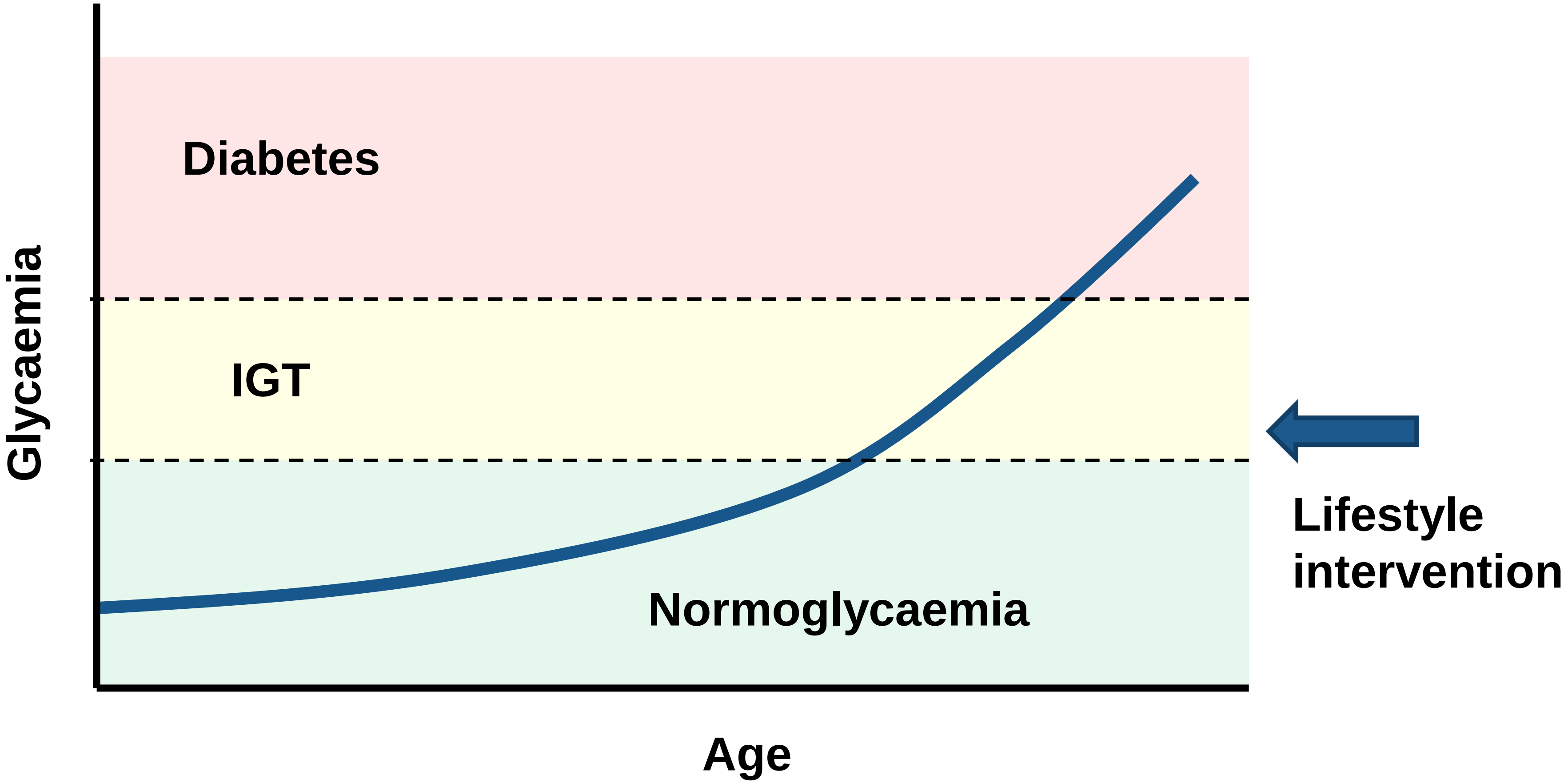
Ntuk et al (2014) Diabetes Care 37:2500-7

Diabetes risk progression



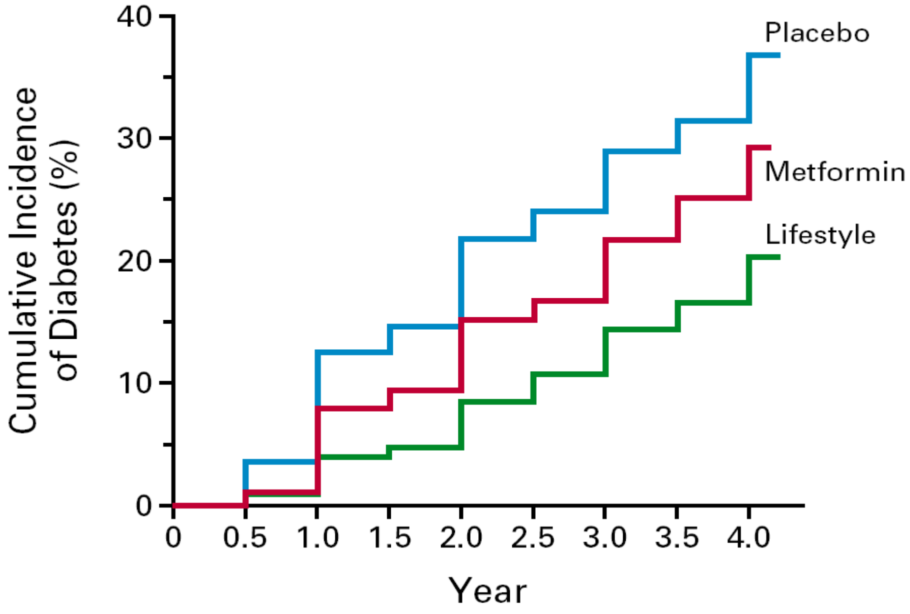
Sattar and Gill (2015) Lancet Diabetes Endocrinol

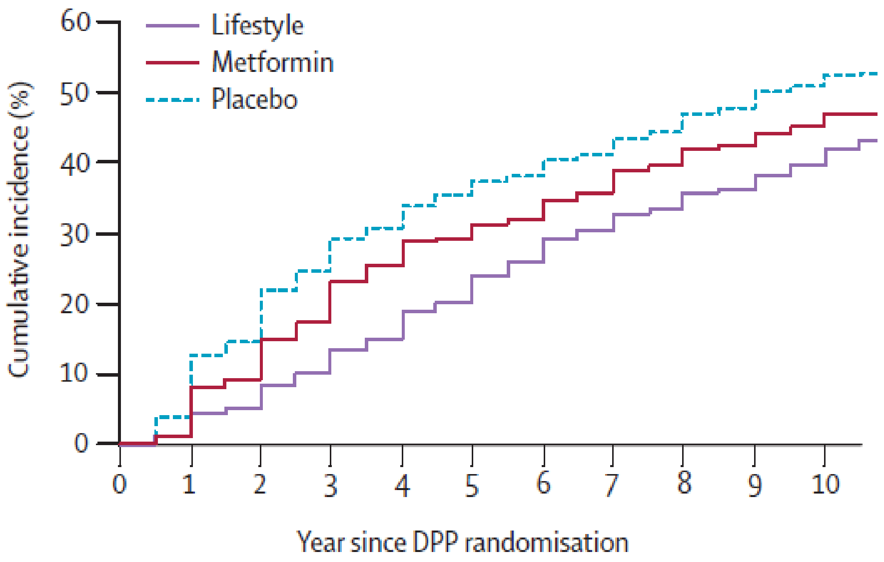
Diabetes risk progression



Sattar and Gill (2015) Lancet Diabetes Endocrinol

Long-term follow-up in US Diabetes Prevention Program





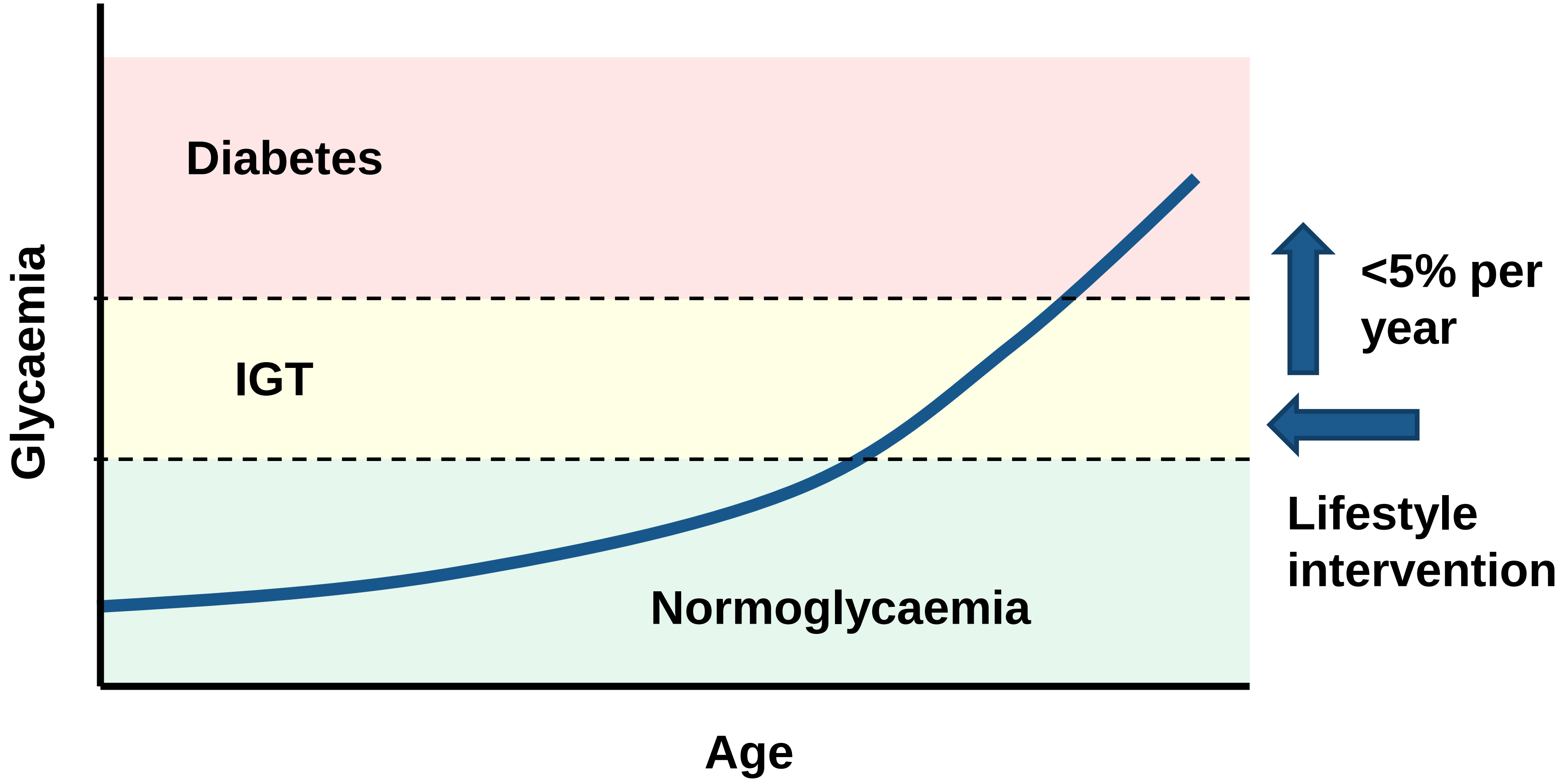
Knowler et al. NEJM 2002; 346:393-403

Knowler et al. Lancet 2009; 374:1677-86

Diabetes risk progression

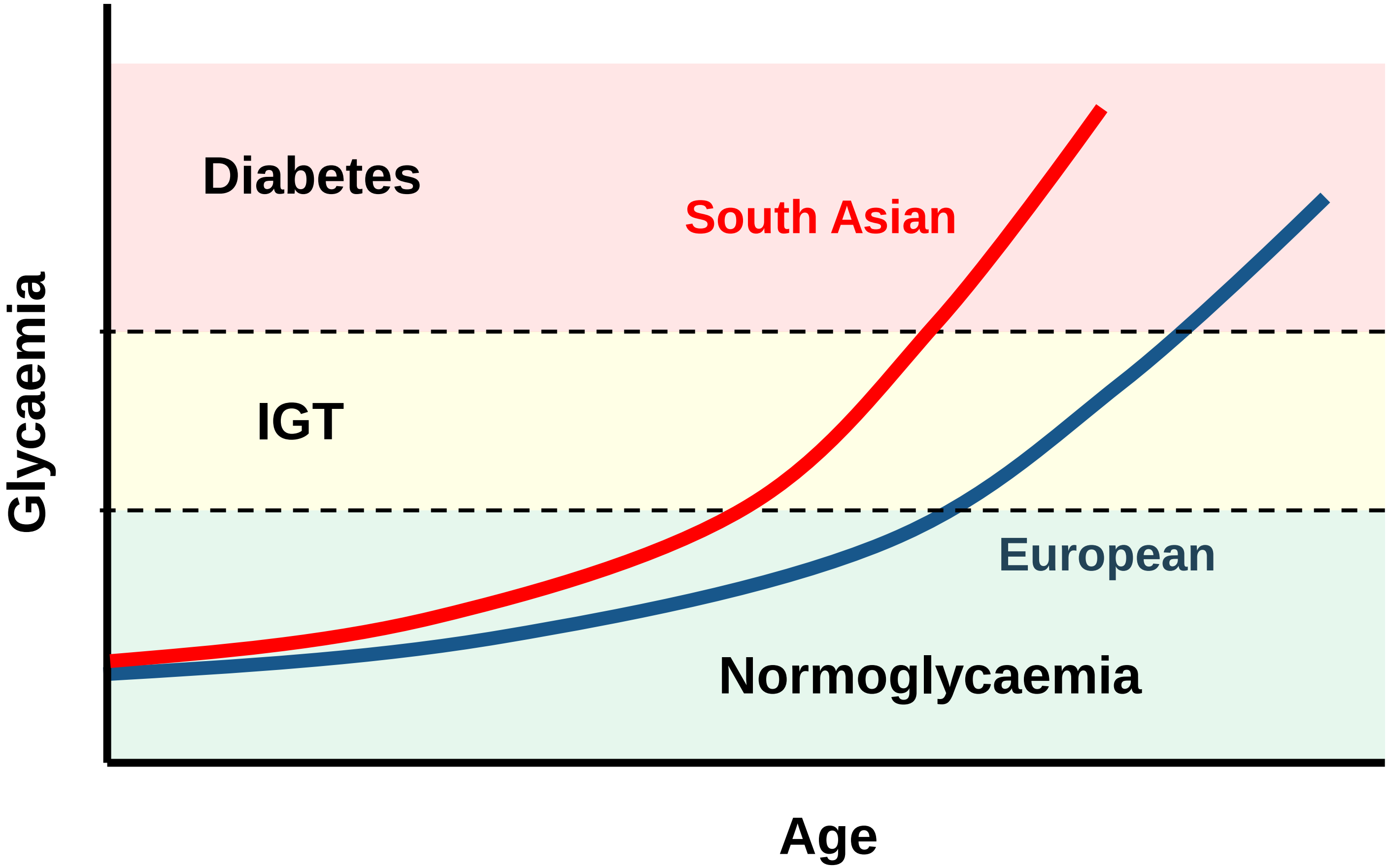
University of Glasgow

Lifestyle reduces absolute diabetes incidence by ~5-7 cases per 100 in patients with IGT



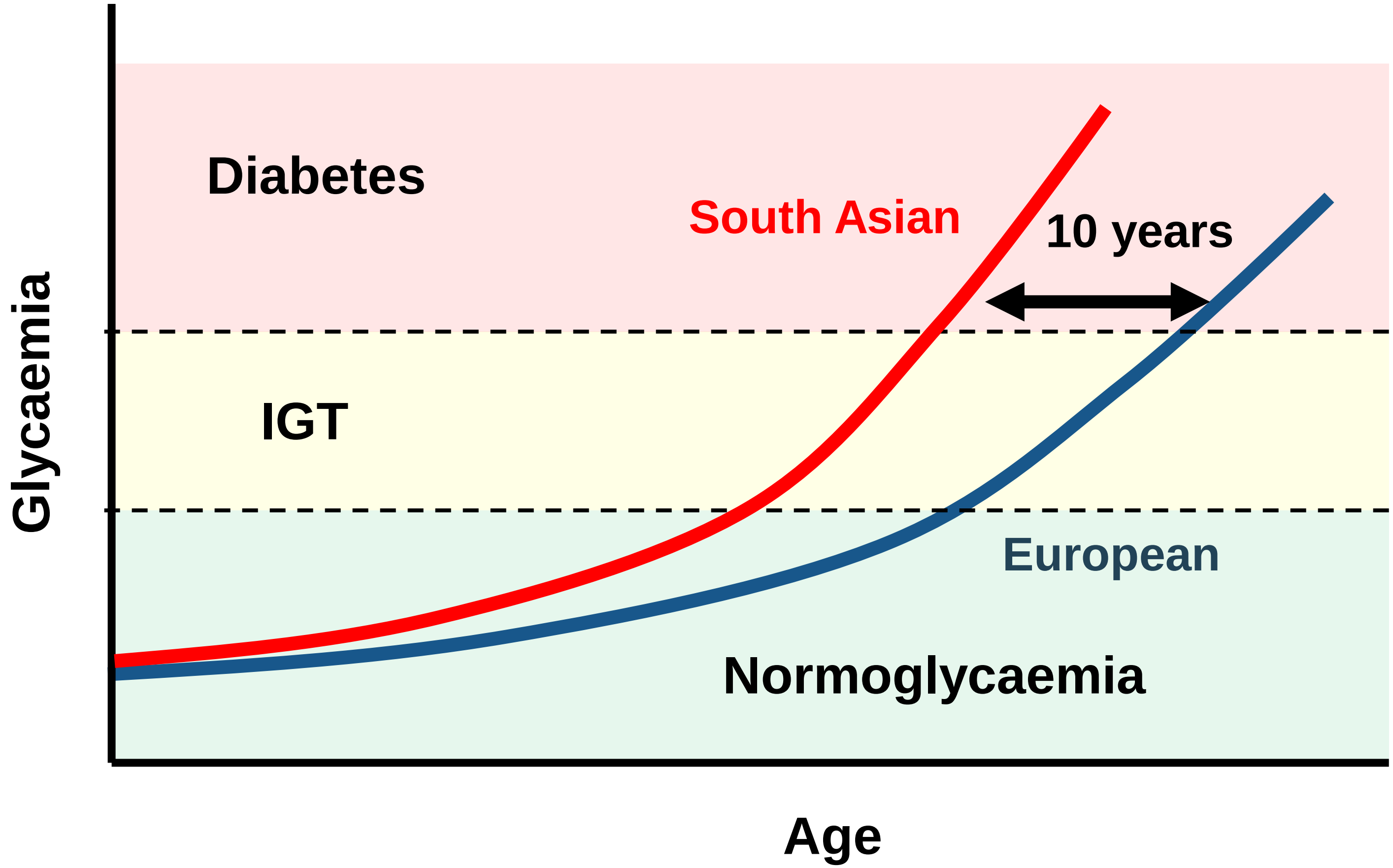
Sattar and Gill (2015) Lancet Diabetes Endocrinol

Diabetes risk progression



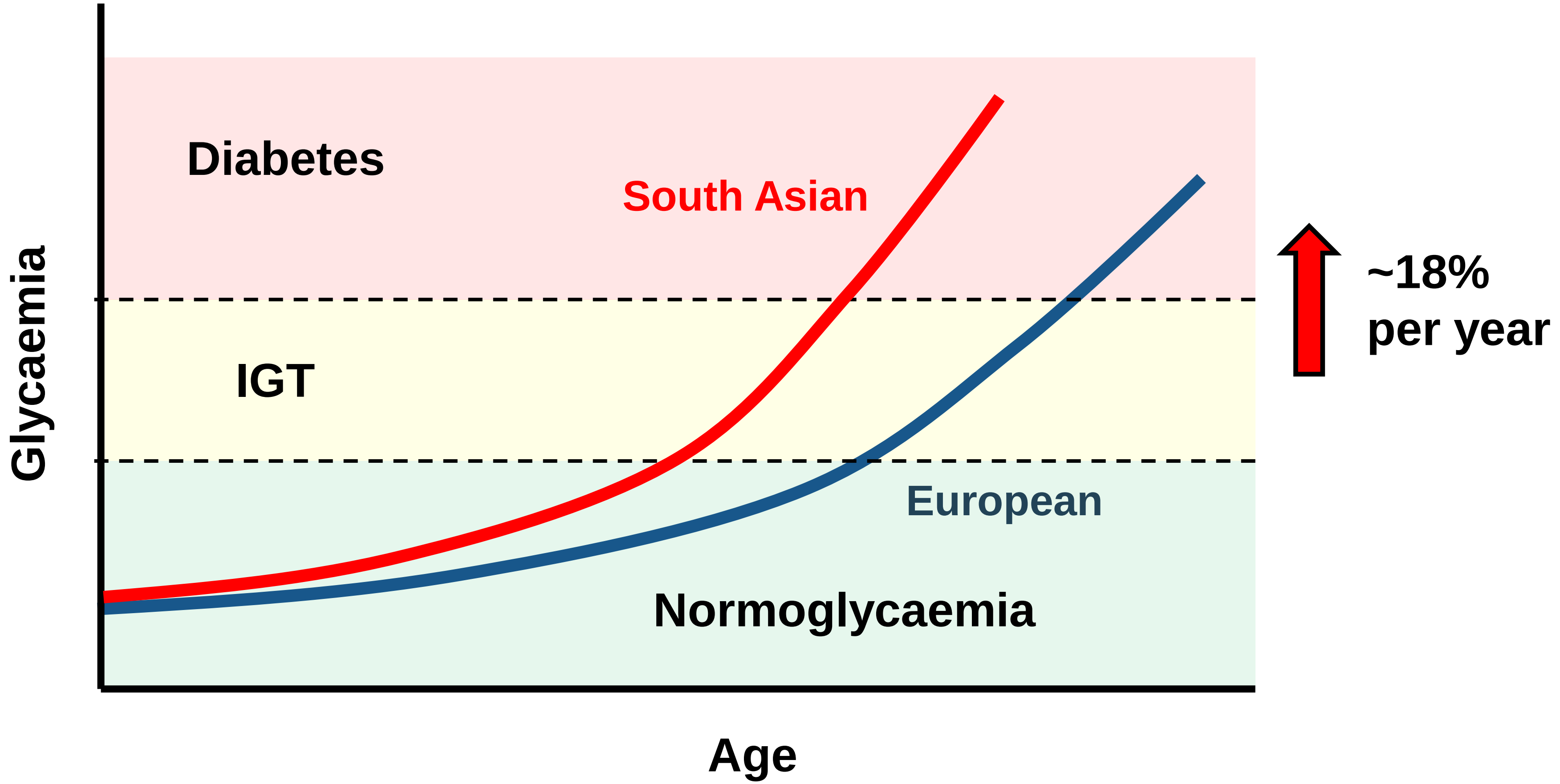
Sattar and Gill (2015) Lancet Diabetes Endocrinol

Diabetes risk progression



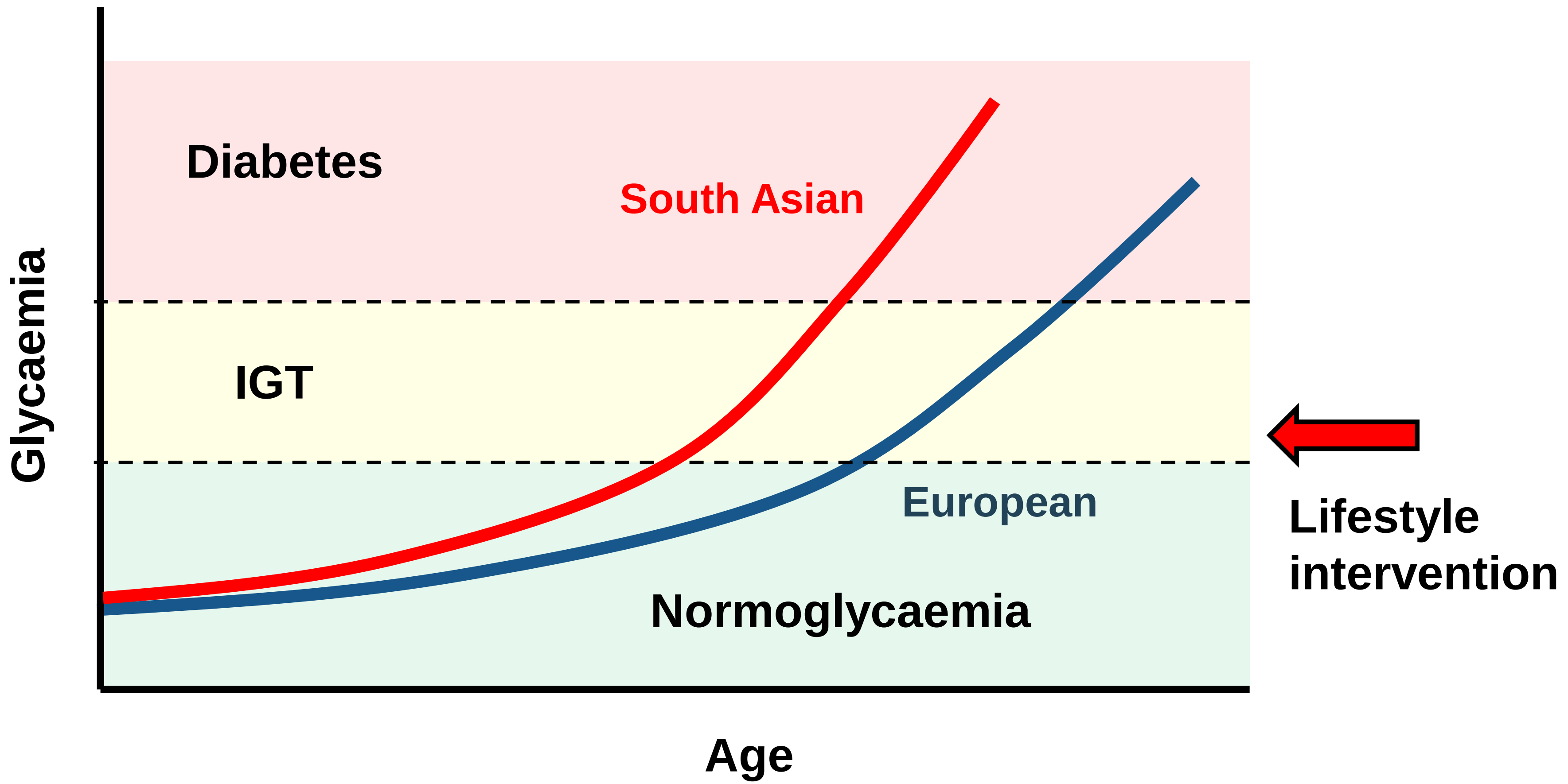
Sattar and Gill (2015) Lancet Diabetes Endocrinol

Diabetes risk progression



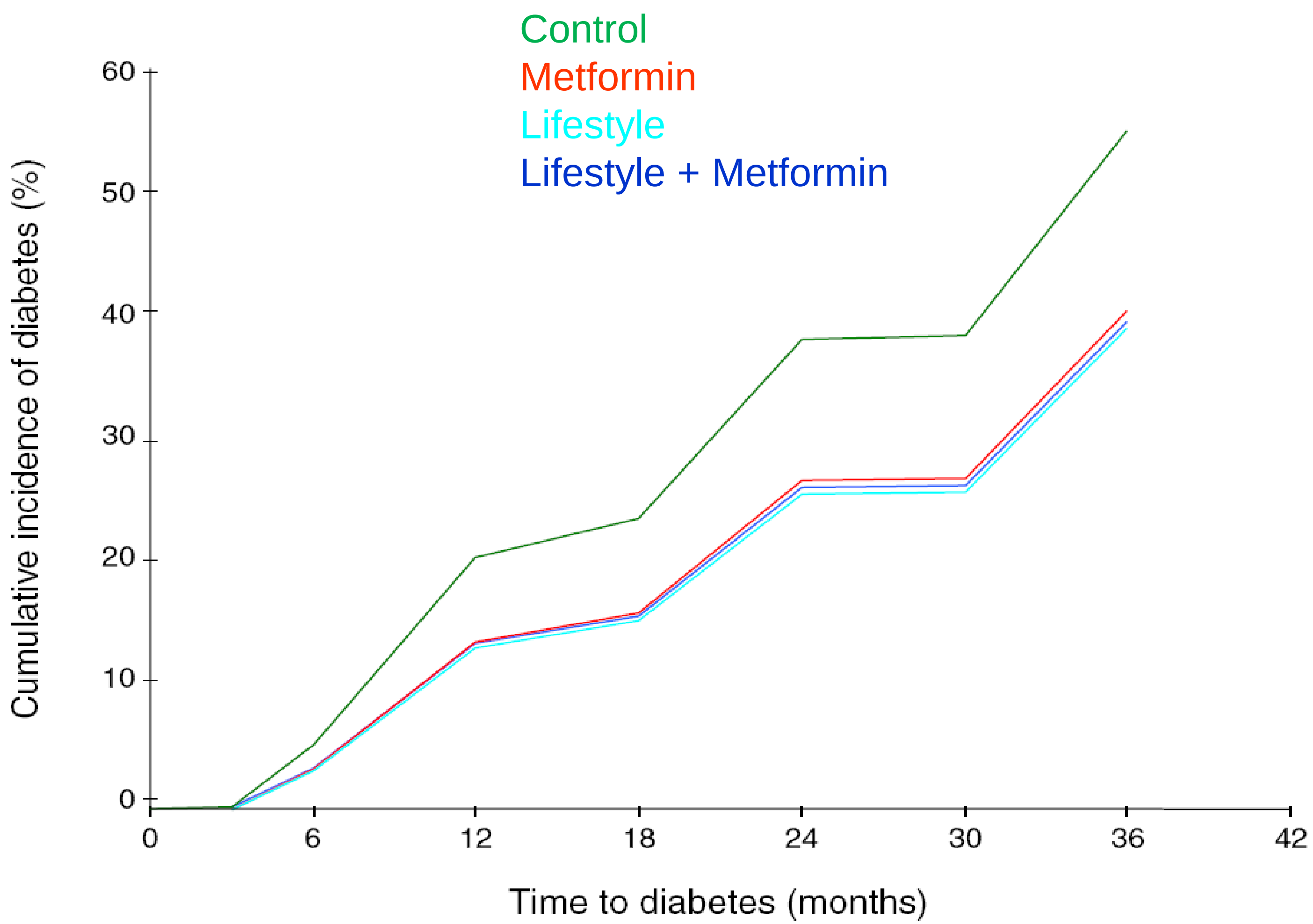
Sattar and Gill (2015) Lancet Diabetes Endocrinol

Diabetes risk progression



Sattar and Gill (2015) Lancet Diabetes Endocrinol

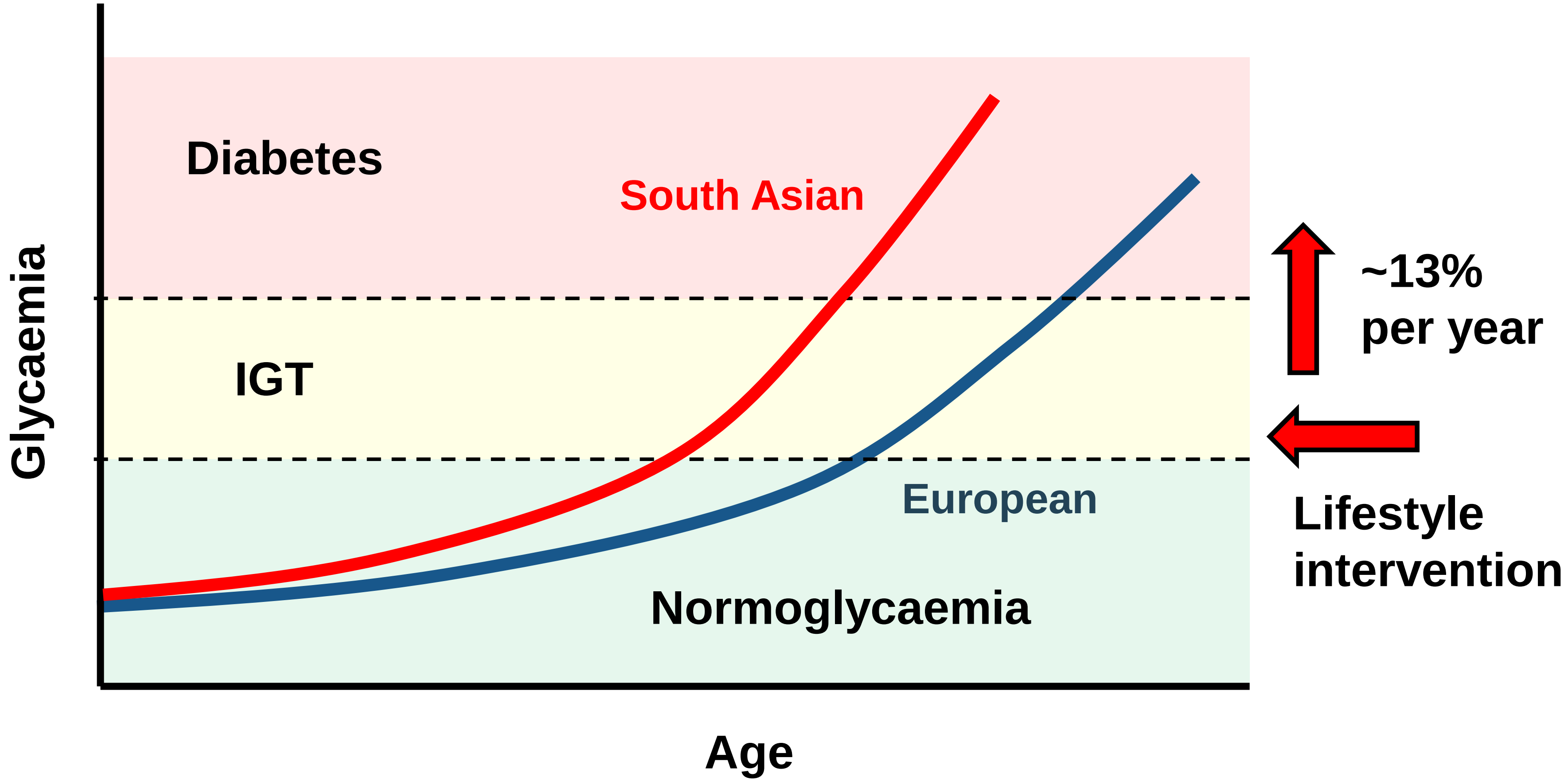
The Indian Diabetes Prevention Programme



Ramachandran et al (2006) Diabetologia, 49:289-297

Diabetes risk progression

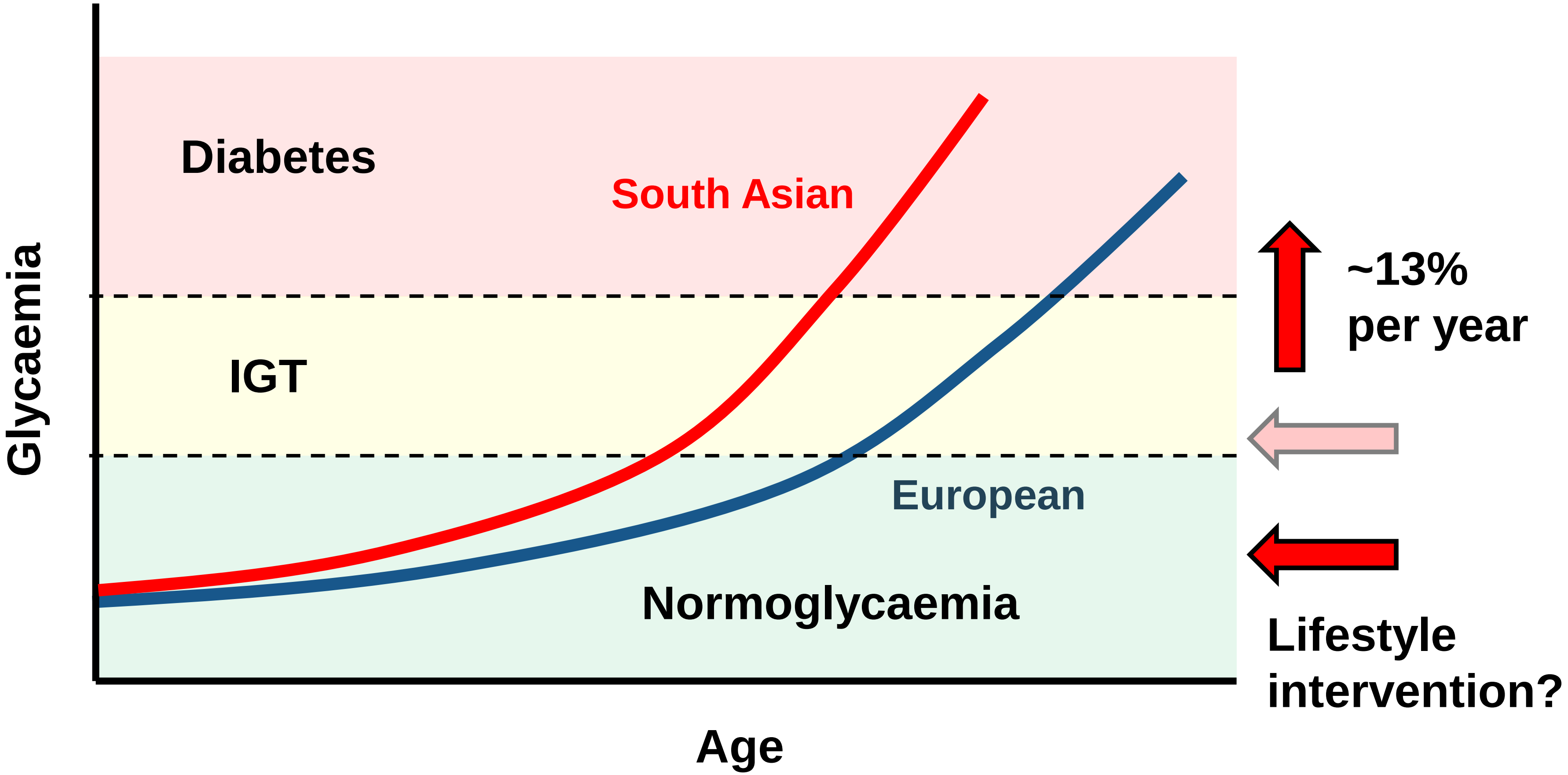
Lifestyle reduces absolute diabetes incidence by ~5 cases per 100 in patients with IGT



Sattar and Gill (2015) Lancet Diabetes Endocrinol

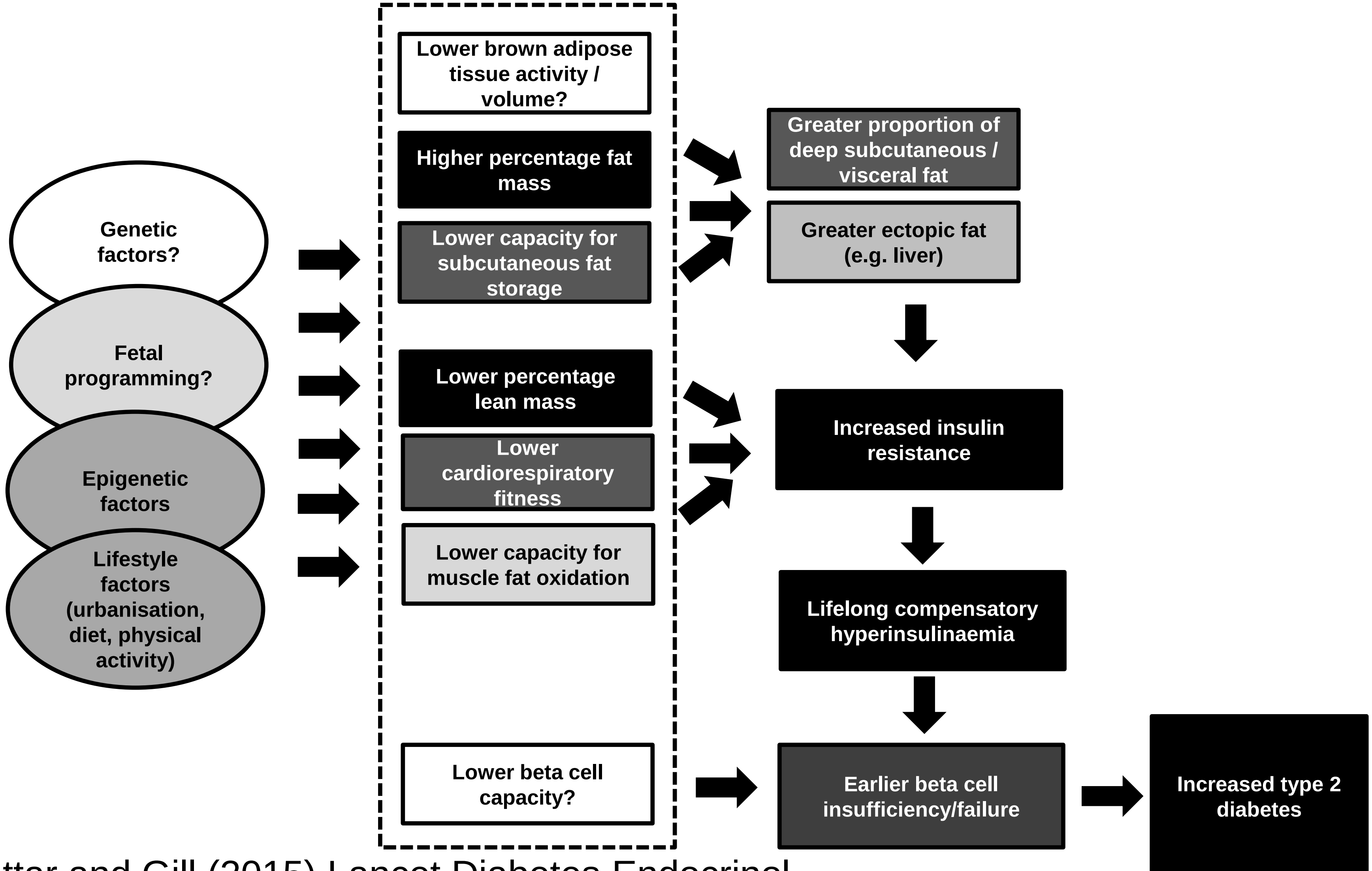
Diabetes risk progression

BUT absolute progression rate still much higher.
Should we target South Asians for earlier intervention?



Sattar and Gill (2015) Lancet Diabetes Endocrinol

Hypothesised mechanisms for South Asians' increased diabetes risk



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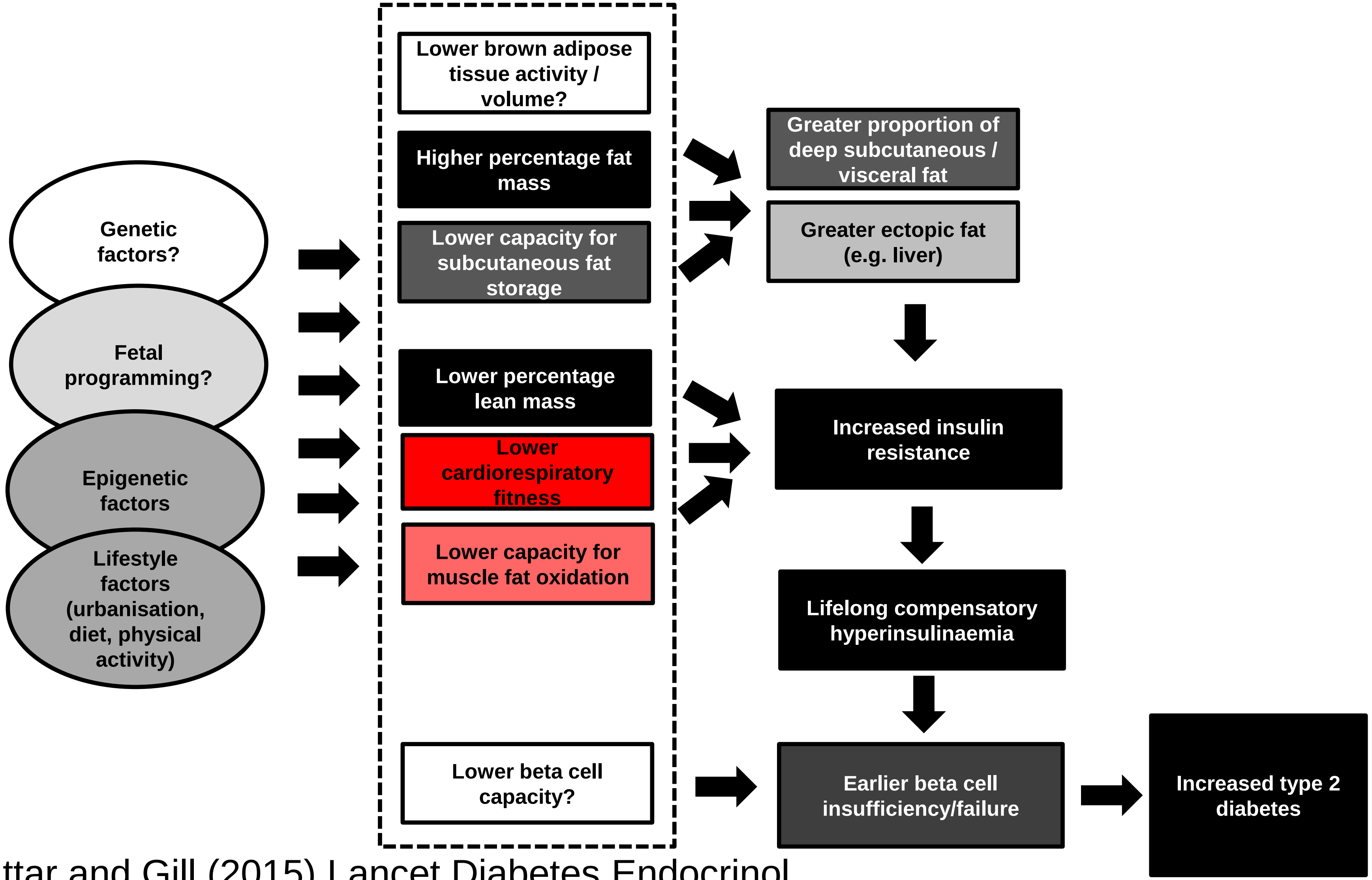


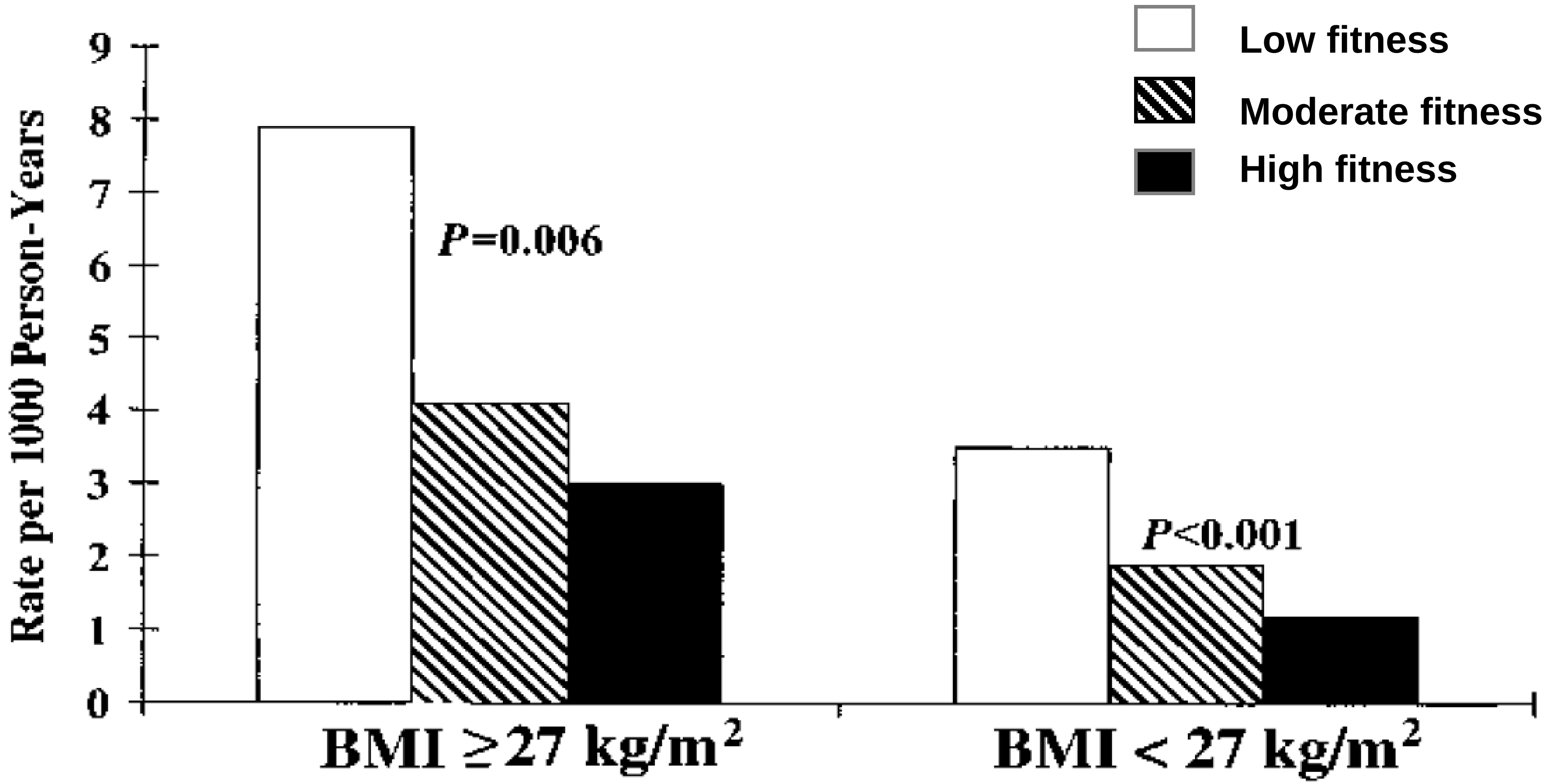
Sattar and Gill (2015) Lancet Diabetes Endocrinol

Adiposity, fitness and insulin resistance in South Asian and European men

	South Asians (n = 20)	Europeans (n = 19)	P (unadjusted)	P (adjusted for age, BMI and fat mass)
Age (years)	26.9 ± 3.9	24.5 ± 5.5	0.12	
BMI ($kg.m^{-2}$)	23.6 ± 2.9	22.6 ± 2.7	0.31	
Total fat mass (kg)	**18.4 ± 5.3**	**13.6 ± 5.2**	**0.007**	
VO_2max ($ml.kg^{-1}.min^{-1}$)	**40.6 ± 6.6**	**52.4 ± 5.7**	**< 0.0005**	**0.001**
VO_2max ($ml.kg^{-1}$ fat-free $mass.min^{-1}$)	**54.1 ± 6.6**	**64.3 ± 5.8**	**< 0.0005**	**0.001**
Fasting glucose ($mmol.l^{-1}$)	5.14 ± 0.47	5.24 ± 0.52	0.53	0.94
Fasting insulin ($mU.l^{-1}$)	**6.56 ± 3.53**	**5.39 ± 4.20**	0.11	**0.023**
2 hour insulin ($mU.l^{-1}$)	**46.6 ± 29.6**	**27.5 ± 5.3**	**0.017**	**0.043**
Insulin sensitivity index	**5.89 ± 2.93**	**7.96 ± 3.49**	**0.048**	**0.012**

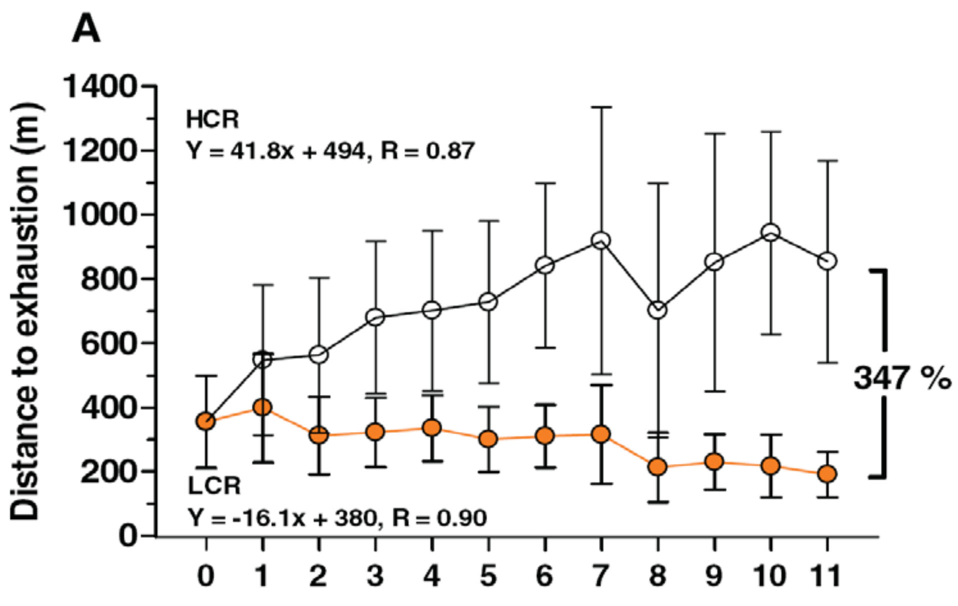
Hall et al (2010) PLoS ONE: 5(12): e14197

Fitness, BMI and risk of type 2 diabetes: The Aerobics Center Longitudinal Study



Wei et al (1999) Ann Intern Med, 130:89-96

Artificial selection for fitness and insulin sensitivity



	LCR	HCR	% Difference LCR vs. HCR	*P* value
Random glucose (mg/dl)	86 ± 6	75 ± 12	15%	0.036
Fasting glucose (mg/dl)	110 ± 9	92 ± 5	20%	0.0007
Insulin (pM)	684 ± 195	296 ± 172	131%	0.002
C-peptide (pM)	1590 ± 338	1077 ± 565	48%	0.061
C-peptide/insulin	2.4 ± 0.4	3.8 ± 1.2	−58%	0.013
Visceral adiposity/body weight (%)	1.55 ± 0.39	0.95 ± 0.32	63%	0.005
Triglycerides (mg/dl)	67 ± 24	25 ± 4	168%	0.013
Free fatty acids (meq/l)	0.64 ± 0.22	0.33 ± 0.04	94%	0.031

Breeding rats for low fitness makes them insulin resistant

Wisloff et al (2005) Science 307: 418-420

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Does lower fitness in South Asians simply reflect lower physical activity levels?

Journal of Public Health
DOI: 10.1093/pubmed/fdh158

Vol. 26, No. 3, pp. 250–258
Printed in Great Britain

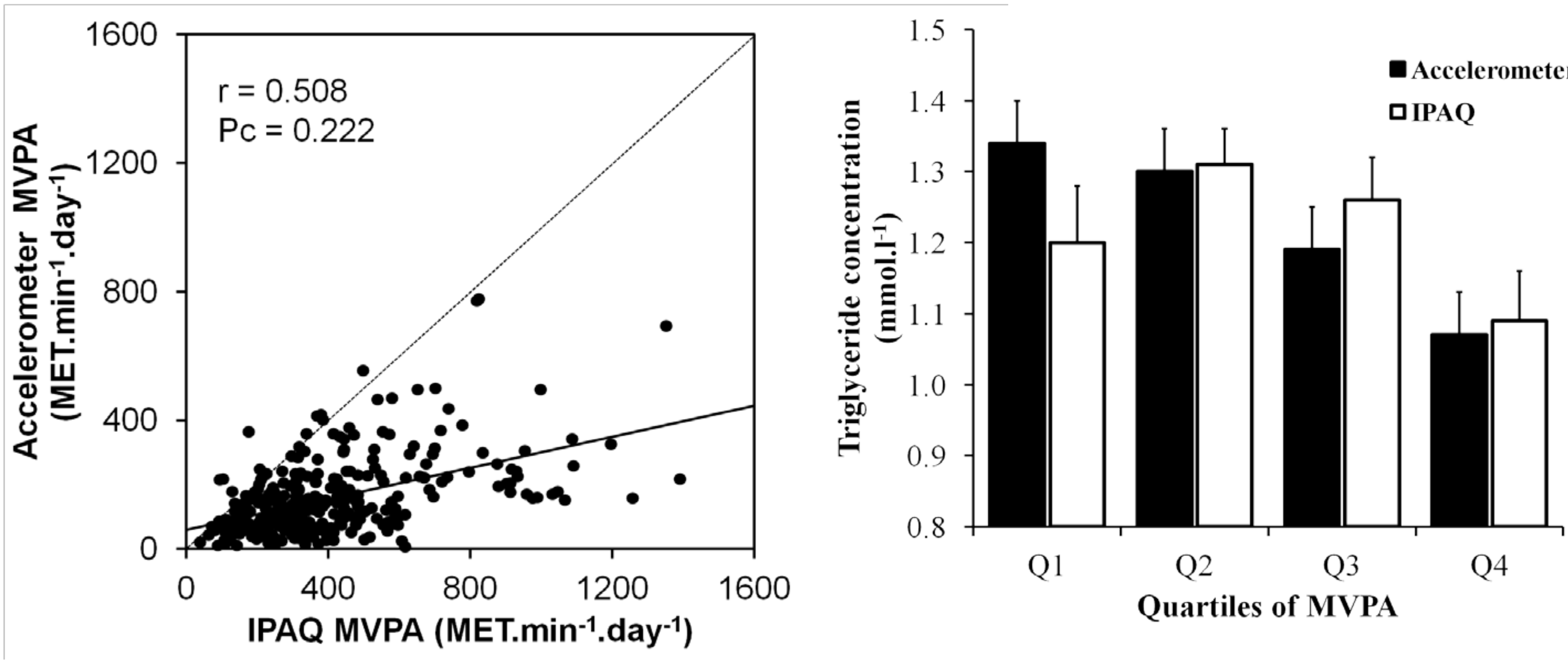
How physically active are South Asians in the United Kingdom? A literature review

C. M. Fischbacher, S. Hunt and L. Alexander

Results We identified 12 studies in adults and five in children. Various methods were used to assess physical activity and fitness, but all the studies reported lower levels among South Asian groups. The differences were substantial, particularly among women and older people. For example, the Health Survey for England found that Indian, Pakistani and Bangladeshi men were 14, 30 and 45 per cent less likely than the general population to meet current guidelines for physical activity. Limited information was provided about translation and adaptation of questionnaires.

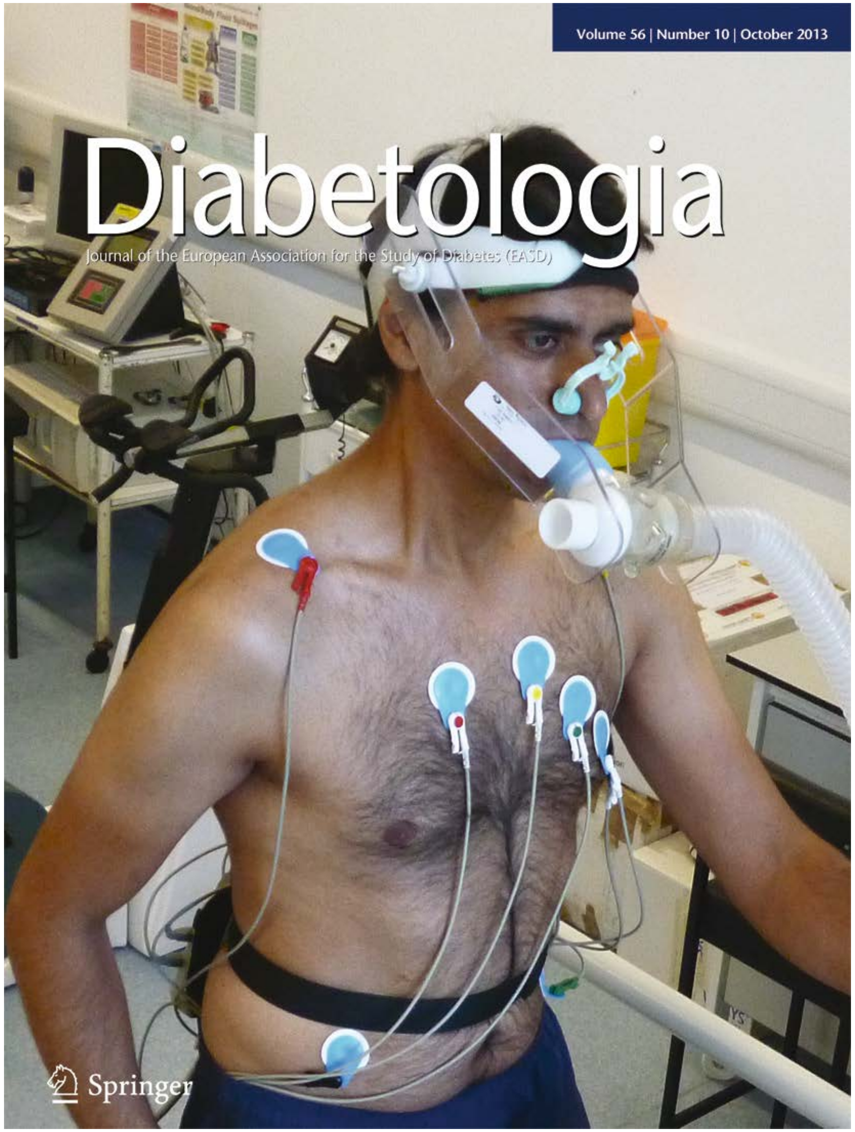
Conclusions Levels of physical activity were lower in all South Asian groups than the general population and patterns of activity differed. No studies used validated measures. Insufficient attention has been paid to issues of cross-cultural equivalence. With these caveats, low levels of physical activity among UK South Asian ethnic groups may contribute to their increased risk of diabetes and CHD. Closer attention to validity, translation and adaptation is necessary to monitor changes and assess the effectiveness of interventions to increase physical activity.

Self-reported vs objective physical activity measurement

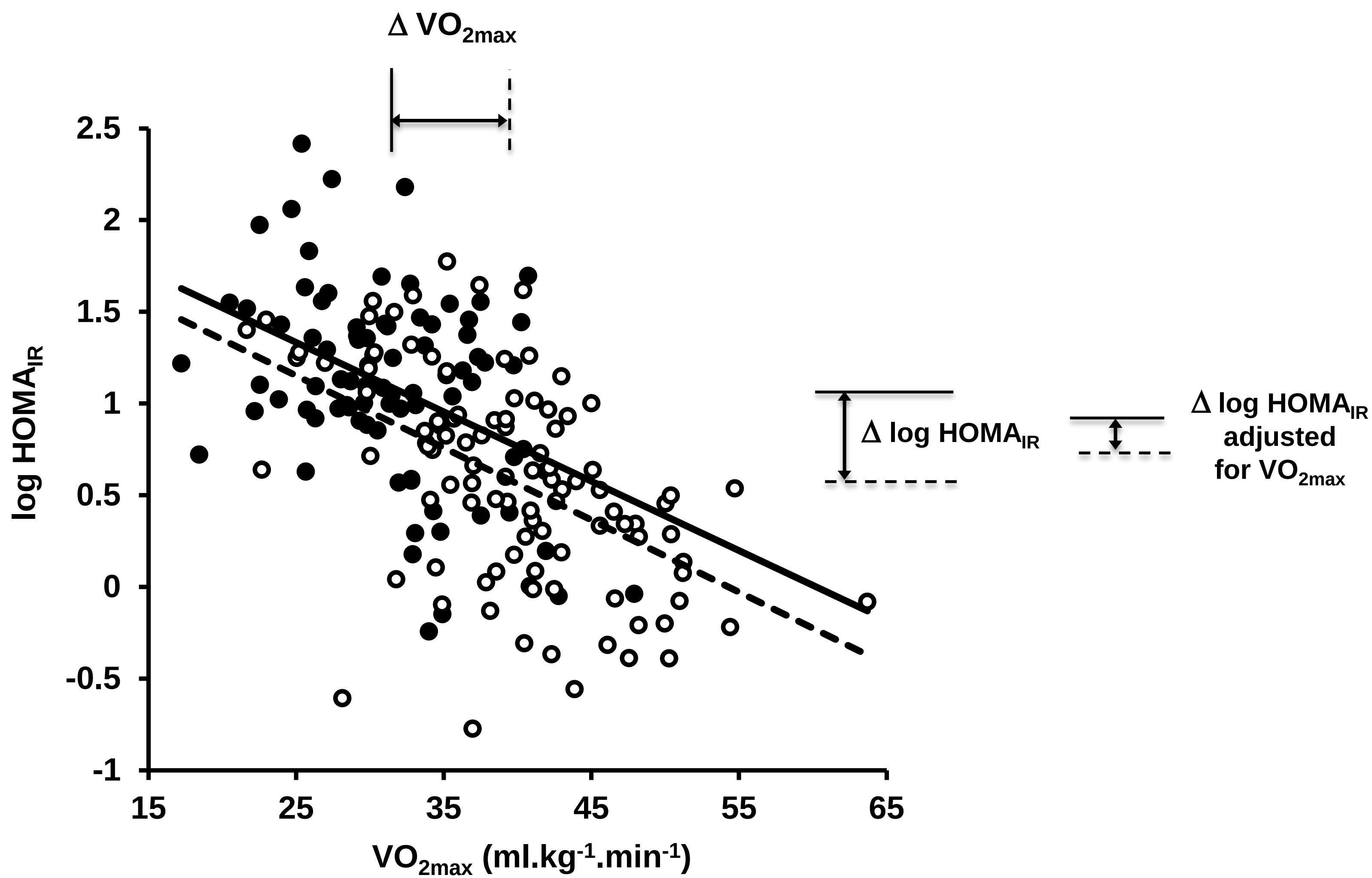


Celis-Morales et al (2012) PLoS ONE 7:e36345

Can lower fitness explain increased insulin resistance in South Asians?

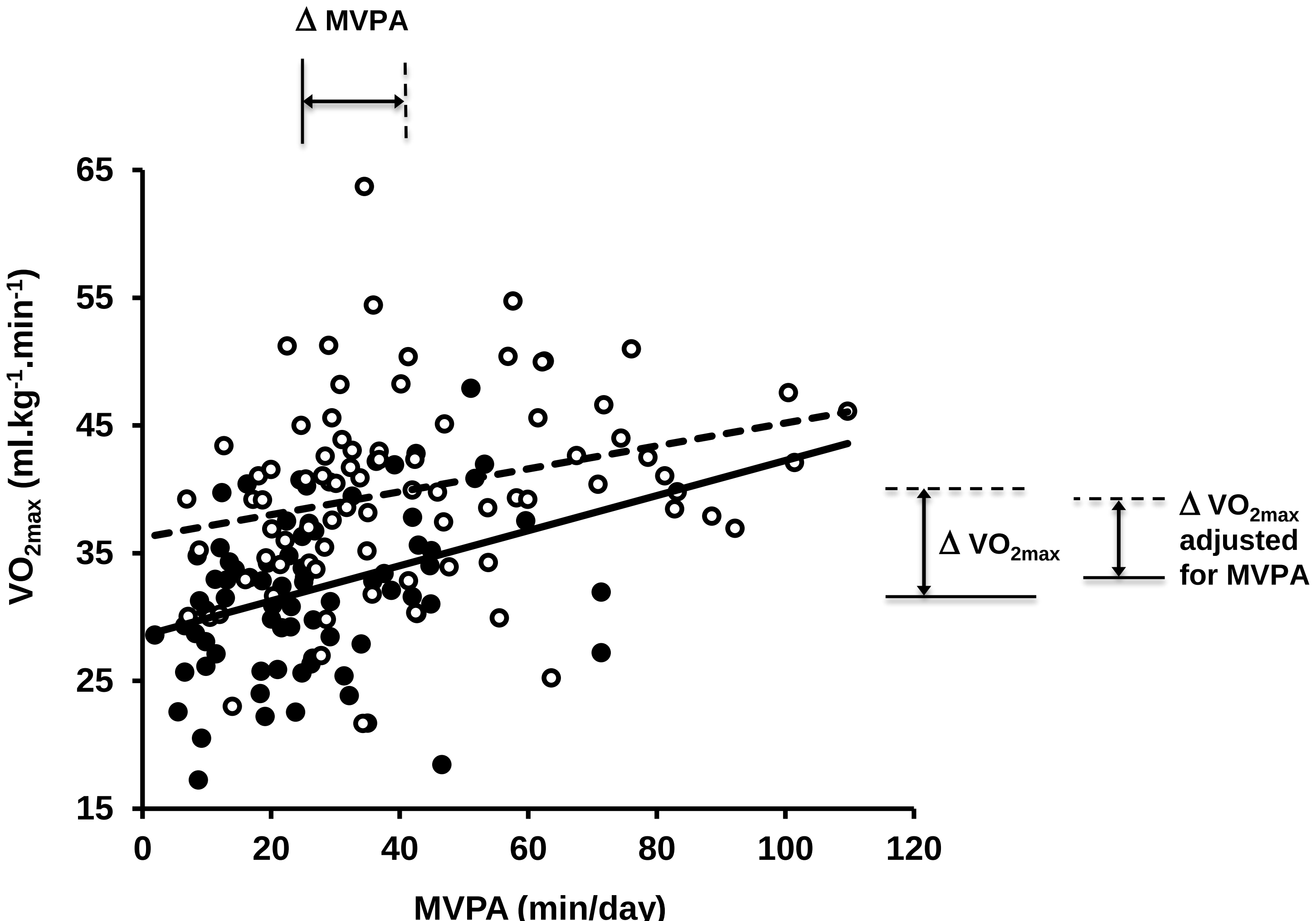


Relationship between fitness and HOMA in European and South Asian men



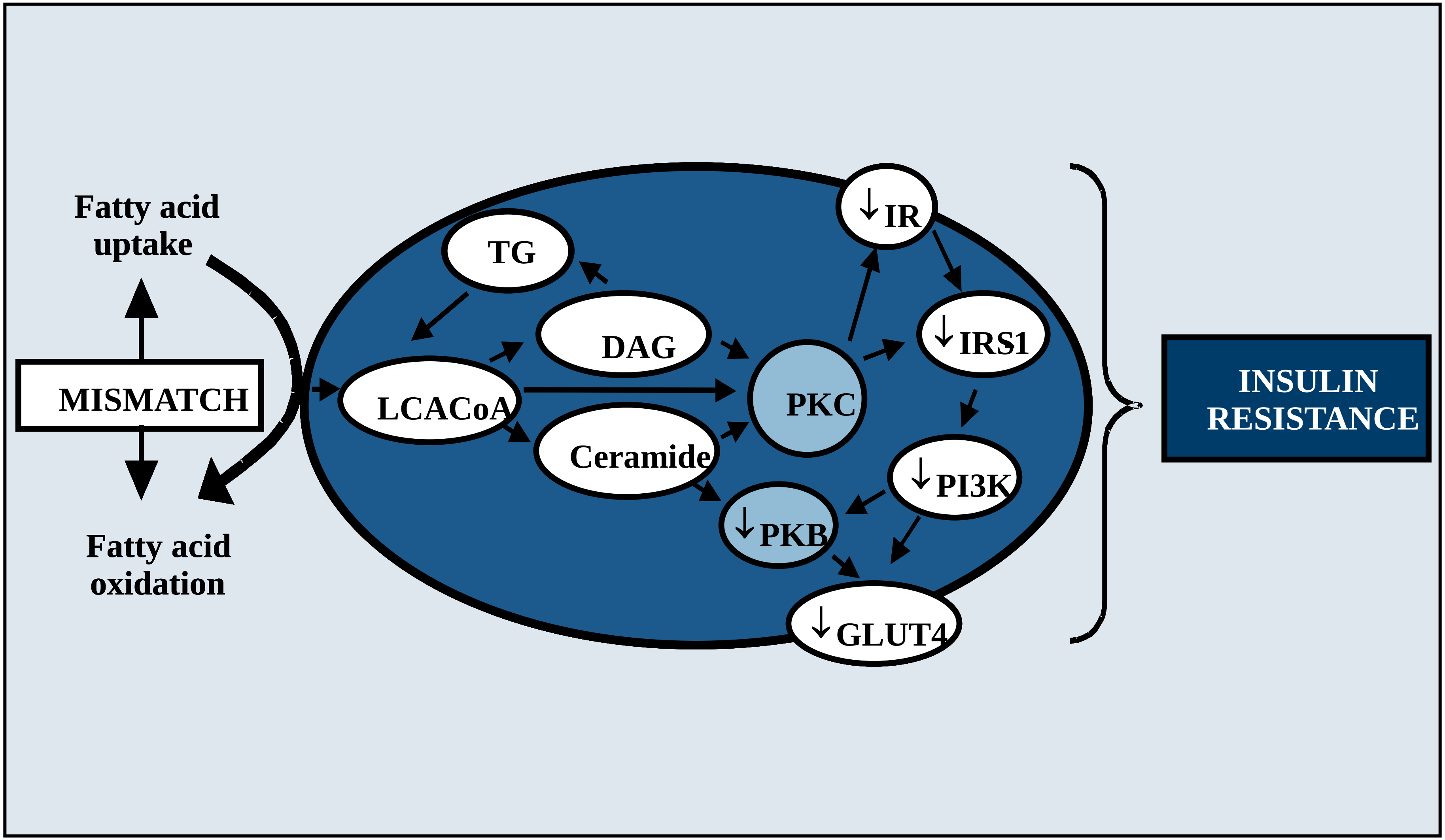
Ghouri et al (2013) Diabetologia, 56:2238-49

Relationship between fitness and physical activity in European and South Asian men



Ghouri et al (2013) Diabetologia, 56:2238-49

Impaired skeletal muscle oxidative capacity as a mechanism for greater insulin resistance in South Asians?



Fat oxidation during submaximal exercise in South Asian and European men

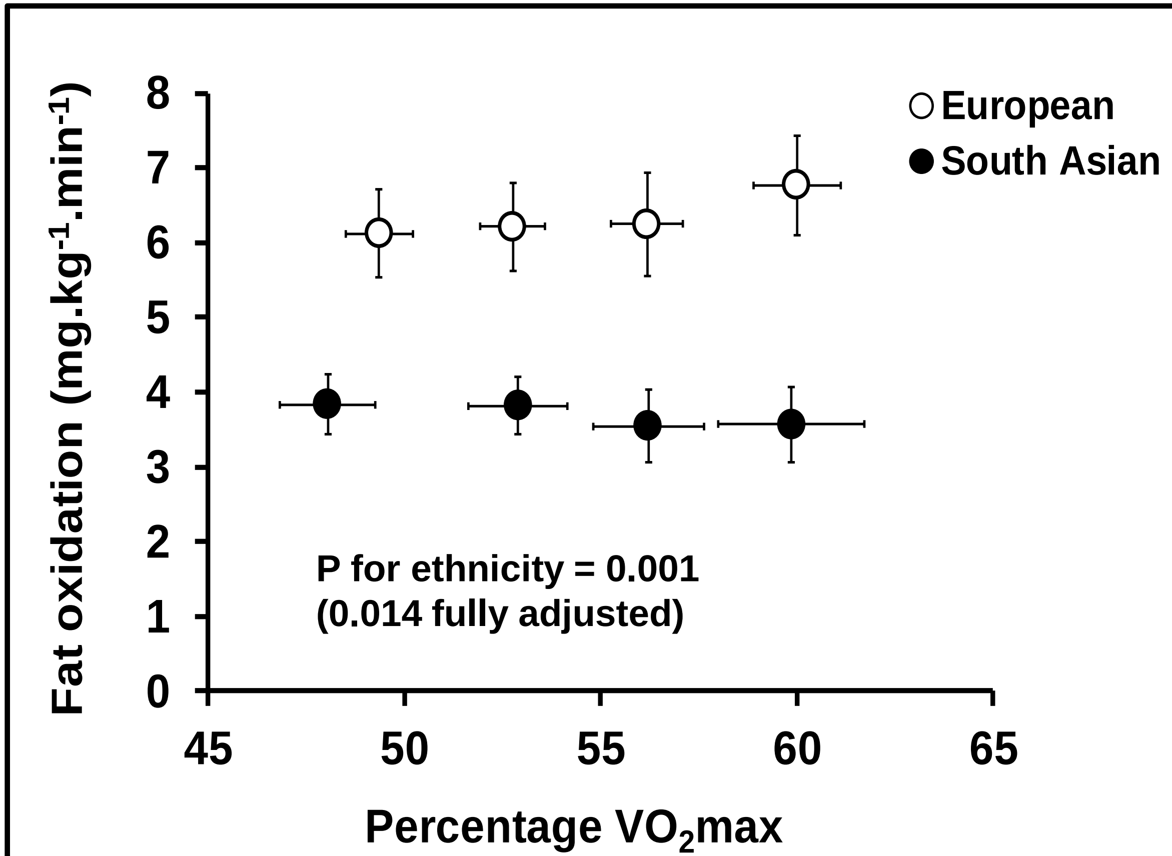
South Asian man

European man

Fat oxidation during submaximal exercise in South Asian and European men

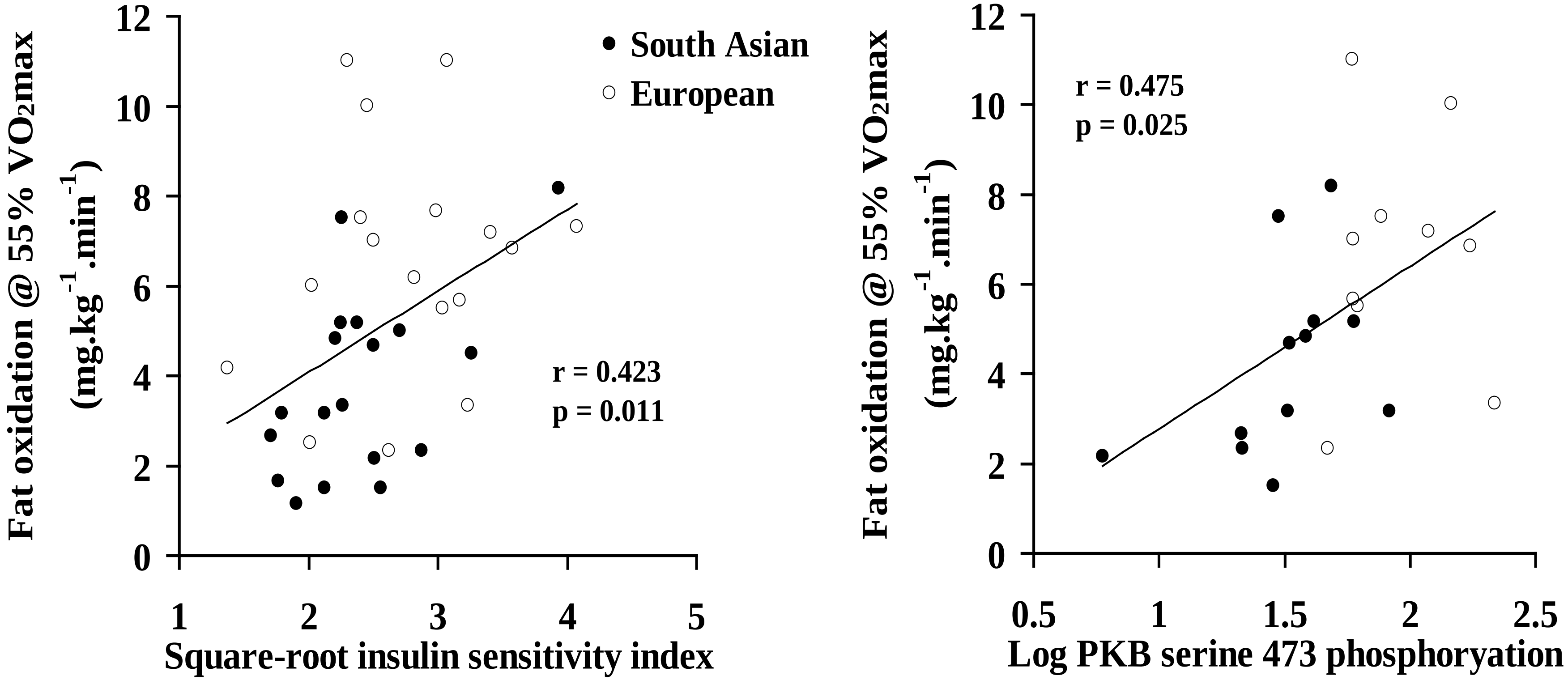
South Asian man

European man



Hall et al (2010) PLoS ONE: 5(12): e14197

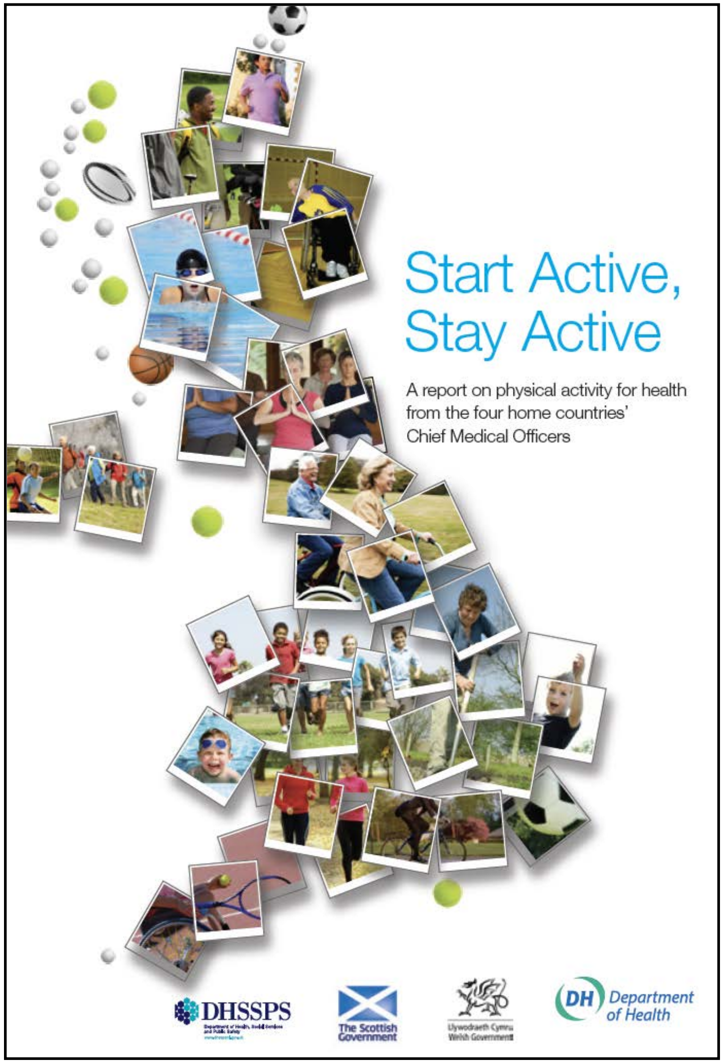
Substrate utilisation during exercise and insulin sensitivity in South Asian and European men



Hall et al (2010) PLoS ONE: 5(12): e14197

Do we need ethnicity-specific public health guidelines to reflect innate ethnic differences in disease risk?

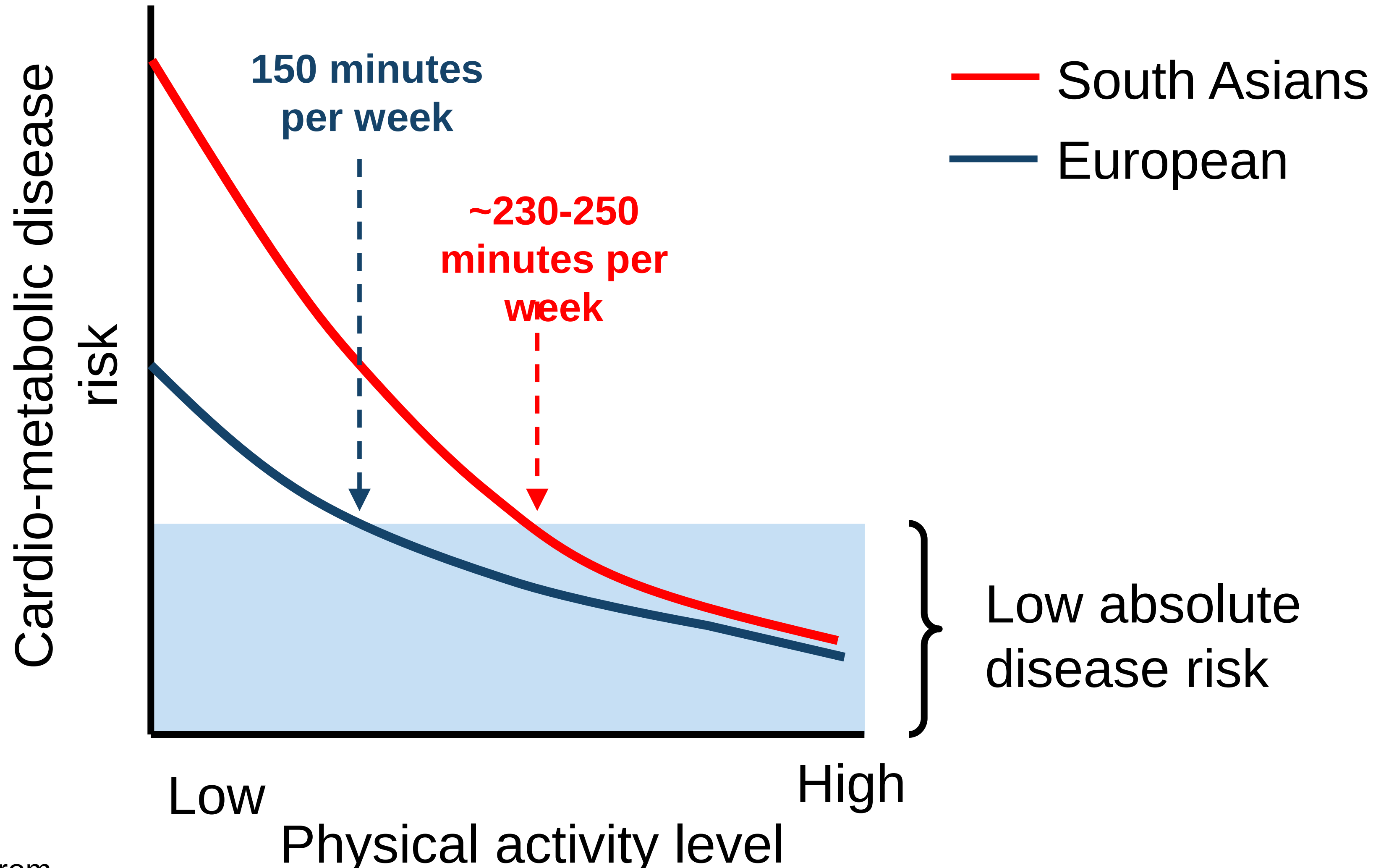
A brief history of physical activity guidelines (for adults)



2011

- 150 minutes of moderate or 75 minutes of vigorous physical activity per week in bouts of at least 10 minutes
- Muscle strengthening activities 2 x per week
- Minimise the amount of time spent sedentary (sitting)

Ethnicity and physical activity



Modified from
Celis-Morales et al (2013) PLOS ONE 8(12):e82568 & Iliodromiti et al (2016) PLOS ONE 11(8): e0160024

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Review

Joint British Societies' consensus recommendations for the prevention of cardiovascular disease (JBS3)

JBS3 Board

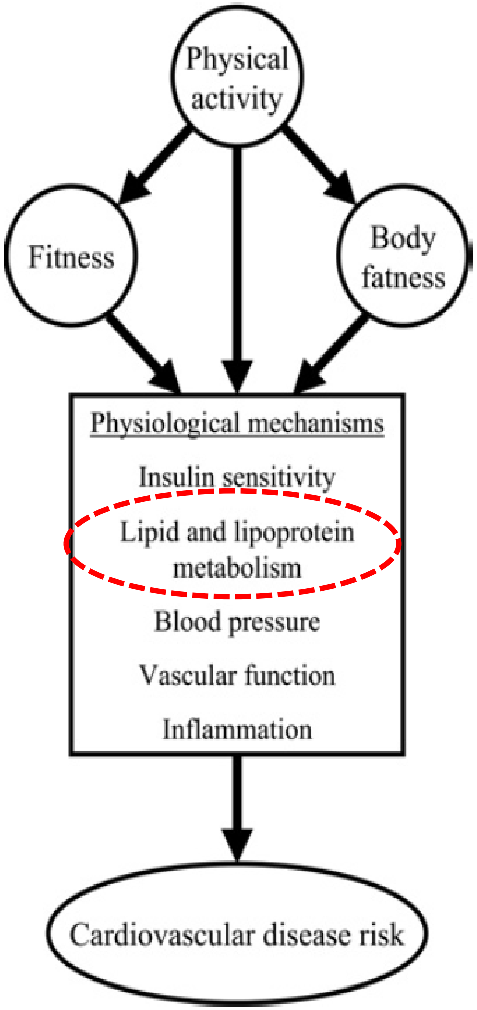
There is recent evidence that certain ethnic groups (eg, South Asian men) may benefit from higher levels of physical activity to improve CVD risk profiles.[166]

166 Celis-Morales CA, Ghouri N, Bailey ME, *et al*. Should physical activity recommendations be ethnicity-specific? Evidence from a cross-sectional study of South Asian and European men. *PLoS ONE* 2013;8:e82568.

JBS3 (2014) Heart 100:ii1-ii67.

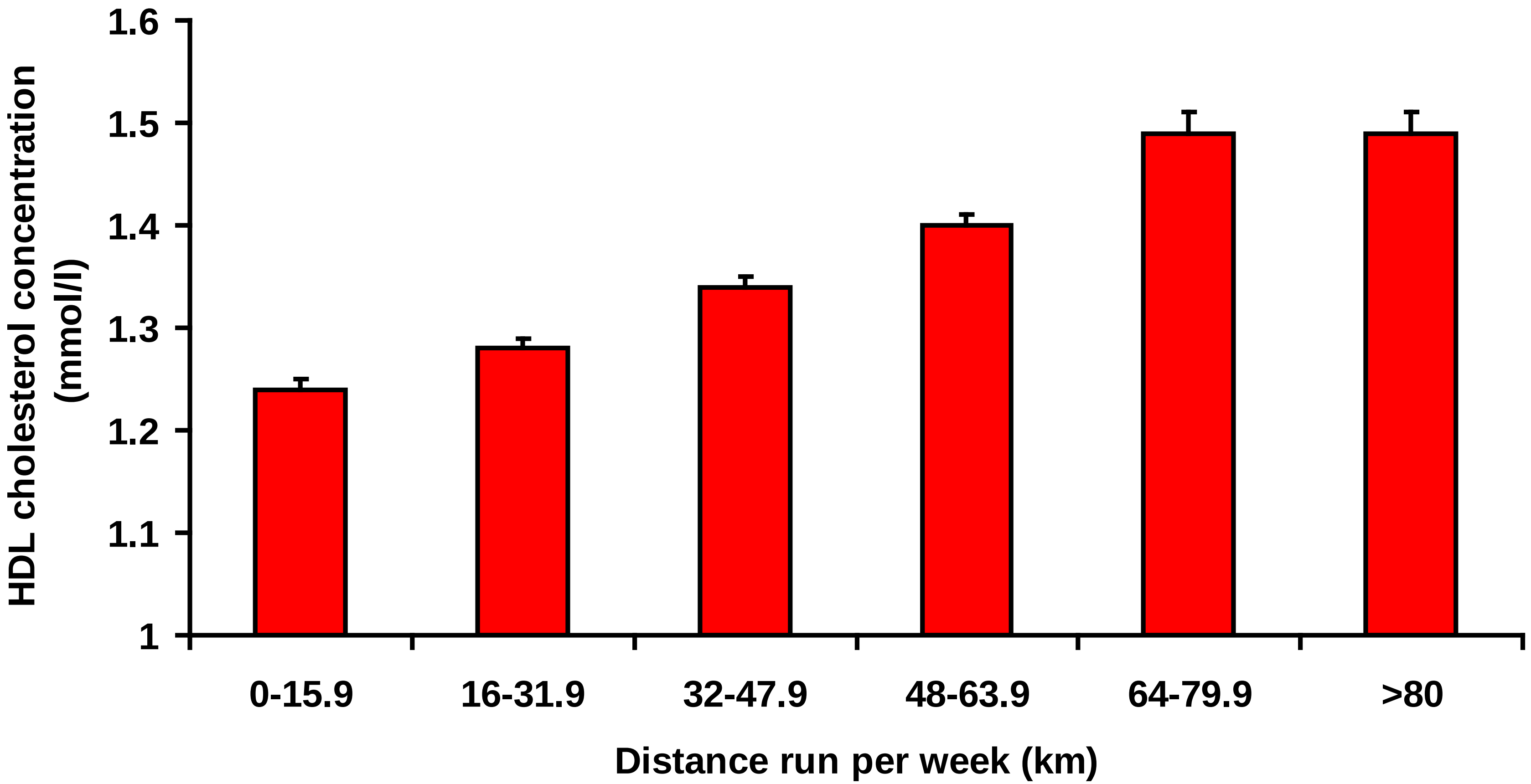
Physical activity and postprandial lipoprotein metabolism

Mechanisms behind protective effect of physical activity



Gill and Malkova (2006) Clin Sci, 110:409-425

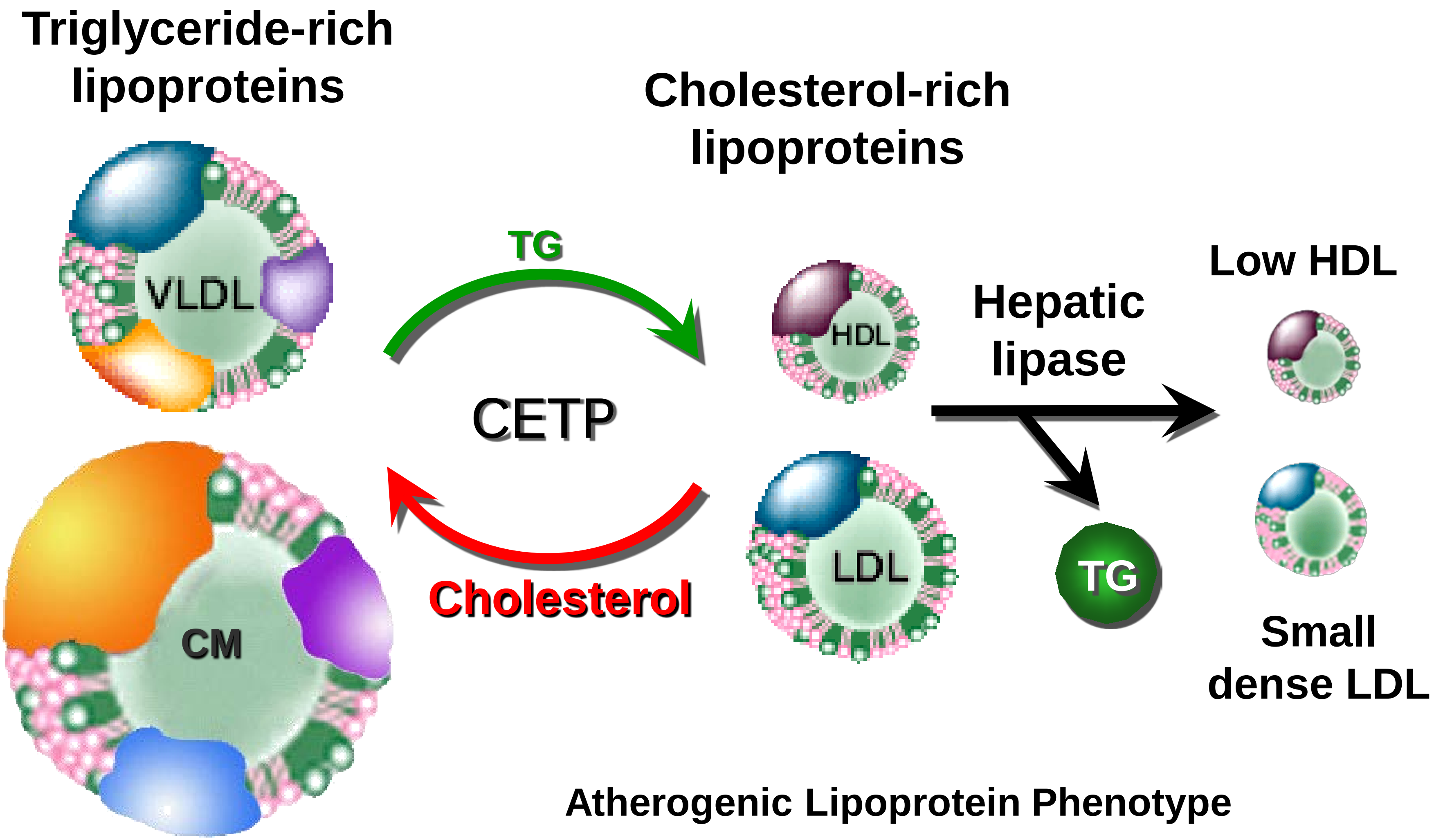
HDL cholesterol in runners



N = 8283 men

Williams (1997), Arch Intern Med, 157:191-198

Neutral Lipid Exchange



Atherogenic Lipoprotein Phenotype

Role of postprandial lipid metabolism in the progression of atherosclerosis

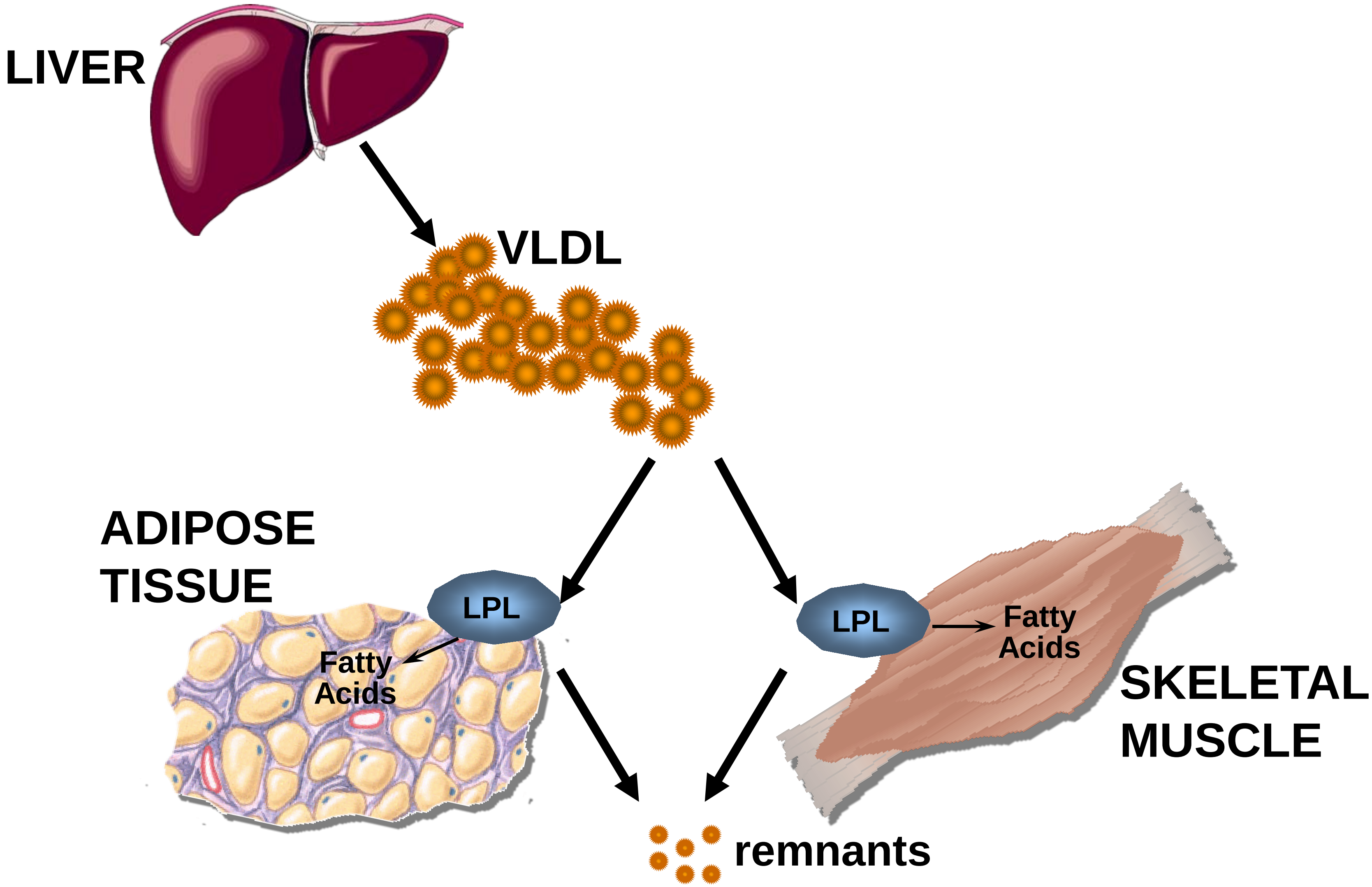
- Postprandial lipoproteins and their remnants may directly deposit into the arterial wall

- High postprandial triglyceride concentrations contribute to the ‘atherogenic lipoprotein phenotype’

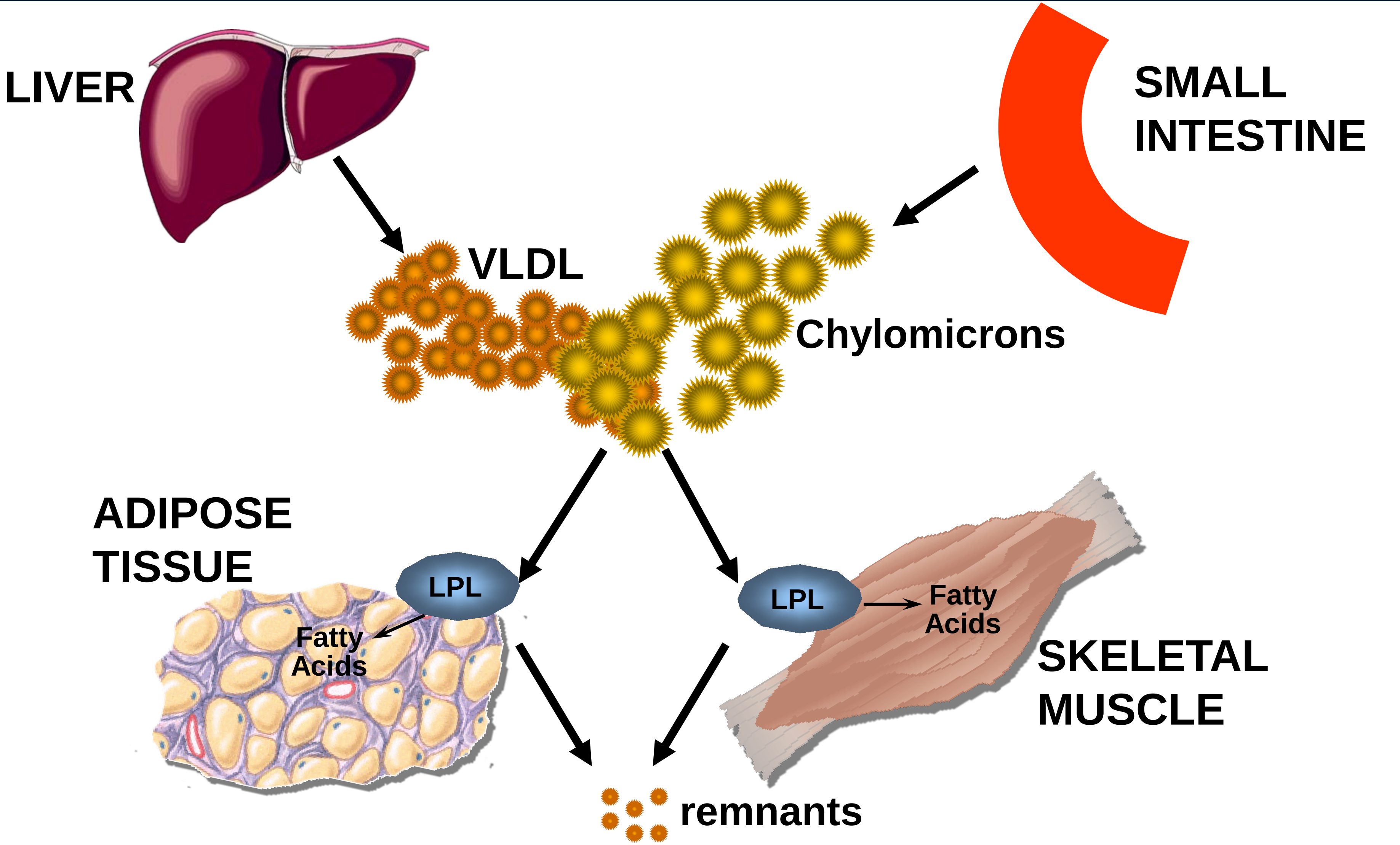
- Endothelial function is impaired following ingestion of a high fat meal

- Pro-thrombotic and pro-inflammatory changes are evident postprandially

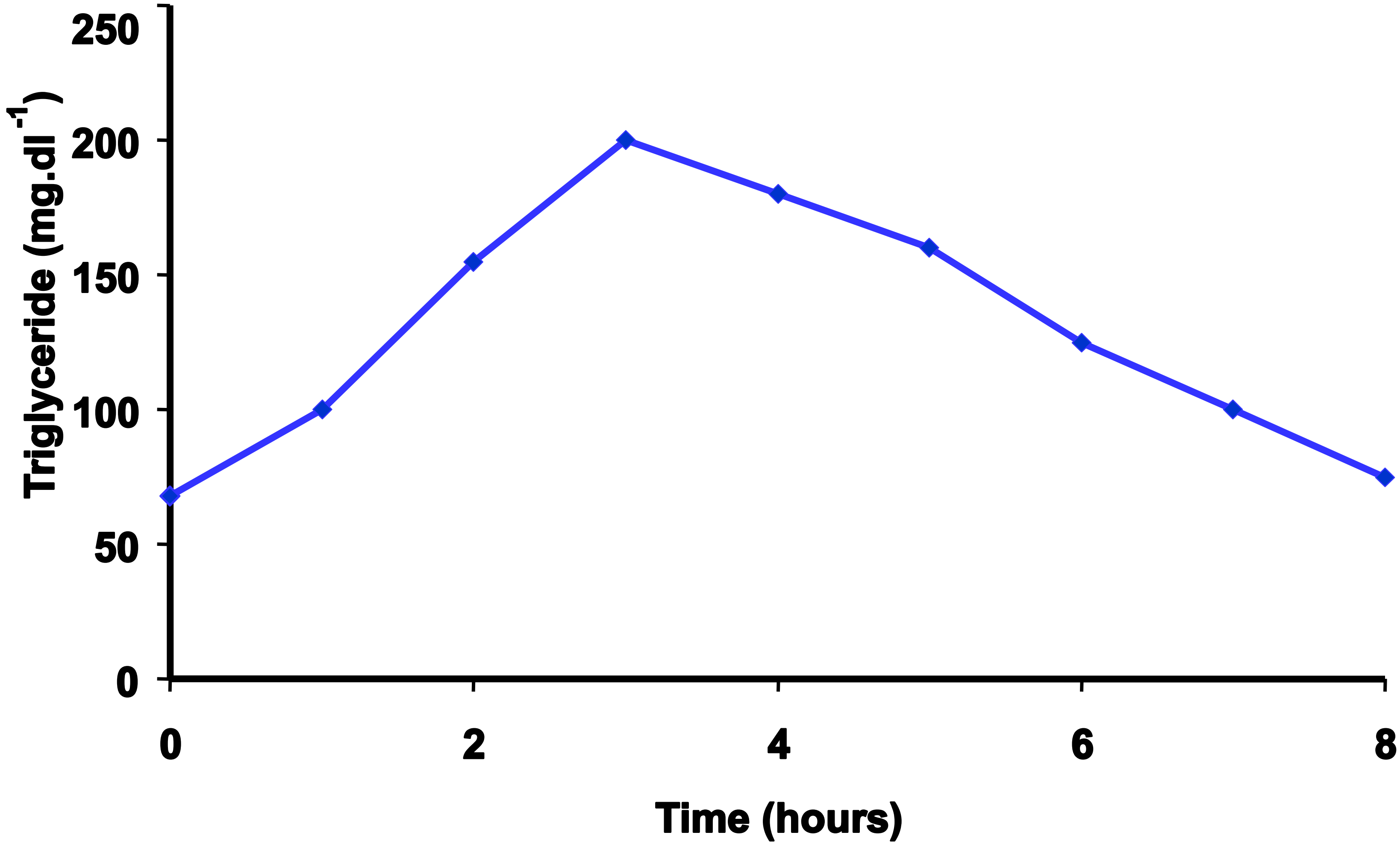
Triglyceride metabolism in the fasted state



Triglyceride metabolism in the postprandial state

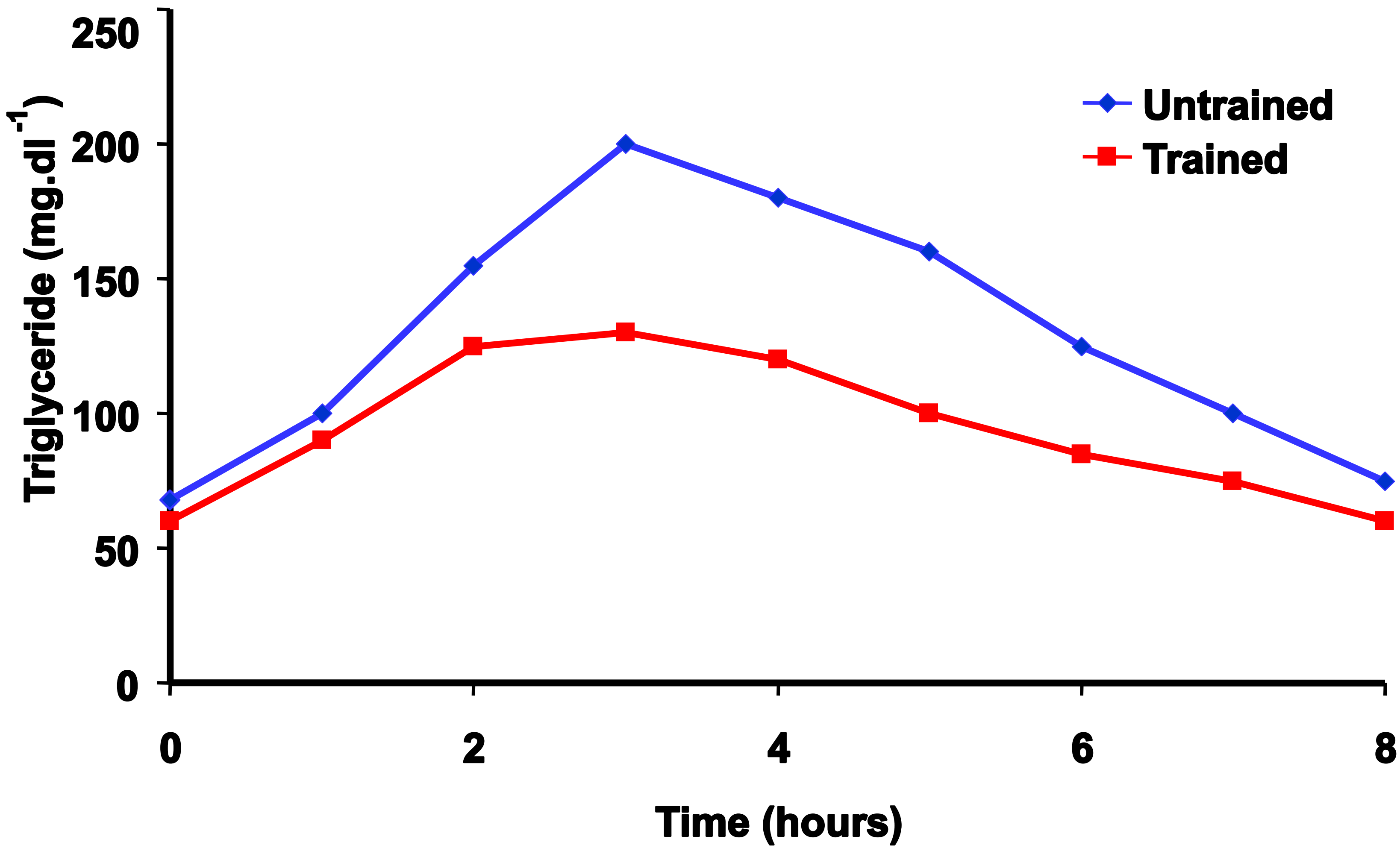


Postprandial lipaemia in trained and untrained men



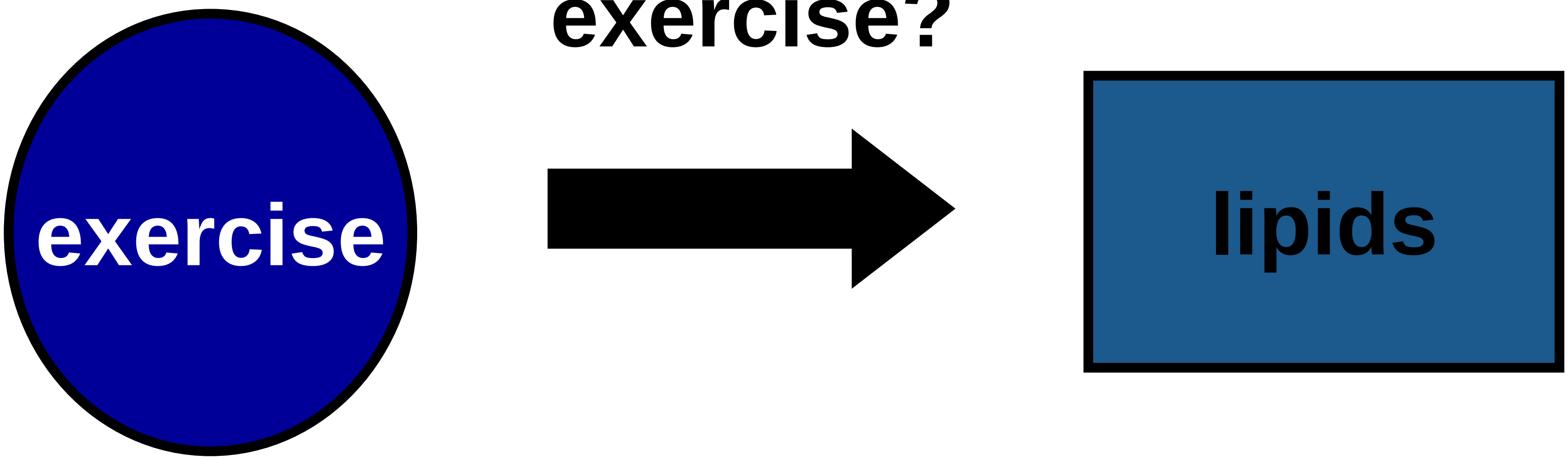
Merrill et al (1989), Arteriosclerosis, 9:217-223

Postprandial lipaemia in trained and untrained men

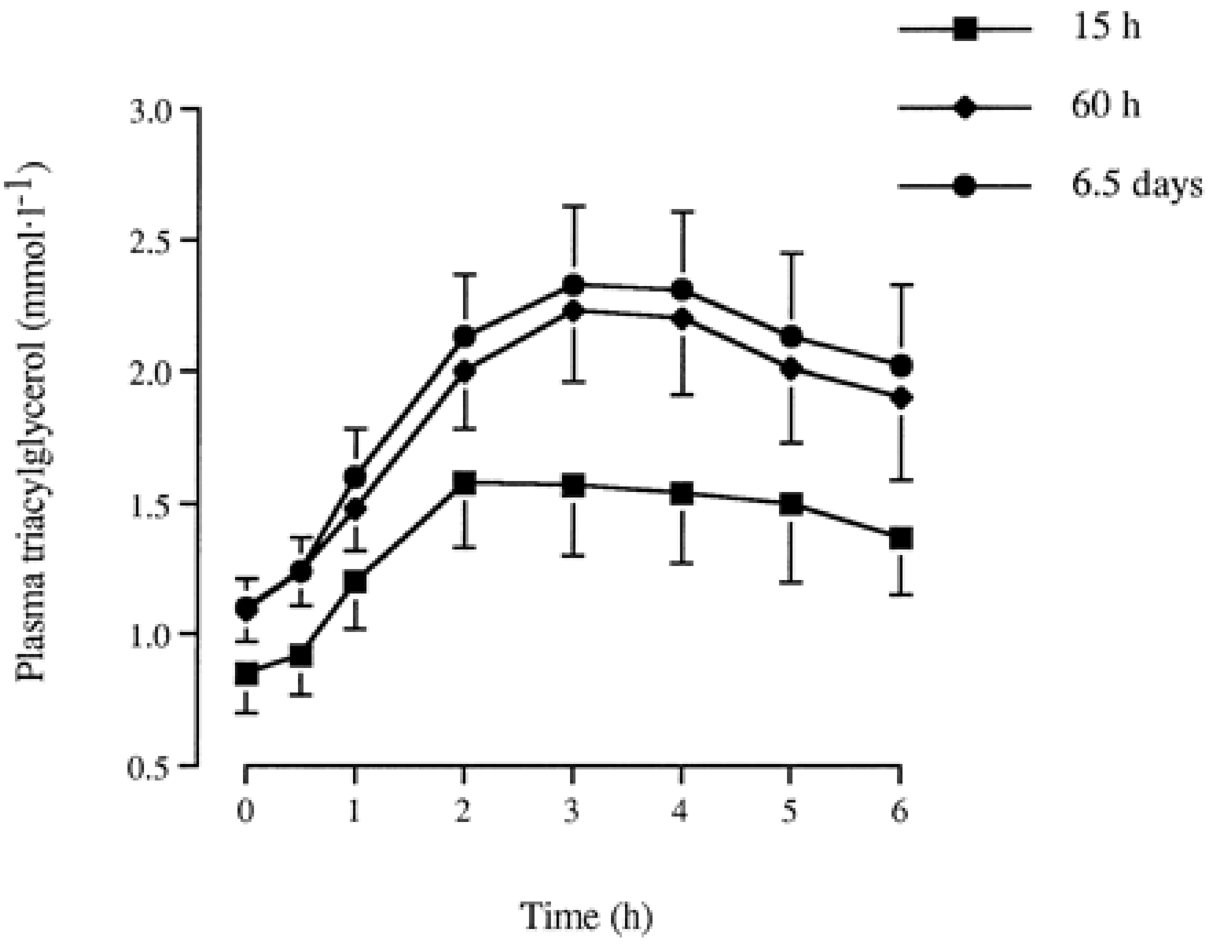


Merrill et al (1989), Arteriosclerosis, 9:217-223

Long-term training adaptation
or
acute effect of recent exercise?

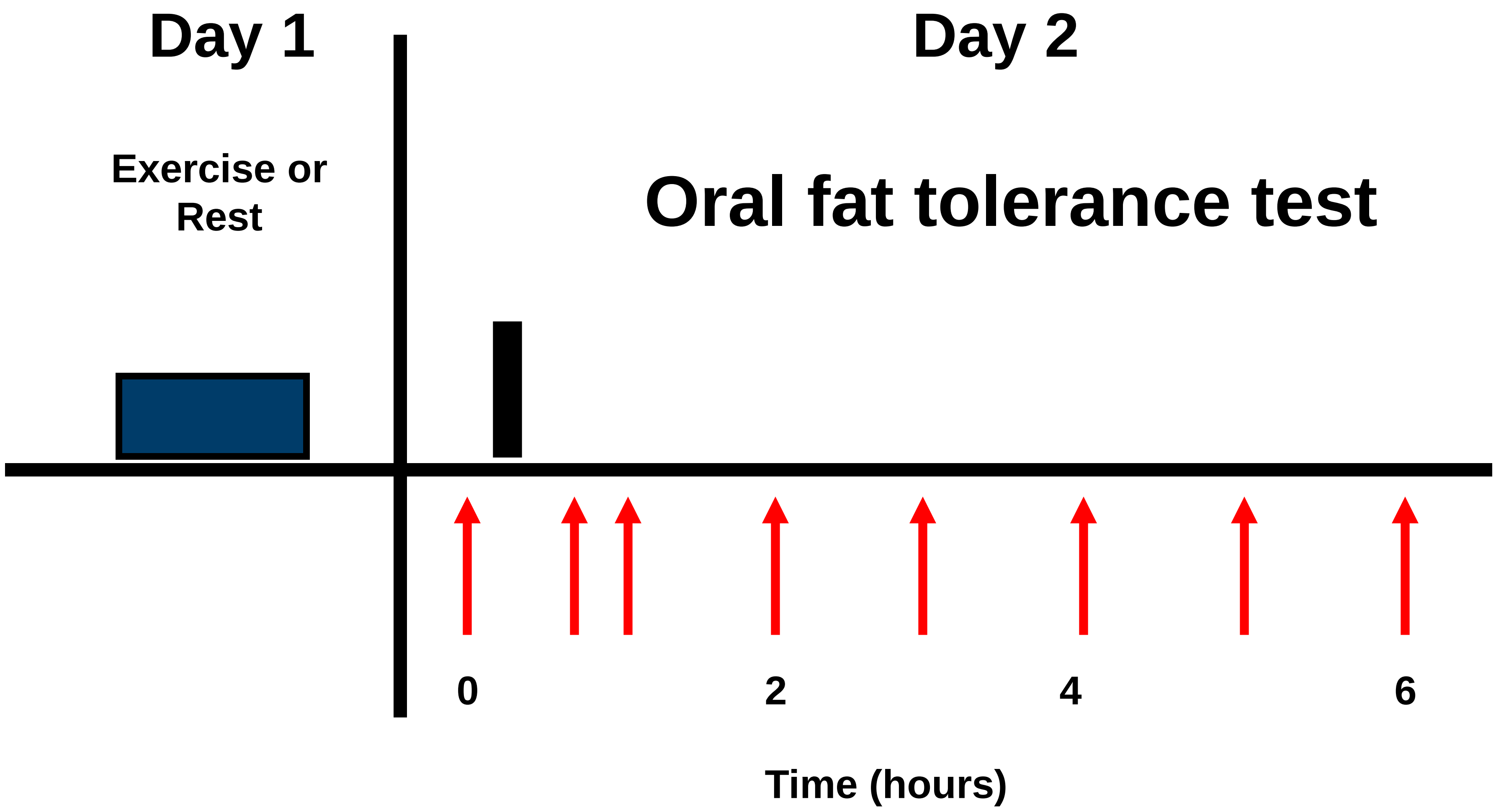


Detraining and postprandial lipaemia

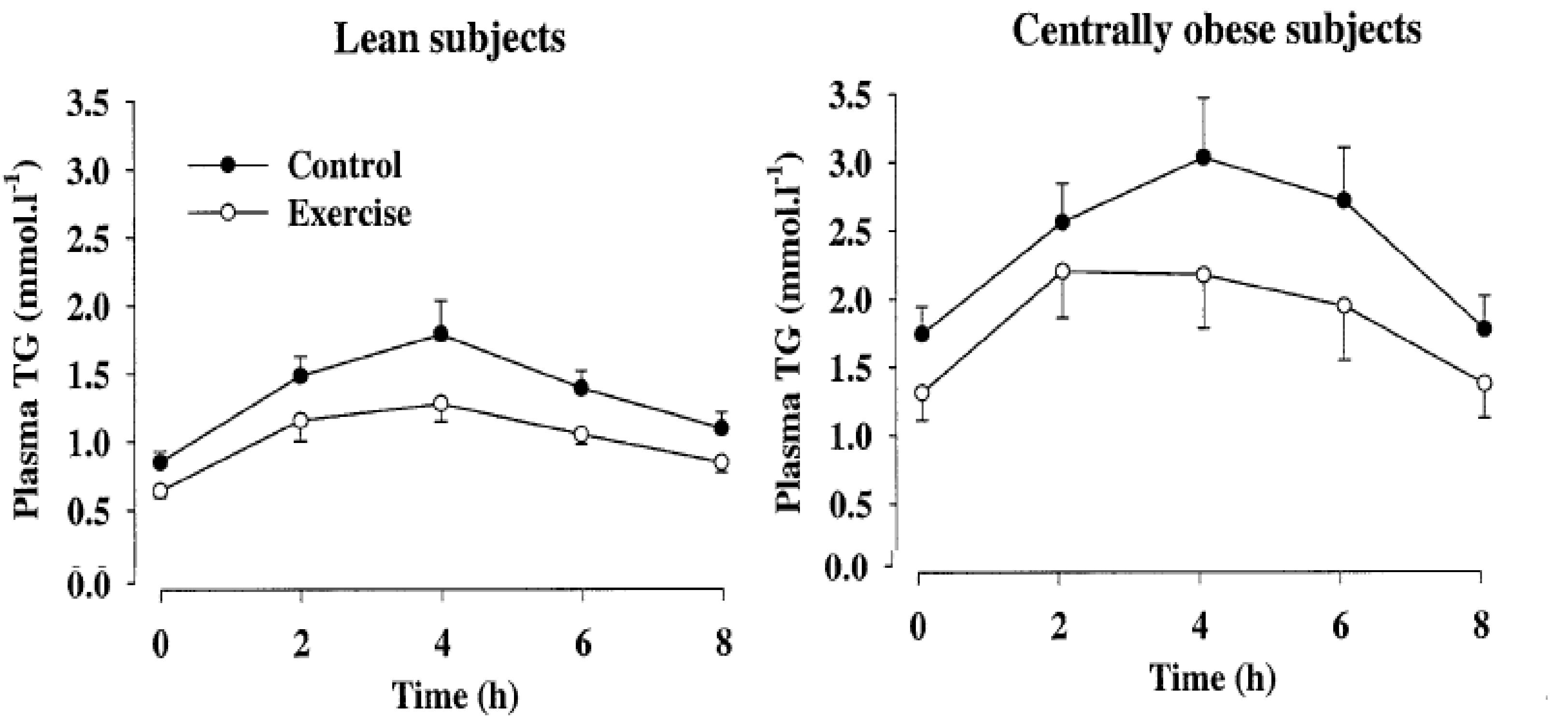


Hardman et al (1998), JAP, 84:1895-1901

Experimental protocol

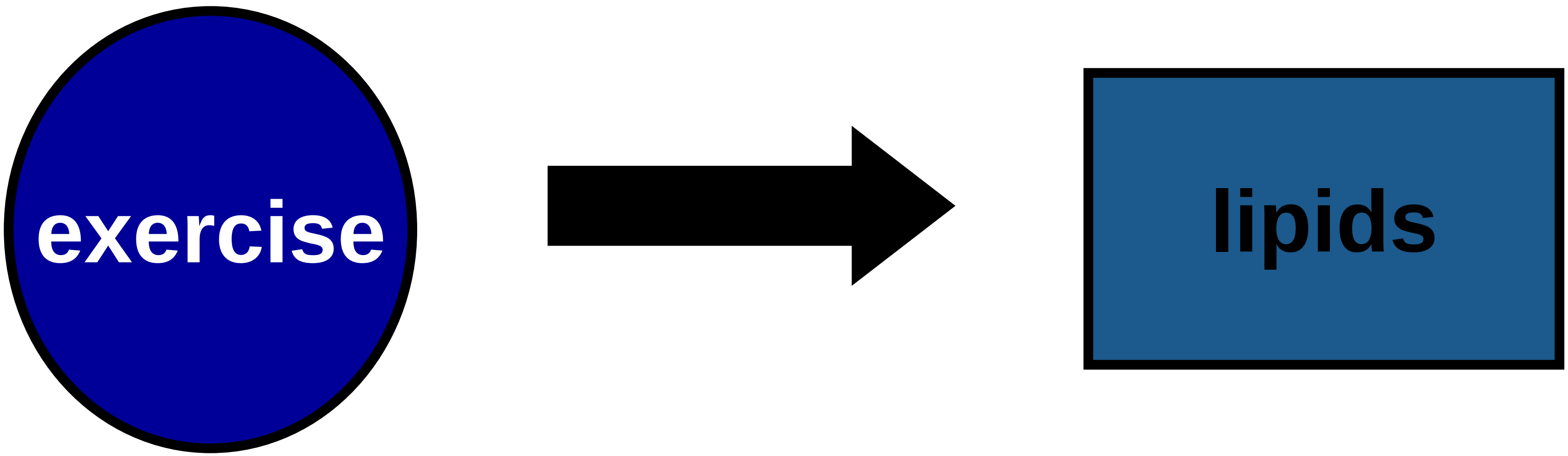


Moderate exercise and postprandial TG concentrations in lean and obese men

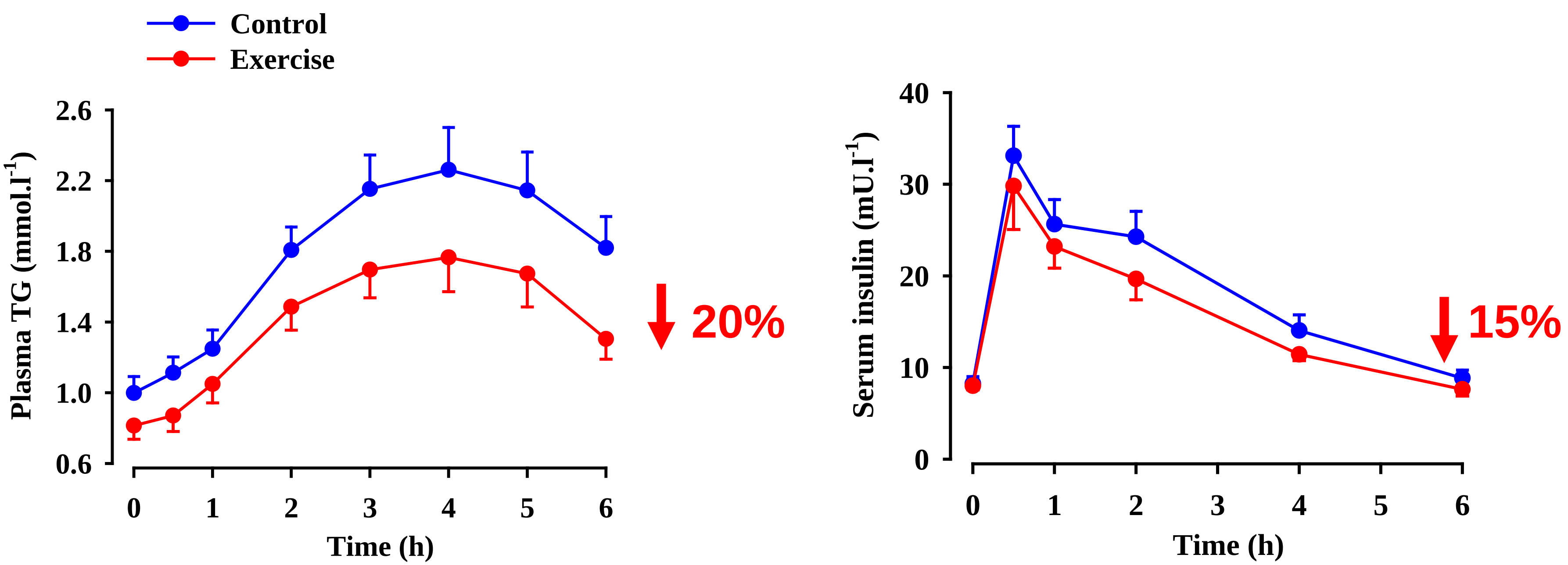


Gill et al (2004) J Am Coll Cardiol, 44:2375-82

Energy deficit?

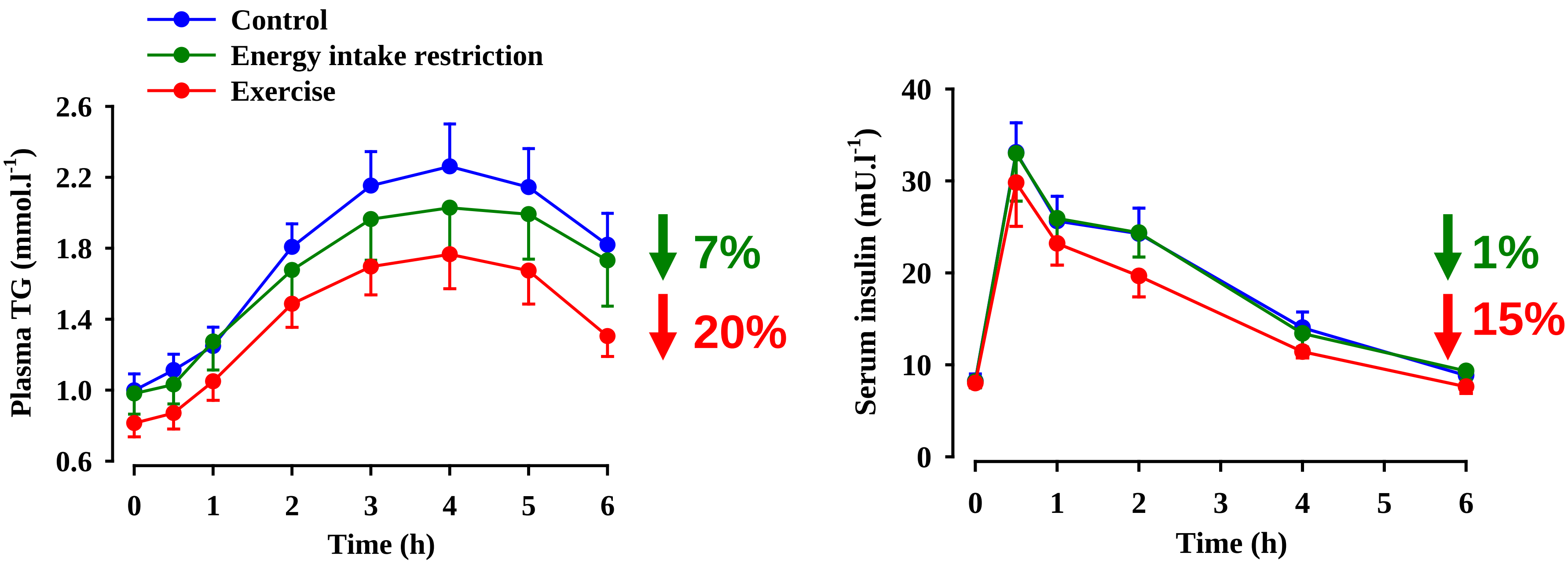


Exercise, energy intake restriction and postprandial metabolism



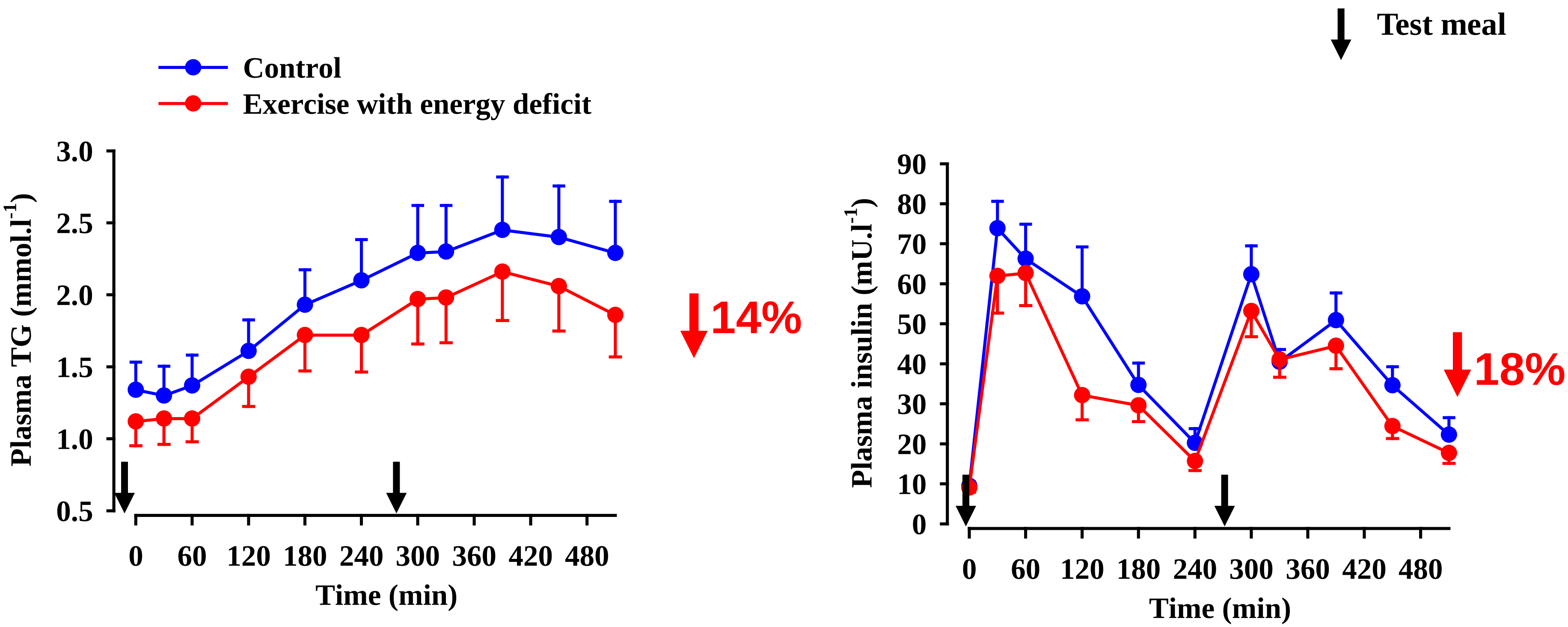
Gill et al (2000), Am J Clin Nutr, 71:465-471

Exercise, energy intake restriction and postprandial metabolism



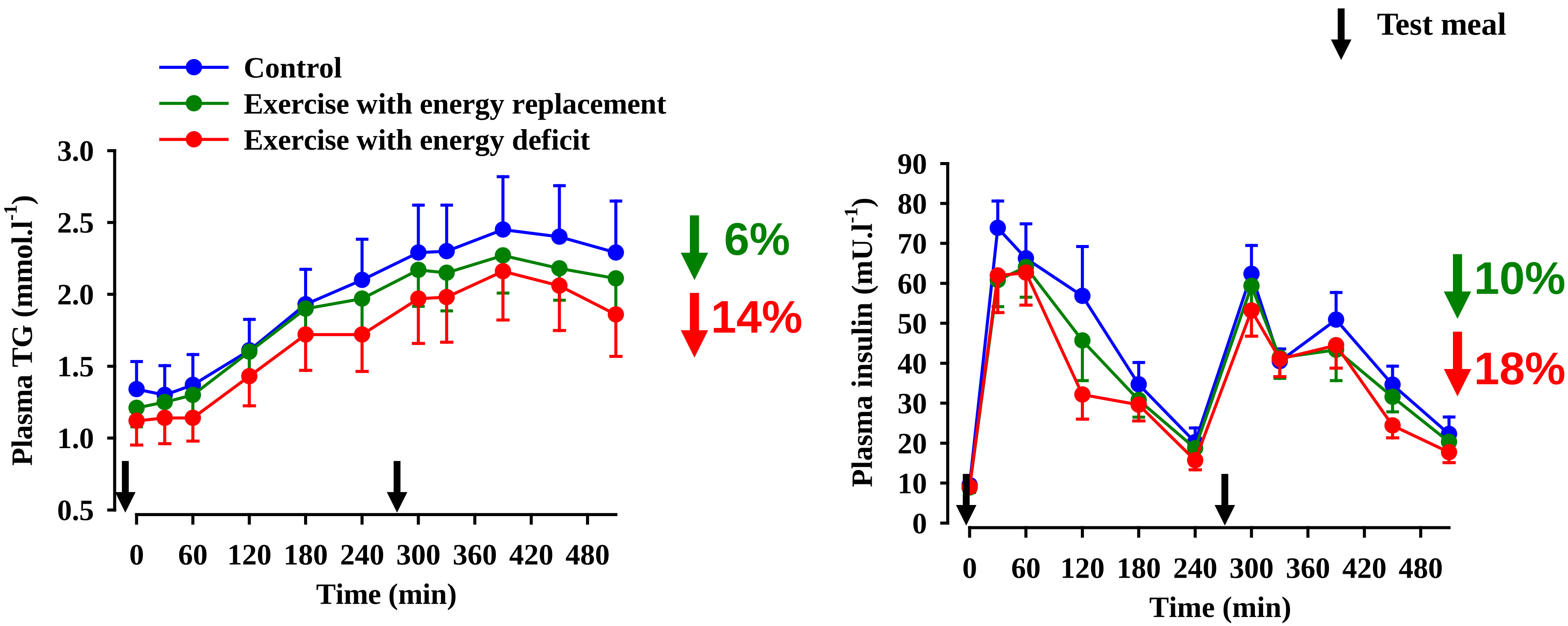
Gill et al (2000), Am J Clin Nutr, 71:465-471

Exercise with and without energy deficit and postprandial metabolism



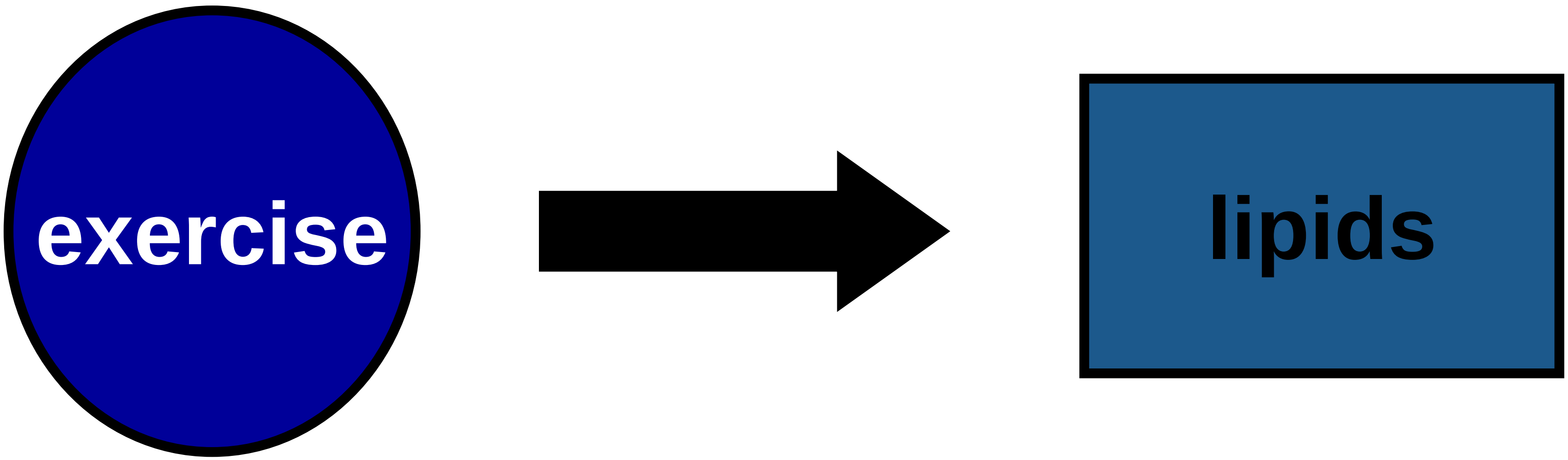
Burton et al (2008) Int J Obes, 32:481-489

Exercise with and without energy deficit and postprandial metabolism

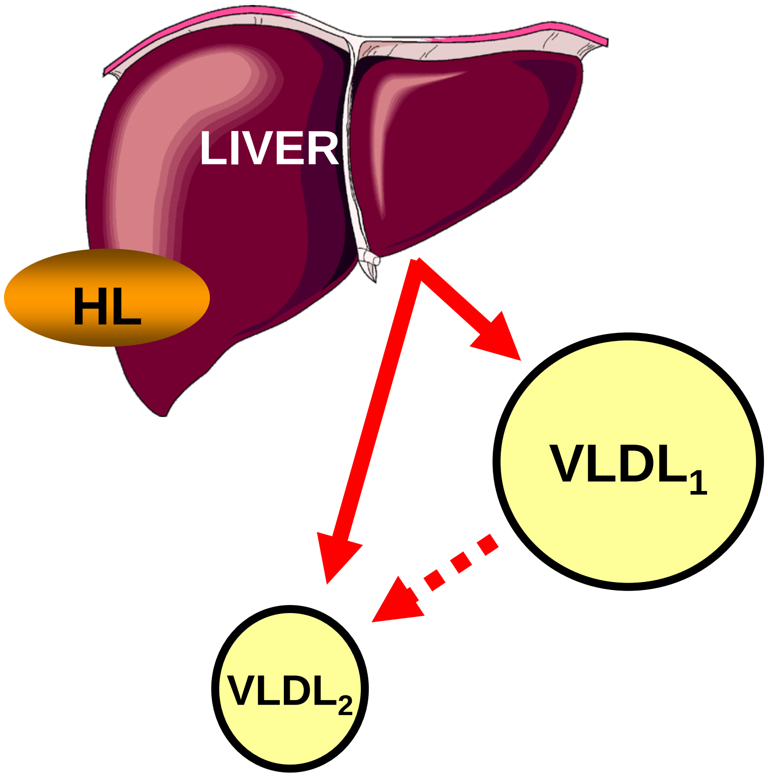


Burton et al (2008) Int J Obes, 32:481-489

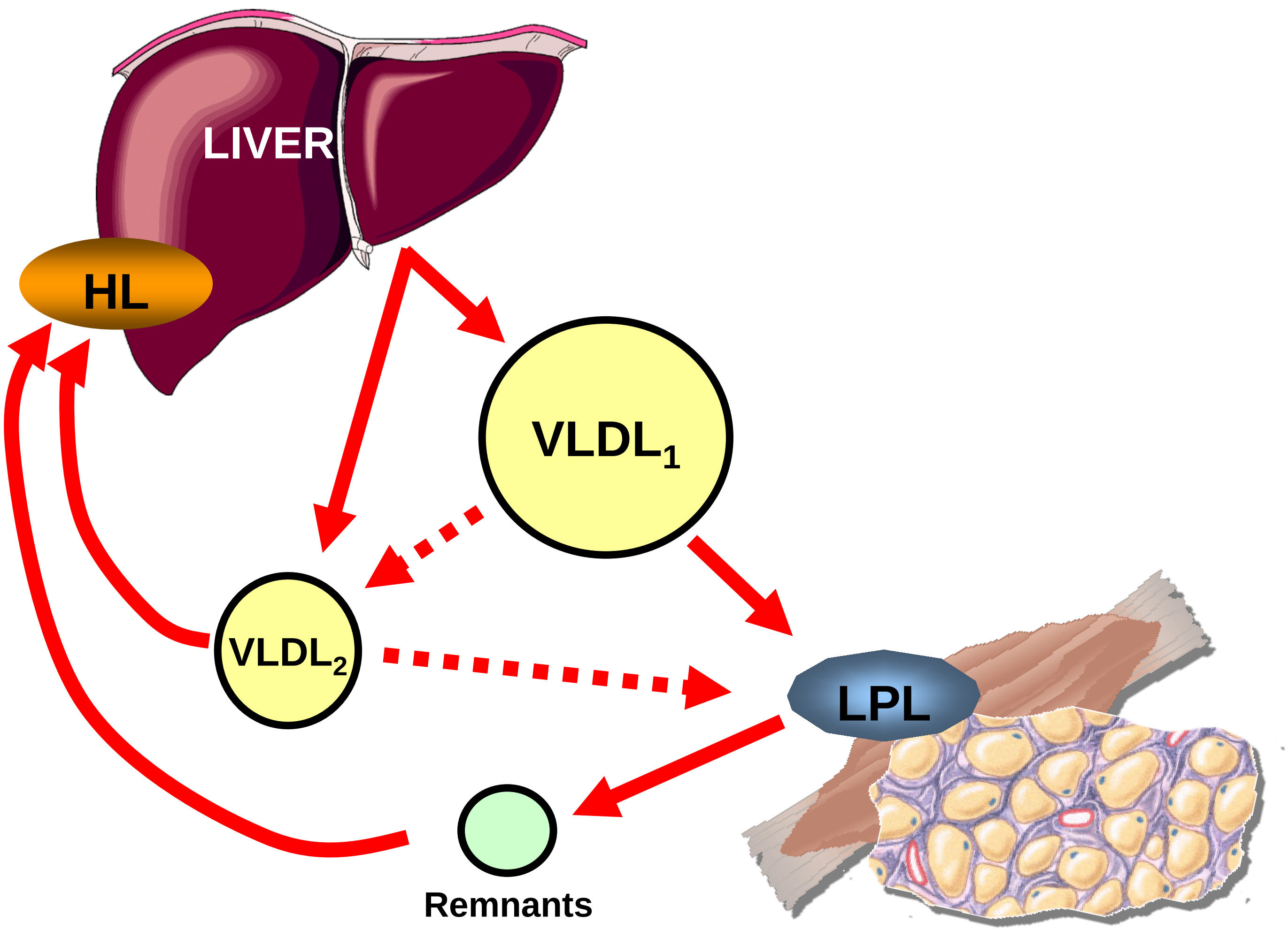
Mechanisms?



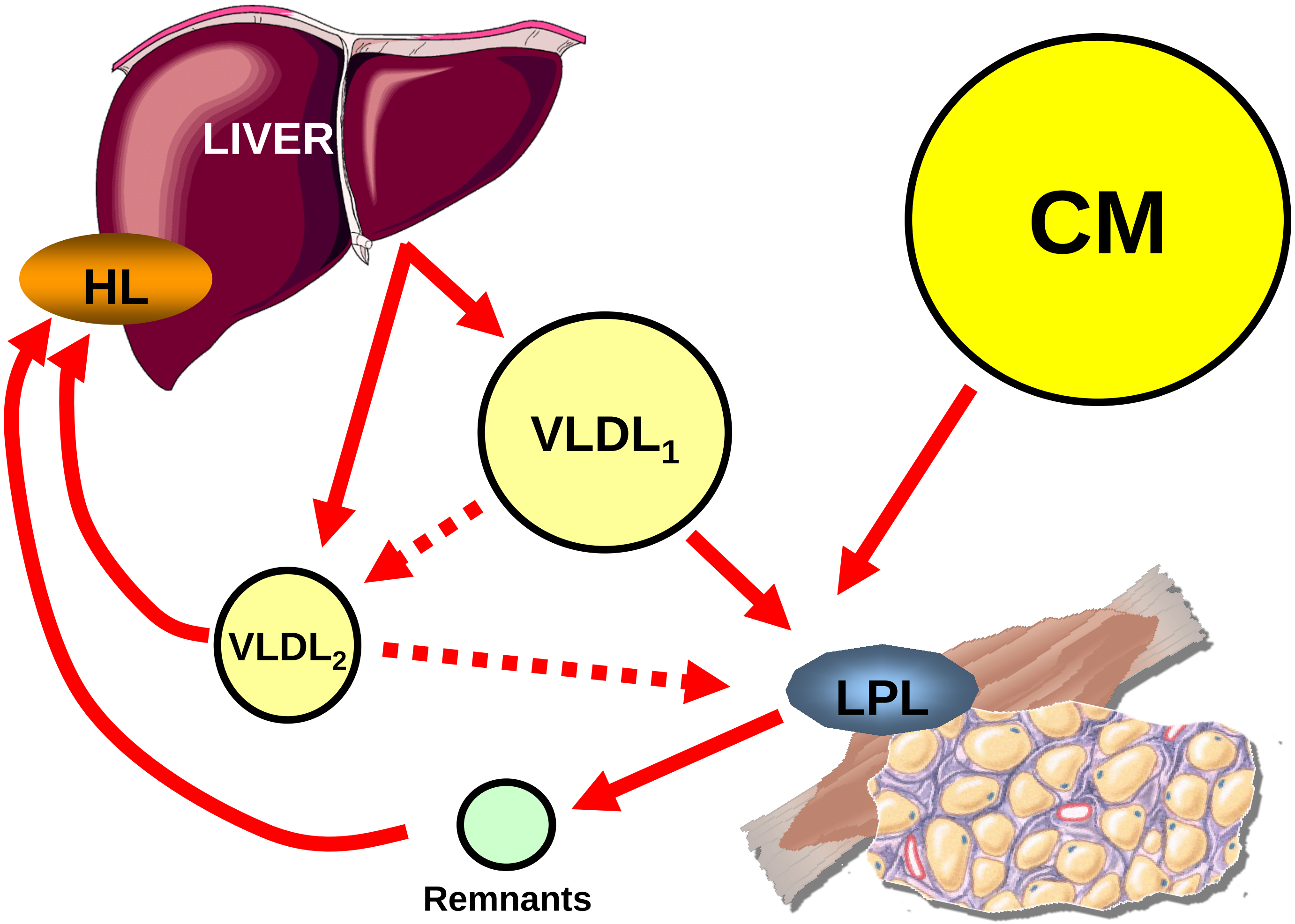
Triglyceride-rich lipoprotein metabolism



Triglyceride-rich lipoprotein metabolism

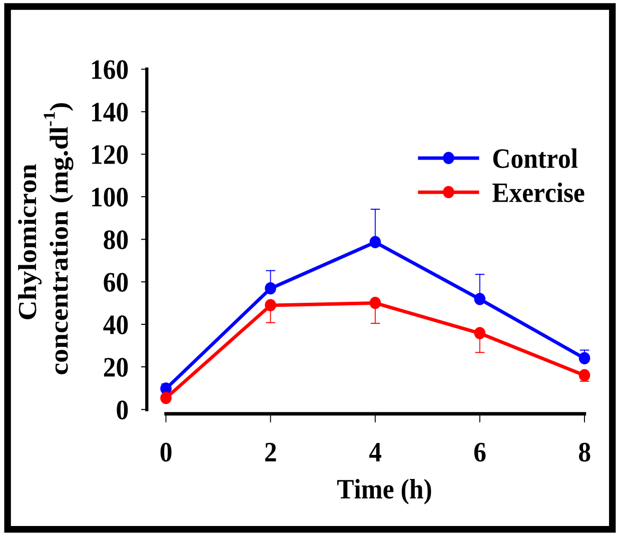


Triglyceride-rich lipoprotein metabolism

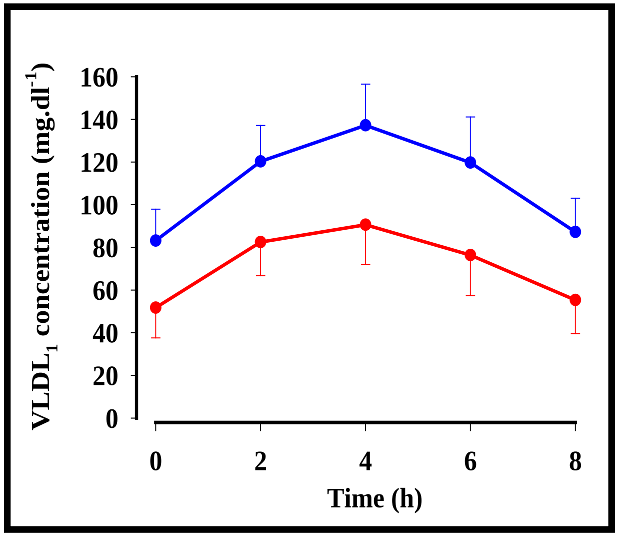


Moderate exercise and postprandial TG-rich lipoprotein concentrations

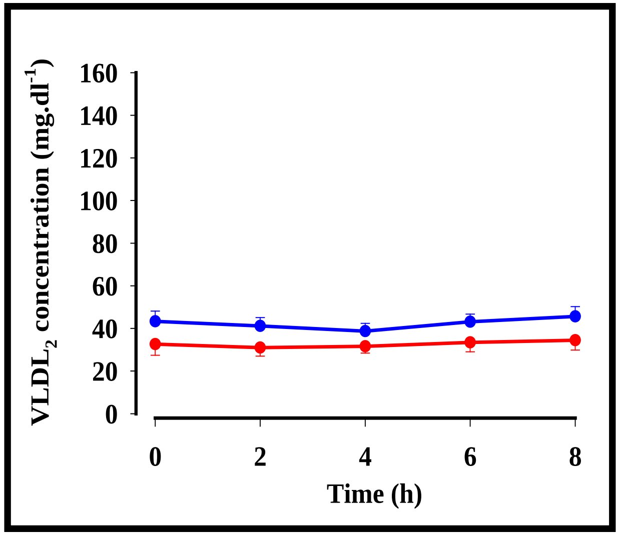
Chylomicrons



Large VLDL ($VLDL_1$)

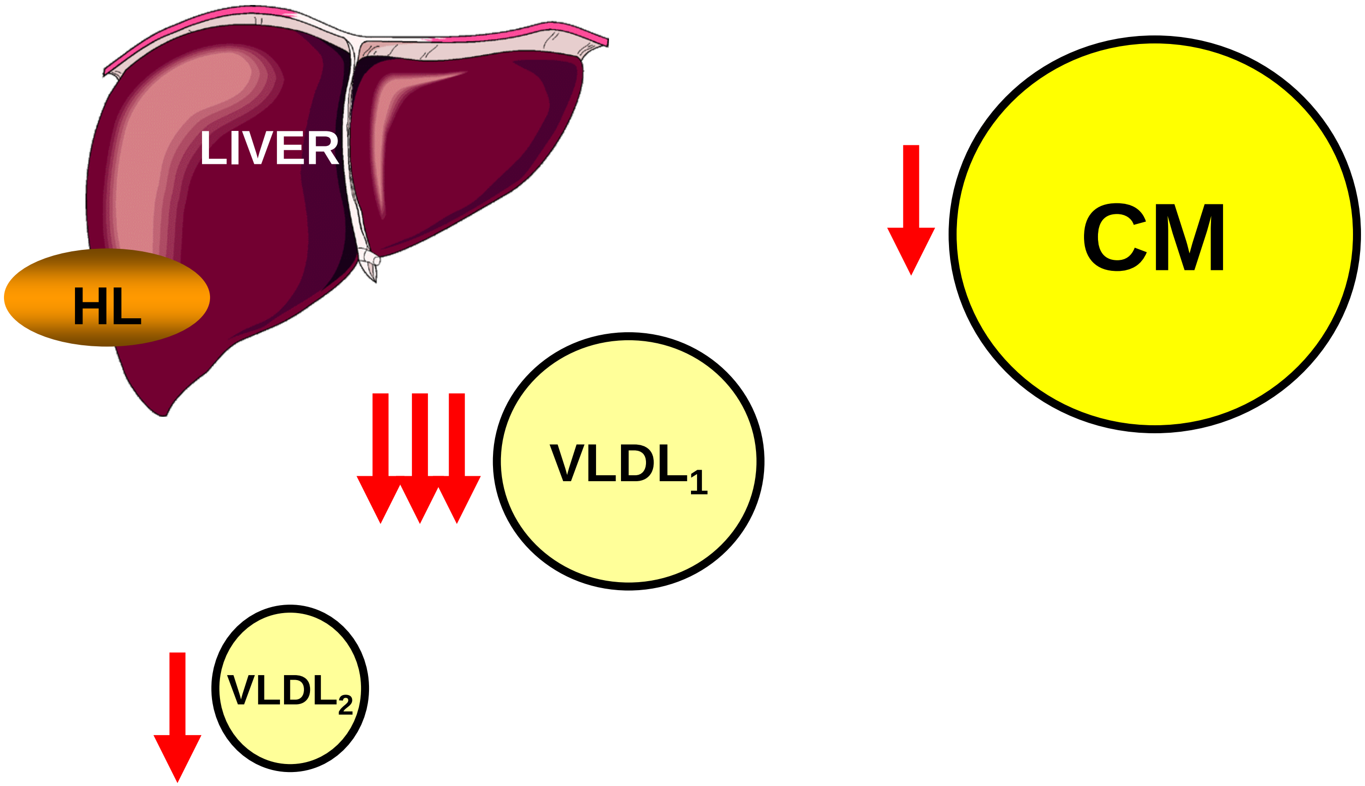


Small VLDL ($VLDL_2$)



Gill et al (2006) Atherosclerosis, 185:87-96

Effects of exercise on triglyceride-rich lipoprotein metabolism



Concentration of VLDL$_1$

Production of $VLDL_1$

Concentration of $VLDL_1$

University of Glasgow

↓ **Production of $VLDL_1$**

↓ **Concentration of $VLDL_1$**

↑ **Clearance of $VLDL_1$**

Journal of Lipid Research Volume 48, 2007

methods

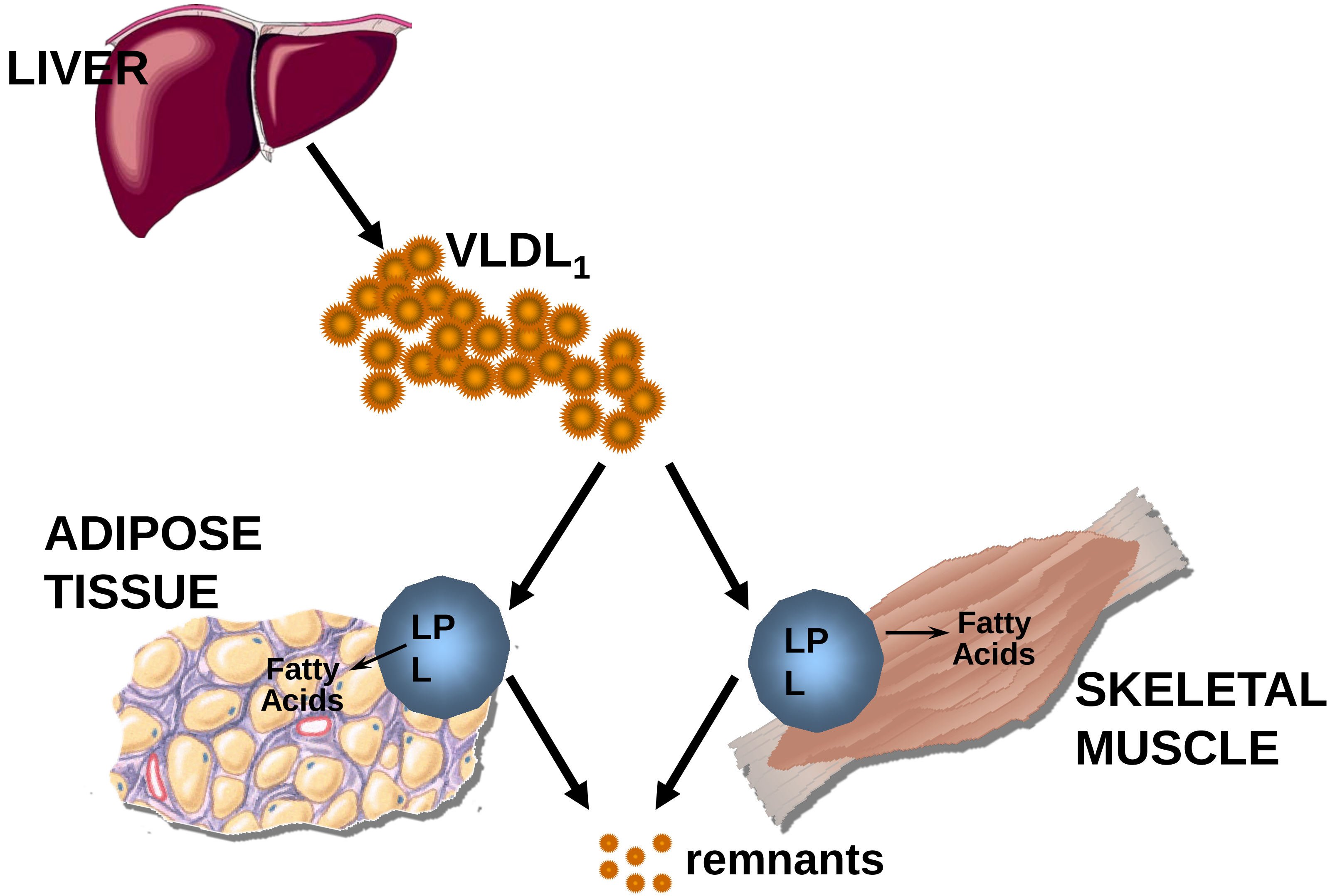
Development of a novel method to determine very low density lipoprotein kinetics

Iqbal A. R. Al-Shayji,*,† Jason M. R. Gill,[1,†] Josephine Cooney,* Samira Siddiqui,*,§ and Muriel J. Caslake*

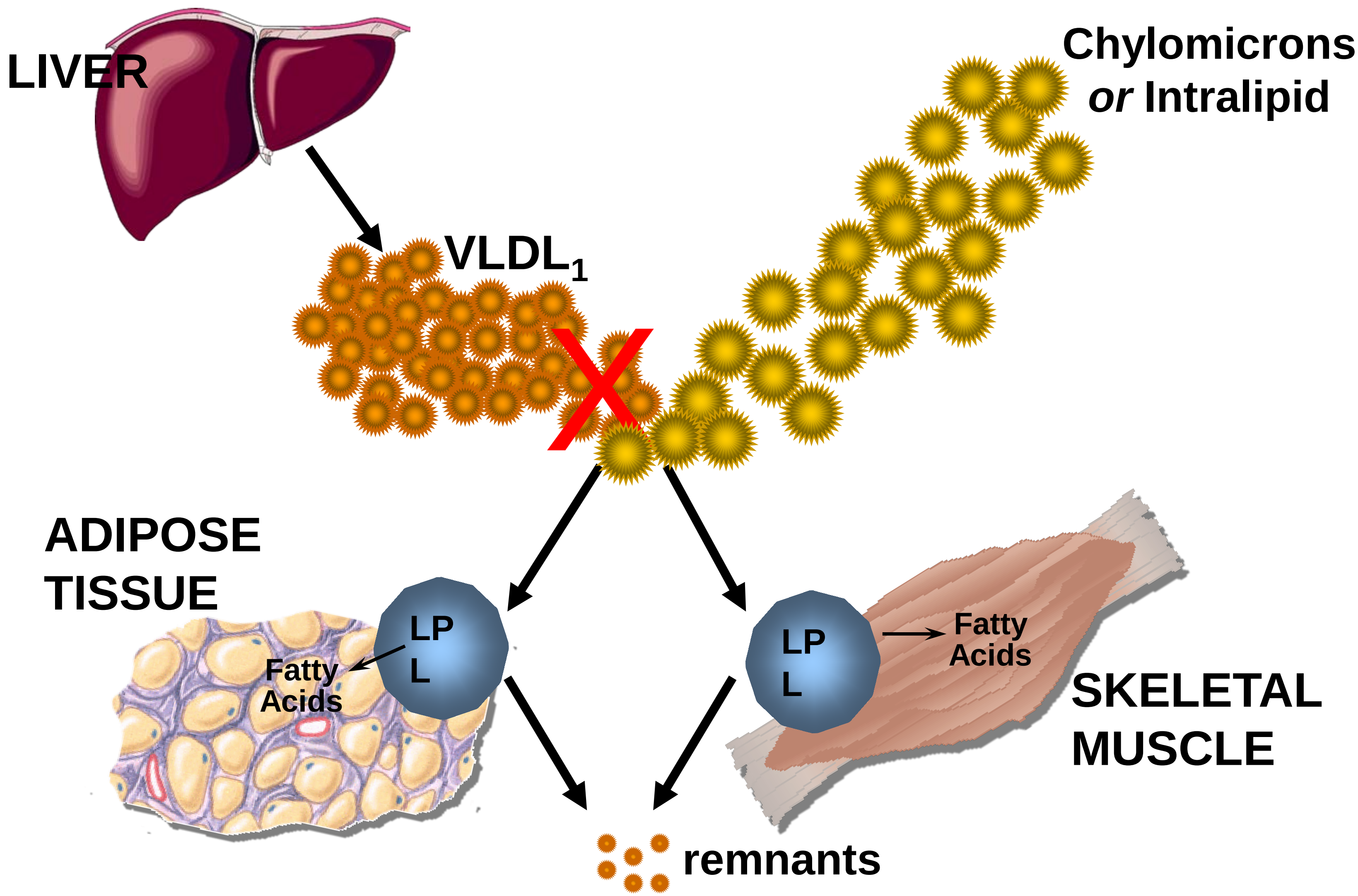
Department of Vascular Biochemistry,* and Institute of Diet, Exercise, and Lifestyle, Institute of Biomedical and Life Sciences,† University of Glasgow, Glasgow, United Kingdom; and Renal Unit,§ Glasgow Royal Infirmary, Glasgow, United Kingdom

In conclusion, we have developed a novel method to determine TRL kinetics. The Intralipid method provides a relatively straightforward and cost-effective way of determining $VLDL_1$-TG and $VLDL_1$-apoB production rates and the clearance rate of chylomicron-like particles that does not require specialized equipment, such as a mass spectrometer. We believe that this method will increase the scope for the study of TRL kinetics, particularly in circumstances in which issues related to funding or equipment availability preclude the use of more traditional isotopic tracer methods.

VLDL$_1$ Metabolism in the Fasted State



Effect of Chylomicrons (CM) & CM-like Particles on $VLDL_1$ Clearance



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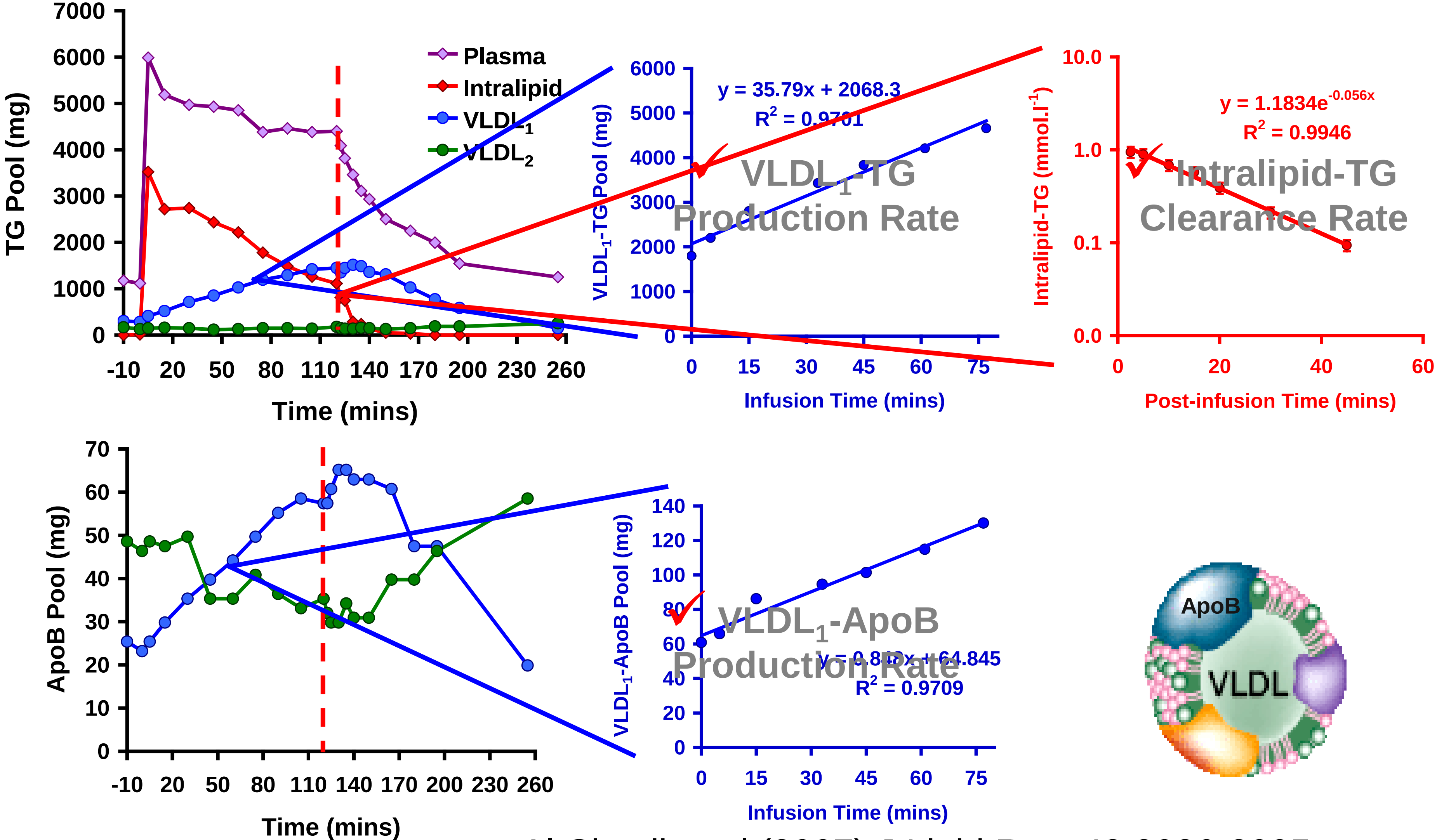
The ‘Intralipid Method’

- Bolus Intralipid dose: 0.1 $g.kg^{-1}$ body mass
- 0.1 $g.kg^{-1}.h^{-1}$ Intralipid infusion for 75 mins
- Two fasting baseline and multiple EDTA blood samples are drawn before, during and post-infusion
- Intralipid, $VLDL_1$ and $VLDL_2$ fractions are separated by density gradient ultracentrifugation.

Al-Shayji et al (2007) J Lipid Res, 48:2086-2095

Kinetic Data Obtained from the 'Intralipid Method'



Al-Shayji et al (2007) J Lipid Res, 48:2086-2095

University of Glasgow

Am J Physiol Endocrinol Metab 302: E349–E355, 2012.
First published November 15, 2011; doi:10.1152/ajpendo.00498.2011.

Effects of moderate exercise on $VLDL_1$ and Intralipid kinetics in overweight/obese middle-aged men

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Submitted 22 September 2011; accepted in final form 14 November 2011

Al-Shayji IA, Caslake MJ, Gill JM. Effects of moderate exercise on $VLDL_1$ and Intralipid kinetics in overweight/obese middle-aged men. *Am J Physiol Endocrinol Metab* 302: E349–E355, 2012. First published November 15, 2011; doi:10.1152/ajpendo.00498.2011.—Prior moderate exercise reduces plasma triglyceride (TG)-rich lipoprotein concentrations, mainly in the large very low-density lipoprotein ($VLDL_1$) fraction, but the mechanism responsible is unclear. We investigated the effects of brisk walking on TG-rich lipoprotein kinetics using a novel method. Twelve overweight/obese middle-aged men underwent two kinetic studies, involving infusion of Intralipid to block $VLDL_1$ catabolism, in random order. On the afternoon prior to infusion, subjects either walked on a treadmill for 2 h at ~50% maximal oxygen uptake or performed no exercise. Multiple blood samples were taken during and after infusion for separation of Intralipid (S_f 400) and $VLDL_1$ (S_f 60–400). $VLDL_1$-TG and -apoB production rates were calculated from their linear rises during infusion; fractional catabolic rates (FCR) were calculated by dividing linear rises by fasting concentrations. Intralipid-TG FCR was determined from the postinfusion exponential decay. Exercise reduced fasting $VLDL_1$-TG concentration by 30% (P = 0.007) and increased TG enrichment of $VLDL_1$ particles [30% decrease in cholesteryl ester

$VLDL_1$ (S_f 60–400) fraction (16), than in intestinally derived chylomicrons. As high concentrations of $VLDL_1$ are the major determinant of elevated plasma TG levels (27, 39), and $VLDL_1$ are the primary precursor particles for atherogenic small-dense LDL (34), reducing $VLDL_1$ concentration is likely to induce clinically important changes to the atherosclerotic risk profile. Exercise-induced reduction in circulating $VLDL_1$ could reflect reduced hepatic $VLDL_1$ production, increased lipoprotein lipase (LPL)-mediated $VLDL_1$ clearance, or a combination of the two. Stable-isotope kinetic studies have demonstrated that, in nonobese, recreationally active young men, moderate-intensity exercise sessions of 90–120 min duration can increase clearance of total VLDL-TG (29, 40) and decrease total hepatic VLDL-apolipoprotein B (apoB) production (29). However, these studies considered all VLDL as a single lipoprotein class, and lipoprotein kinetic studies have shown that VLDL is metabolically heterogeneous, with accumulating evidence demonstrating that both the production and catabolism of large TG-rich $VLDL_1$ (S_f 60–400) and smaller cholesterol-rich

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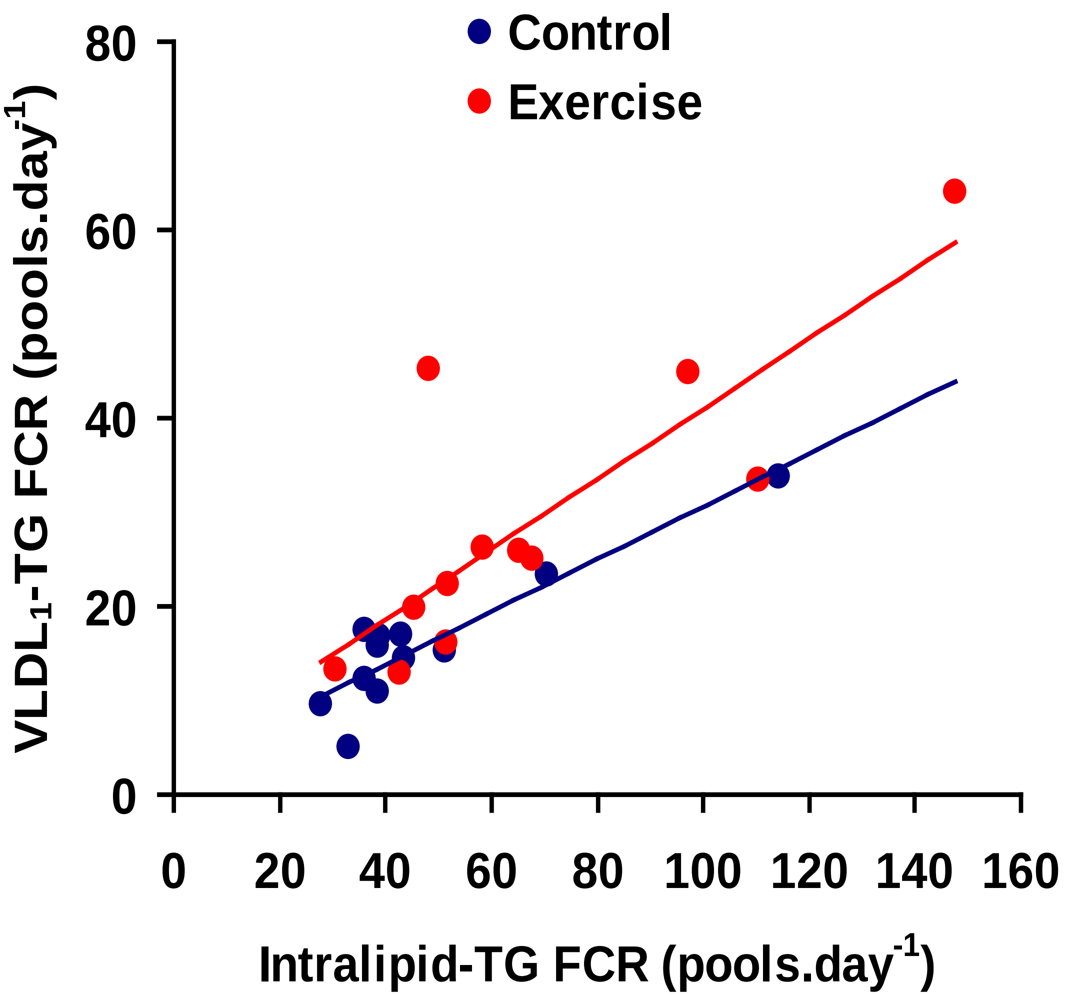
Effects of moderate exercise on TRL kinetics

	Control	Exercise	Change (%)
Fasting plasma TG (mmol/l)	1.54 ± 0.16	1.21 ± 0.15*	-21%
Fasting $VLDL_1$ concentration (mg/dl)	94.9 ± 14.1	62.9 ± 11.4*	-34%
$VLDL_1$-TG production rate (mg/h)	1272 ± 156	1432 ± 148	+13%
$VLDL_1$-apoB production rate (mg/h)	37.2 ± 7.4	41.5 ± 5.4	+12%
Intralipid-TG FCR (pools/d)	47.6 ± 6.8	68.1 ± 9.7*	+43%
$VLDL_1$-TG FCR (pools/d)	16.0 ± 2.1	29.1 ± 4.4*	+82%
$VLDL_1$-apoB FCR (pools/d)	10.4 ± 2.0	25.6 ± 5.1*	+146%

*$p < 0.05$ for Control vs Exercise

Al-Shayji *et al* (2012) Am J Physiol 302:E349-E355

Effects of moderate exercise on TRL kinetics



Exercise
$y = 0.37x + 3.69$
$r = 0.82$, $p = 0.001$

Control
$y = 0.28x + 2.68$
$r = 0.91$, $p < 0.0005$

Exercise increases relative affinity for $VLDL_1$ clearance compared to chylomicron-like particle clearance

Al-Shayji *et al* (2012) Am J Physiol 302:E349-E355

University of Glasgow

JCEM THE JOURNAL OF CLINICAL ENDOCRINOLOGY & METABOLISM

ORIGINAL ARTICLE

Moderate exercise increases affinity of large very low density lipoproteins for hydrolysis by lipoprotein lipase

Khloud Ghafouri, Josephine Cooney, Dorothy K. Bedford, John Wilson, Muriel J. Caslake*, Jason M.R. Gill*

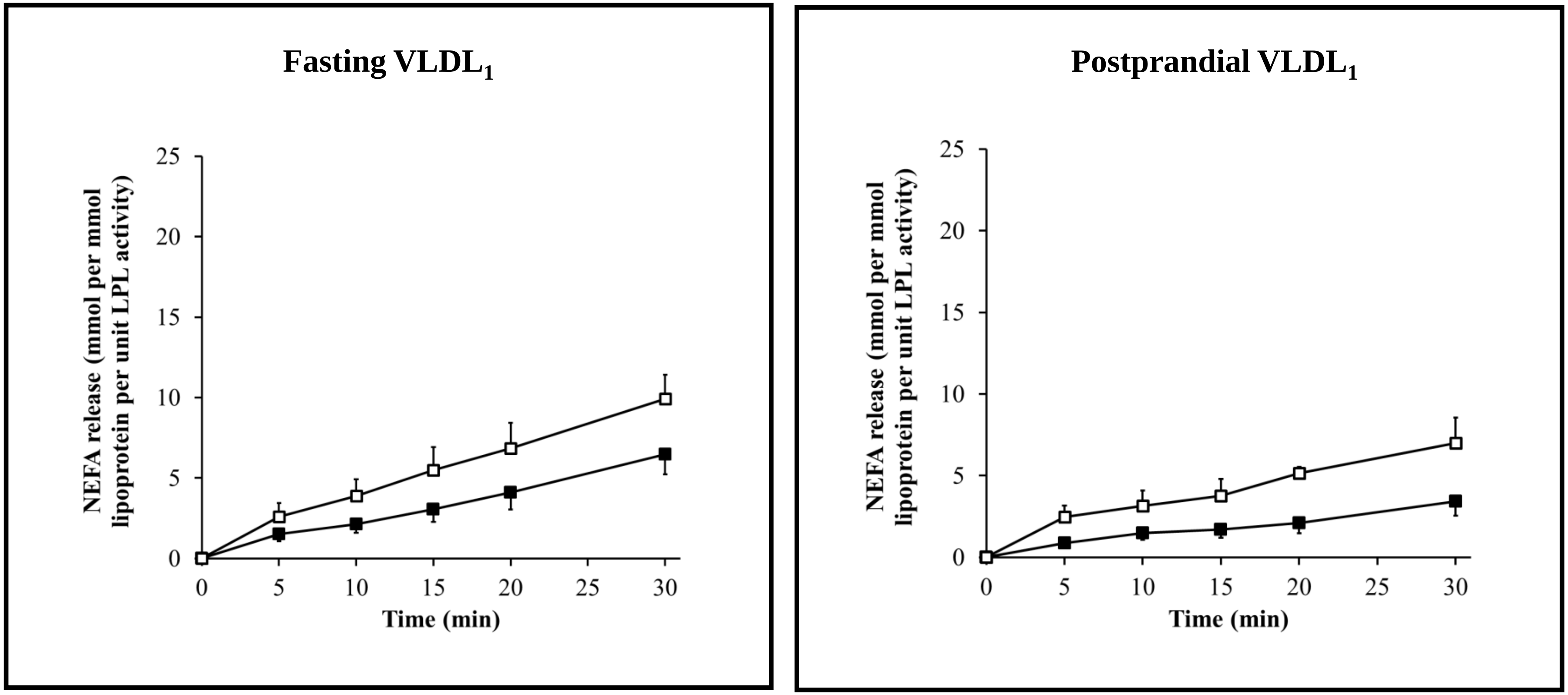
Institute of Cardiovascular and Medical Sciences, College of Medical, Veterinary and Life Sciences, University of Glasgow, Glasgow, U.K.

Context: Postprandial triglyceride (TG) concentration is independently associated with cardiovascular disease risk. Exercise reduces postprandial TG concentrations but the mechanisms responsible are unclear.

Objective: To determine the effects of exercise on affinity of chylomicrons, large very low density lipoproteins ($VLDL_1$) and smaller VLDL ($VLDL_2$) for lipoprotein lipase (LPL) mediated TG hydrolysis.

Ghafouri *et al* (2015) J Clin Endocrinol Metab 100:2205-13

Effects of moderate exercise on affinity of TRL for LPL



Ghafouri *et al* (2015) J Clin Endocrinol Metab 100:2205-13

Effects of moderate exercise on affinity of TRL for LPL

Table 3. Lipoprotein Affinity for LPL

	NEFA release (mmol·min^{-1} per mmol lipoprotein per unit LPL activity)					
	Fasting (0 min)			Postprandial (240 min)		
	Control	Exercise	p-value	Control	Exercise	p-value
Chylomicrons				1.25 (0.94 to 1.66)	1.52 (0.98 to 2.34)	0.53*
$VLDL_1$	0.16 (0.09 to 0.29)	0.35 (0.24 to 0.52)	0.018*	0.08 (0.03 to 0.19)	0.25 (0.15 to 0.42)	0.002*
$VLDL_2$	0.013 (0.004 to 0.044)	0.018 (0.007 to 0.049)	0.60	0.021 (0.006 to 0.070)	0.013 (0.004 to 0.048)	0.34

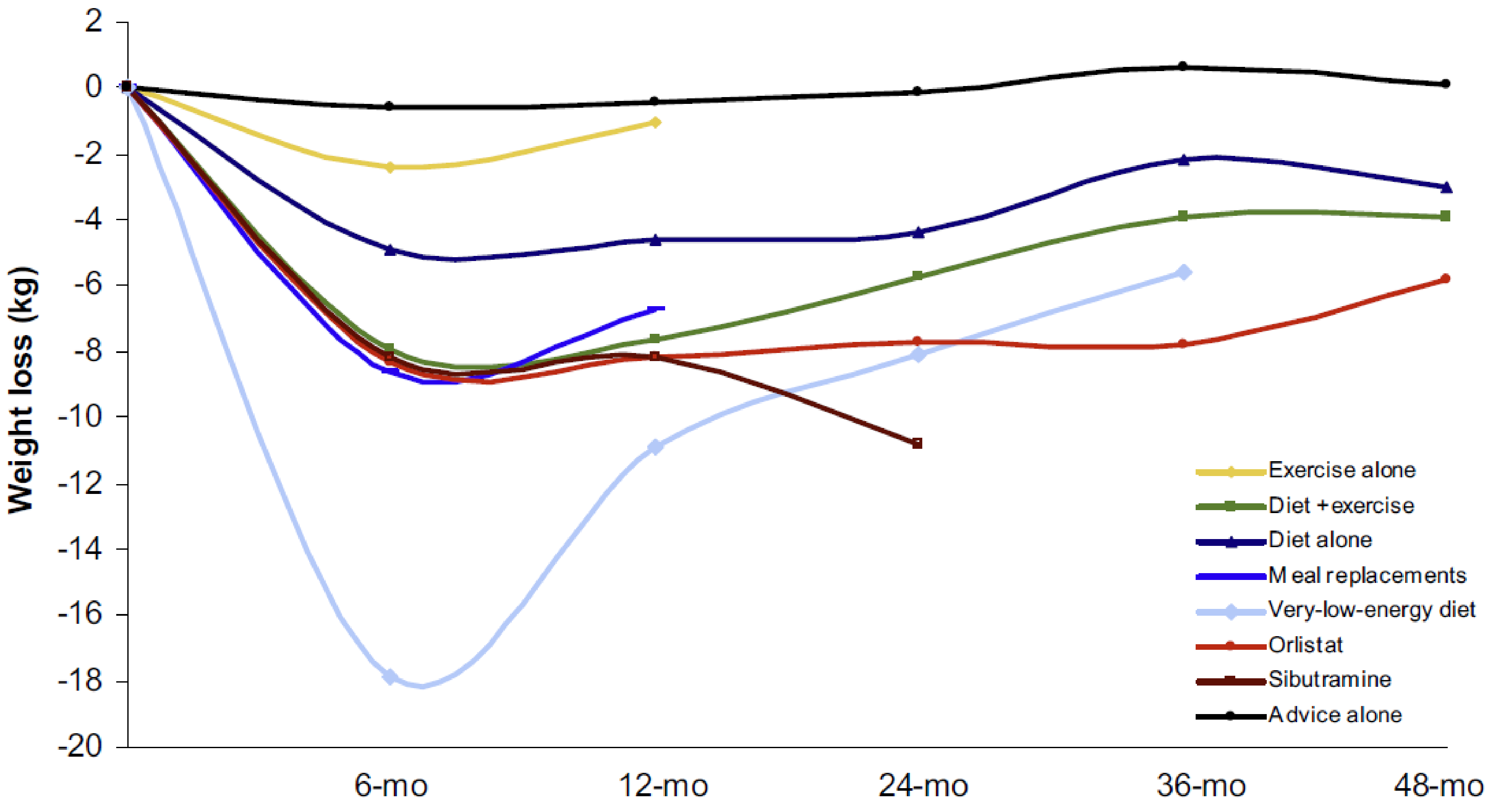
Values are mean ± SEM, *n* = 10. *Statistical analysis performed on log-transformed data, and values are geometric mean (95% confidence interval)

Ghafouri *et al* (2015) J Clin Endocrinol Metab 100:2205-13

University of Glasgow

Physical activity, dietary intake and energy balance

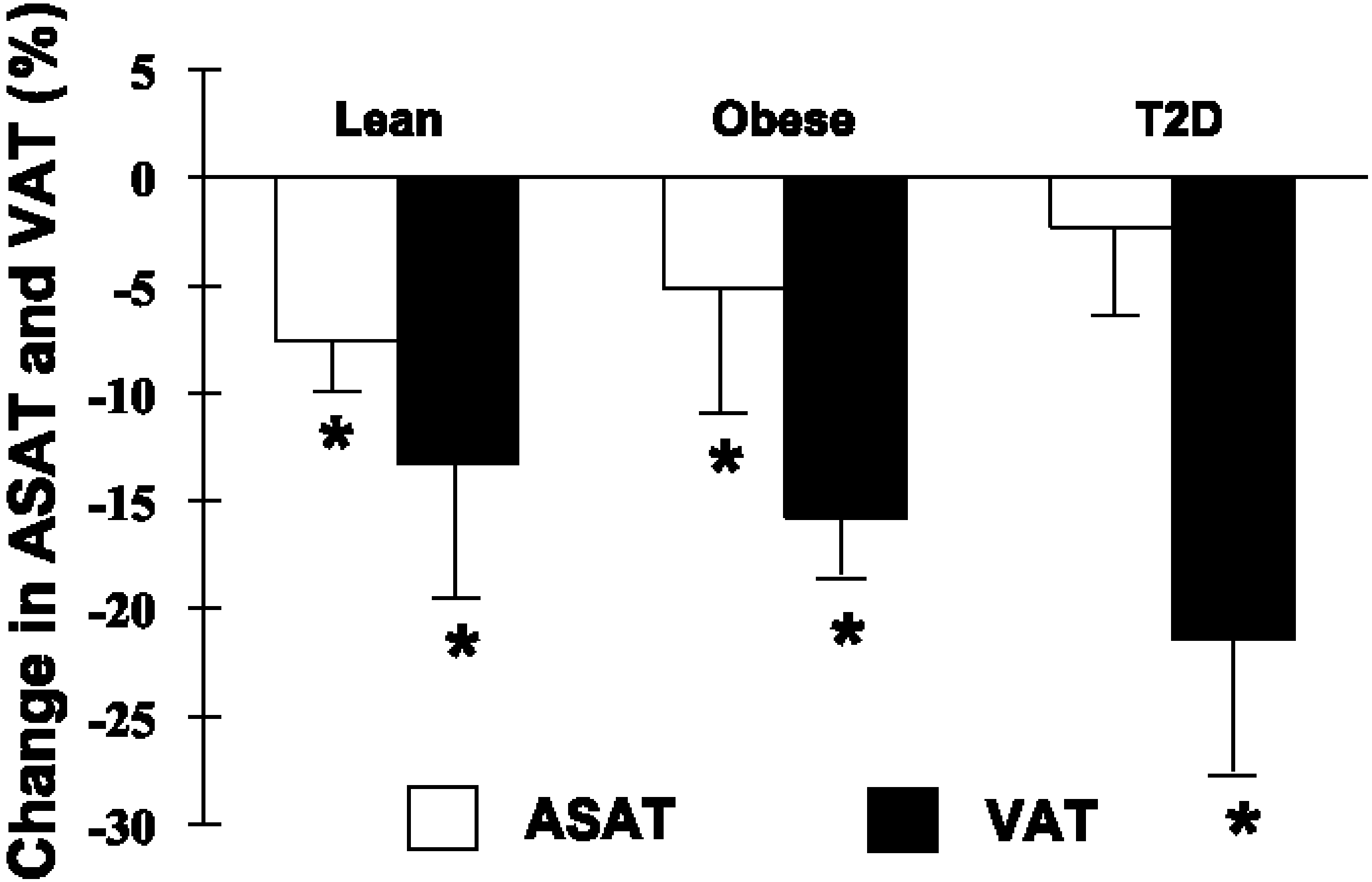
Weight loss outcomes in clinical trials: Systematic review and meta-analysis



80 studies, n = 26,455
(18,199 completers)

Franz et al (2007) J Am Diet Assoc.*107:1755-1767*

Effects of exercise training, without weight loss, on body fat



Lee et al (2005) J Appl Physiol 99:1220-1225

60 min moderate exercise, 5 x per week for 13 weeks

The substrate balance equation

Fat intake
CHO intake
Protein intake

Fat expenditure
CHO expenditure
Protein expenditure

Fat balance
CHO balance
Protein balance

Fat oxidation and weight gain in Pima Indians

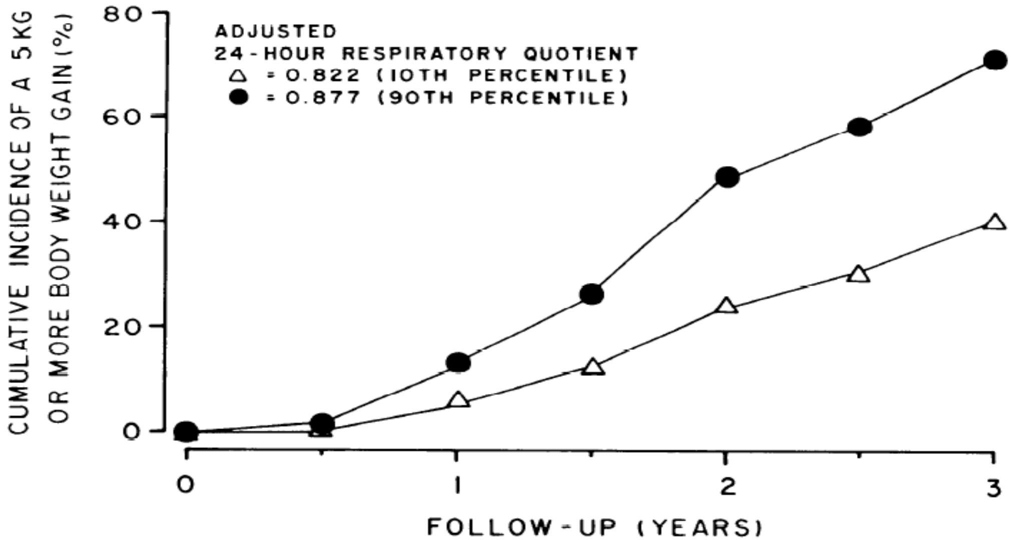
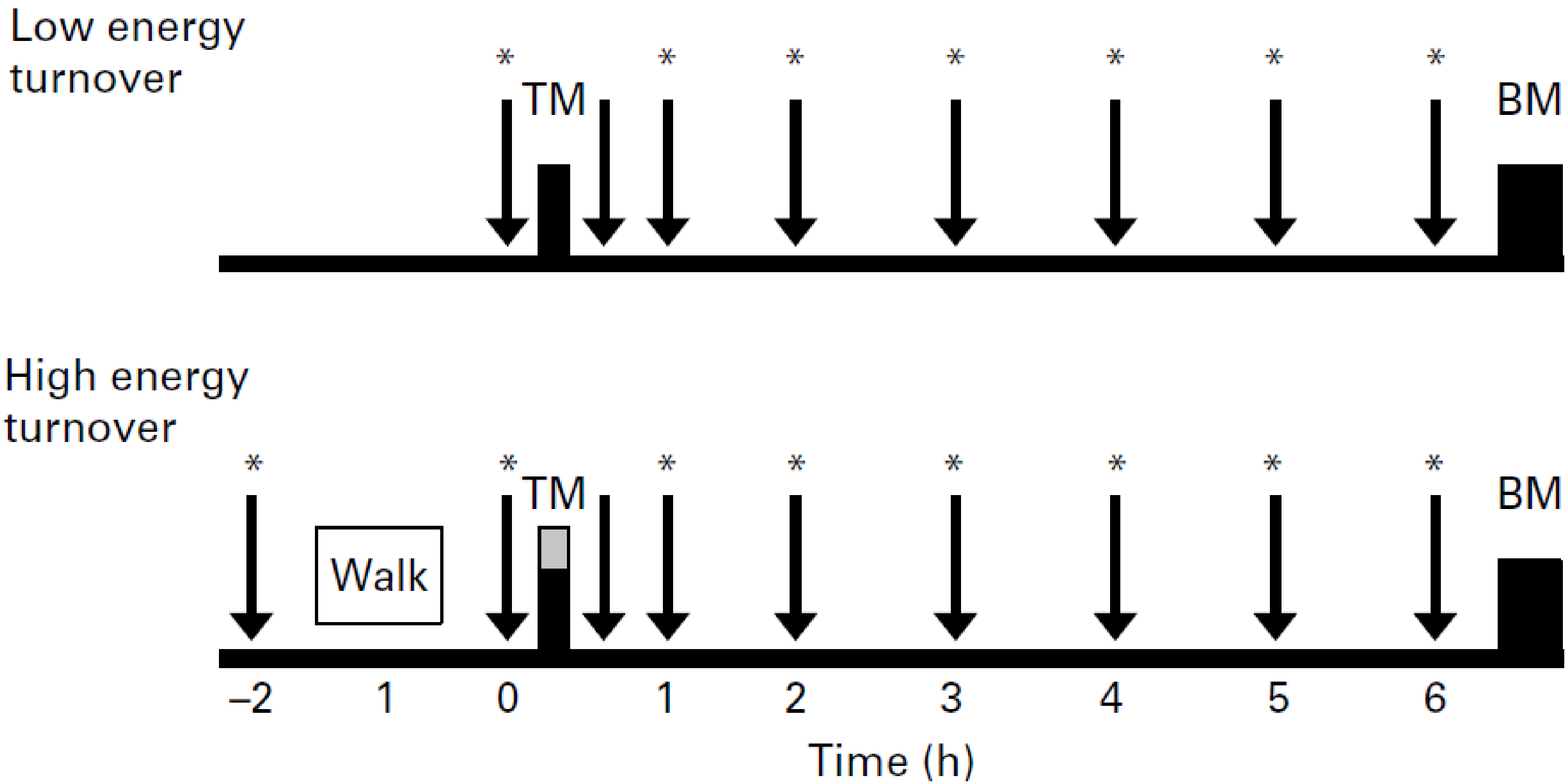


FIG. 4. Cumulative incidence of 5 kg body wt gain or more at 10th and 90th percentile of adjusted 24-h respiratory quotient (RQ; 0.822 and 0.877, respectively) measured in 111 subjects on whom follow-up measurements were available. No. of subjects studied at each time interval was 109 after 6 mo, 95 after 1 yr, 79 after 1.5 yr, 57 after 2 yr, 43 after 2.5 yr, and 18 after 3 yr. Cumulative incidence was calculated by proportional-hazards model adjusting 24-h RQ for differences in rate of body wt change on metabolic ward, acute energy balance, percent body fat, and sex and controlling for energy expenditure adjusted for fat-free mass and fat mass. With outcome defined as a weight gain of 5 kg, ratio of hazard rates for a person at 90th percentile of adjusted RQ compared with one at 10th percentile was 2.5 (95% confidence interval 1.3–4.9).

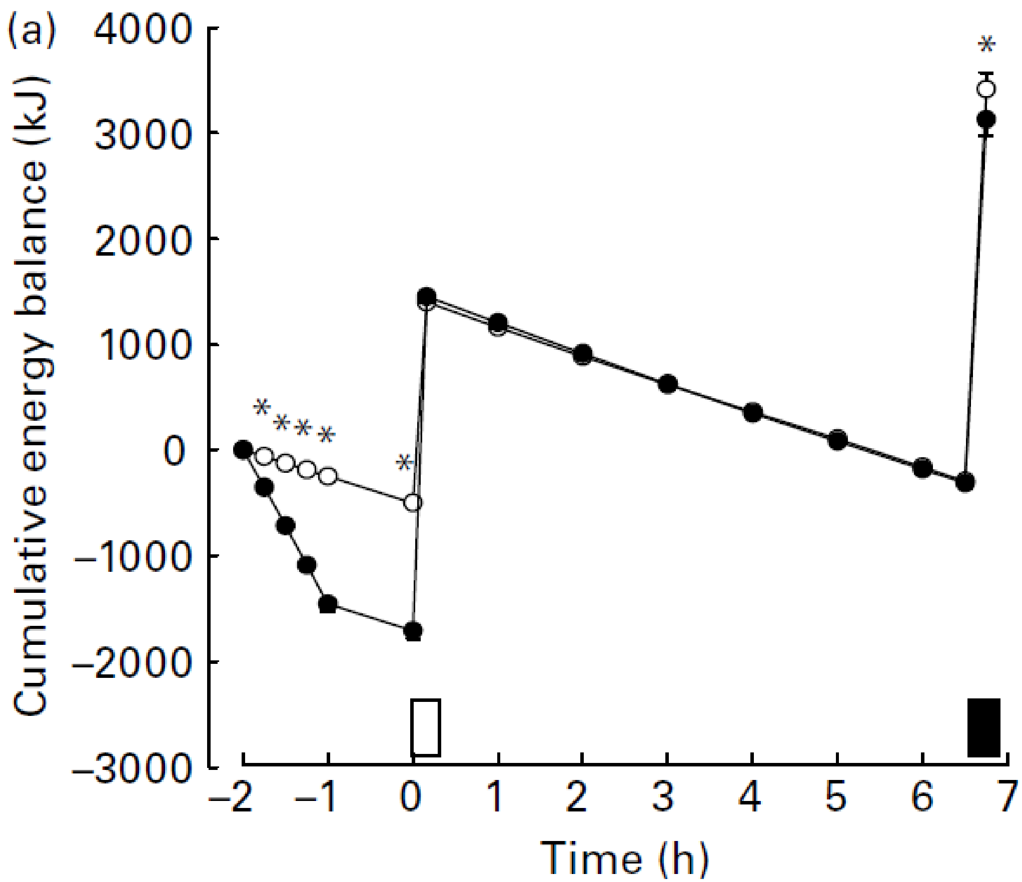
Zurlo et al (1990) Am J Physiol, 259:E650-E657

Substrate metabolism and feeding behaviour under high and low energy turnover conditions



Burton et al (2010) Br J Nutr 104:1249-1259

Substrate metabolism and feeding behaviour under high and low energy turnover conditions



Burton et al (2010) Br J Nutr 104:1249-1259

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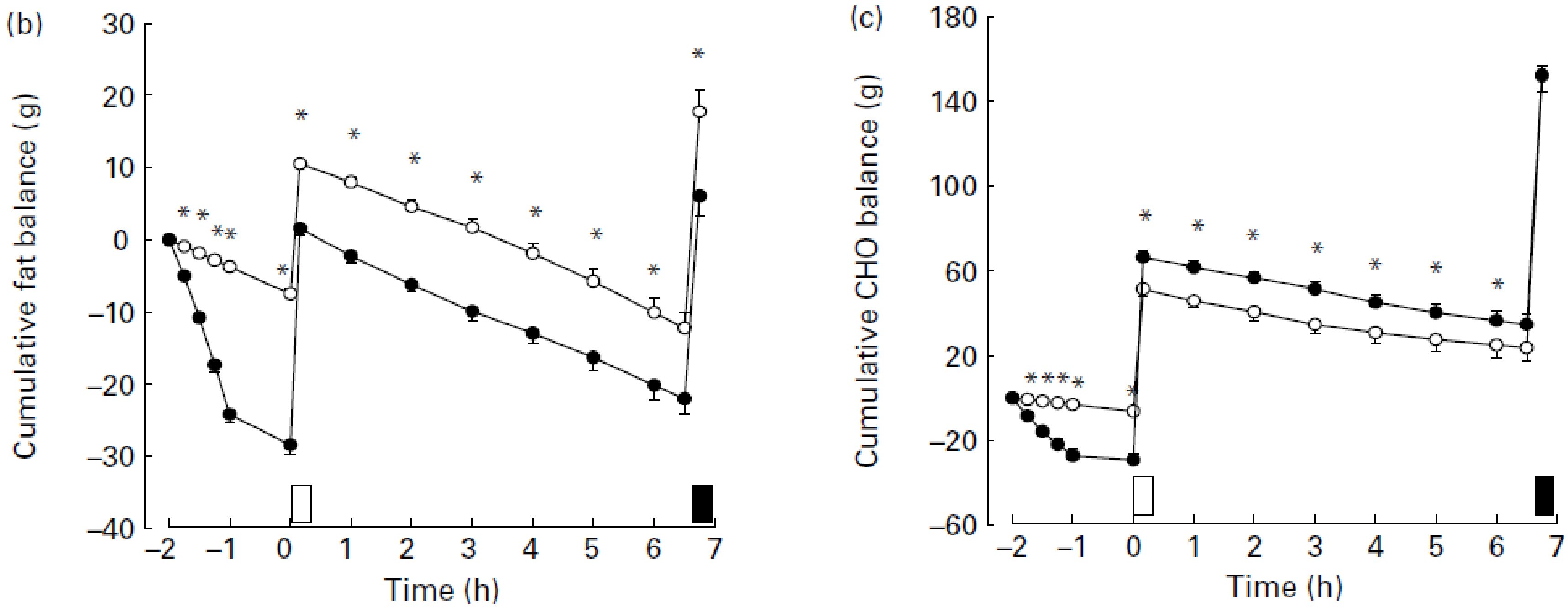
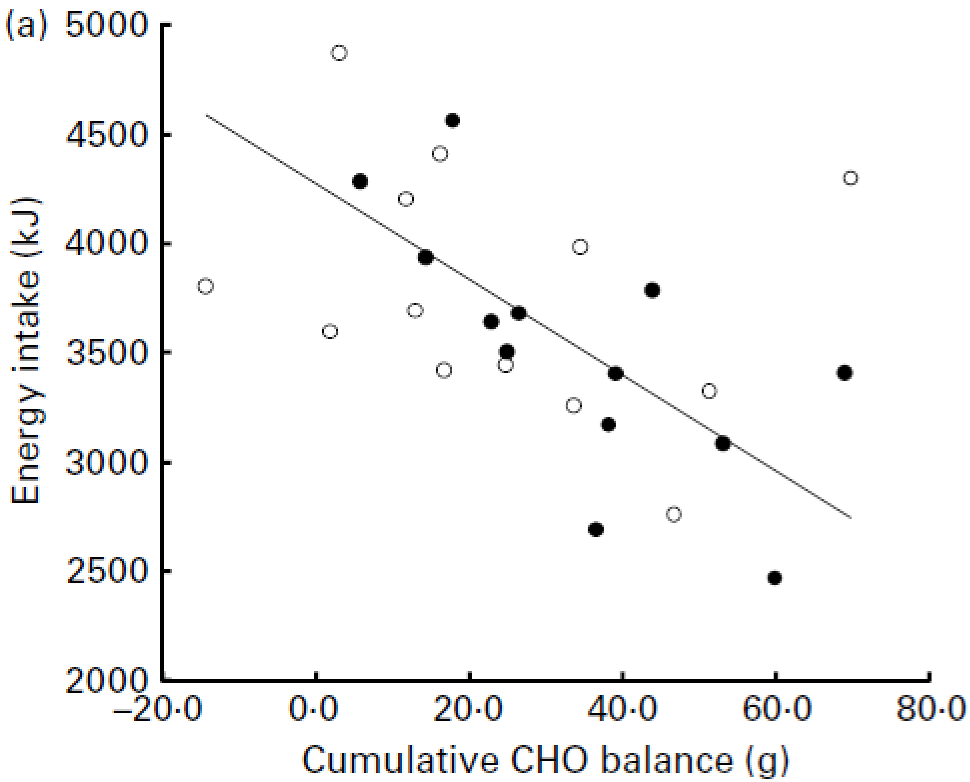


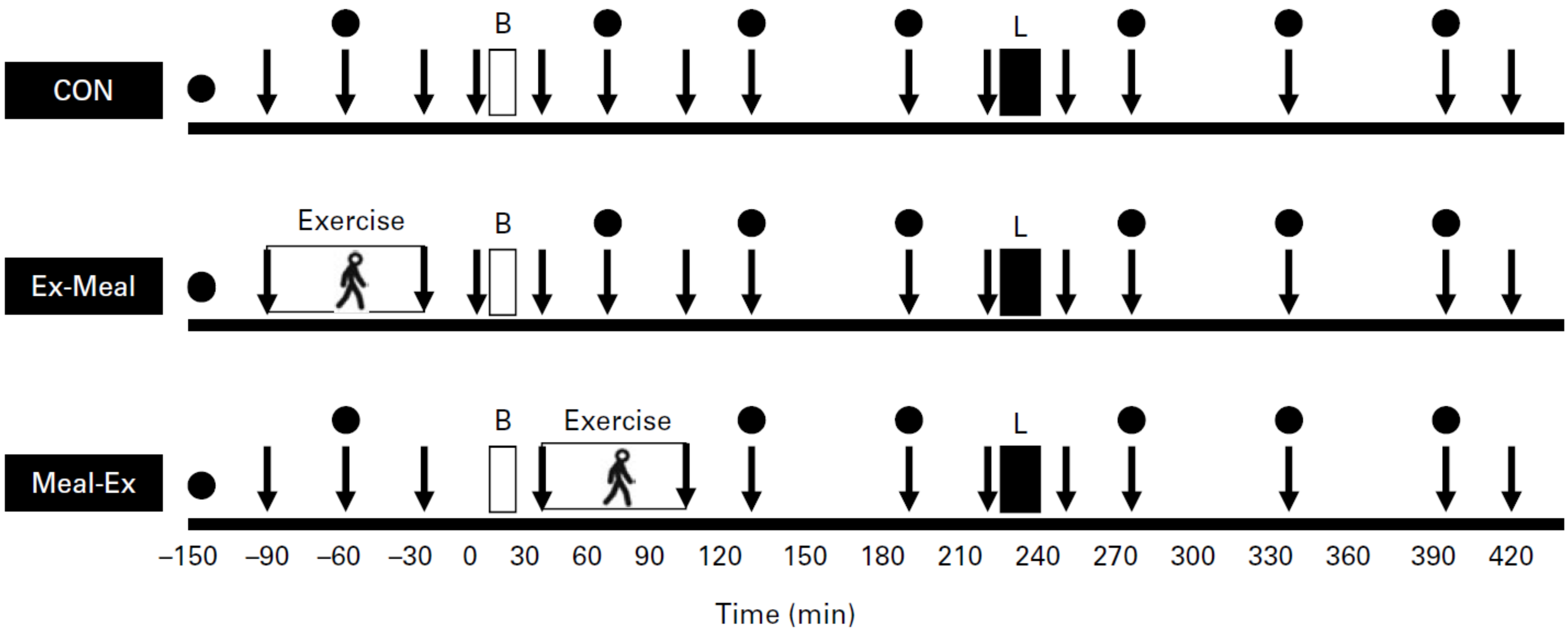
Burton et al (2010) Br J Nutr 104:1249-1259

Substrate metabolism and feeding behaviour under high and low energy turnover conditions



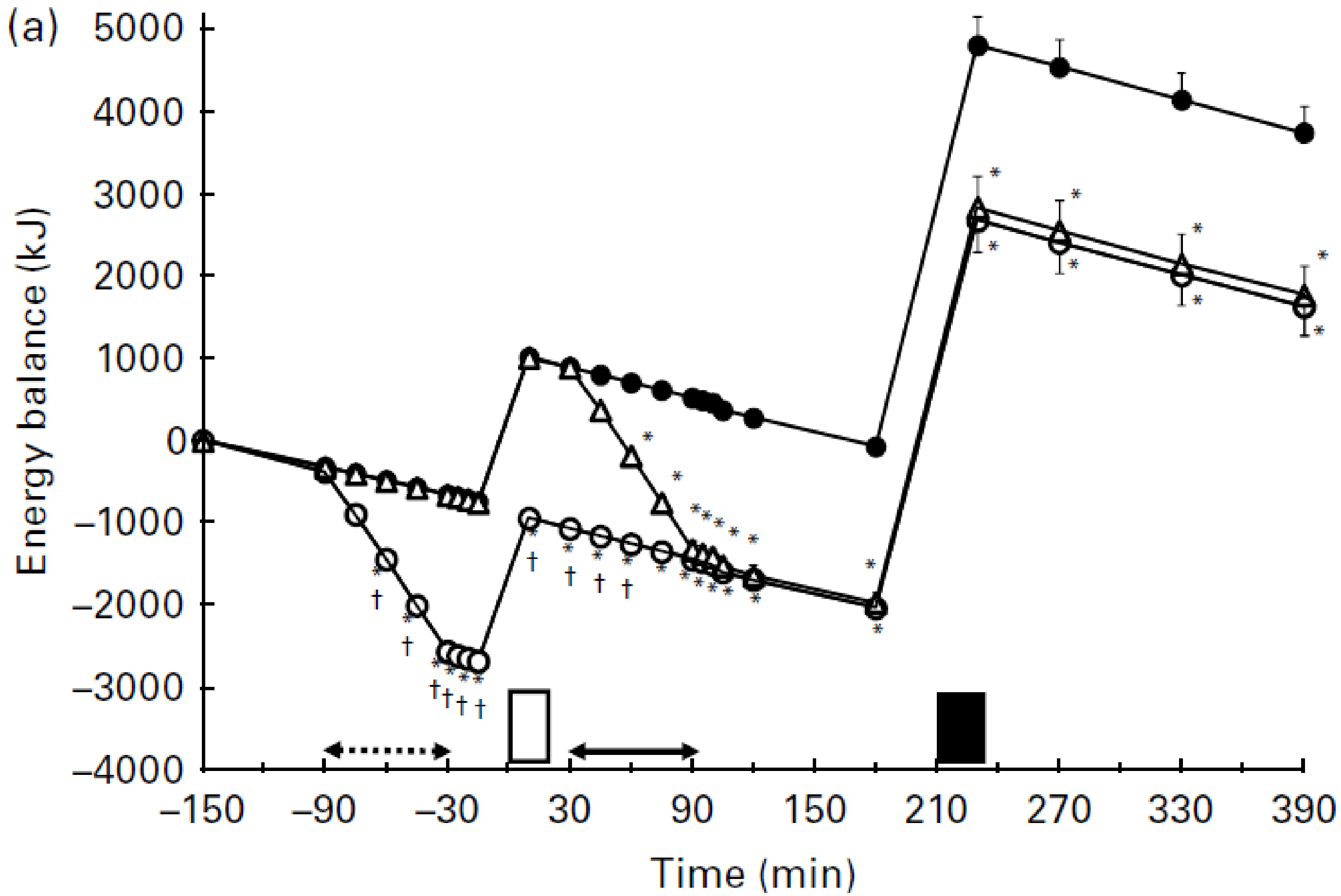
Burton et al (2010) Br J Nutr 104:1249-1259

Effects of exercise before or after breakfast on energy and fat balance



Farah et al (2013) Br J Nutr 109: 2297-2307

Effects of exercise before or after breakfast on energy and fat balance



Farah et al (2013) Br J Nutr 109: 2297-2307

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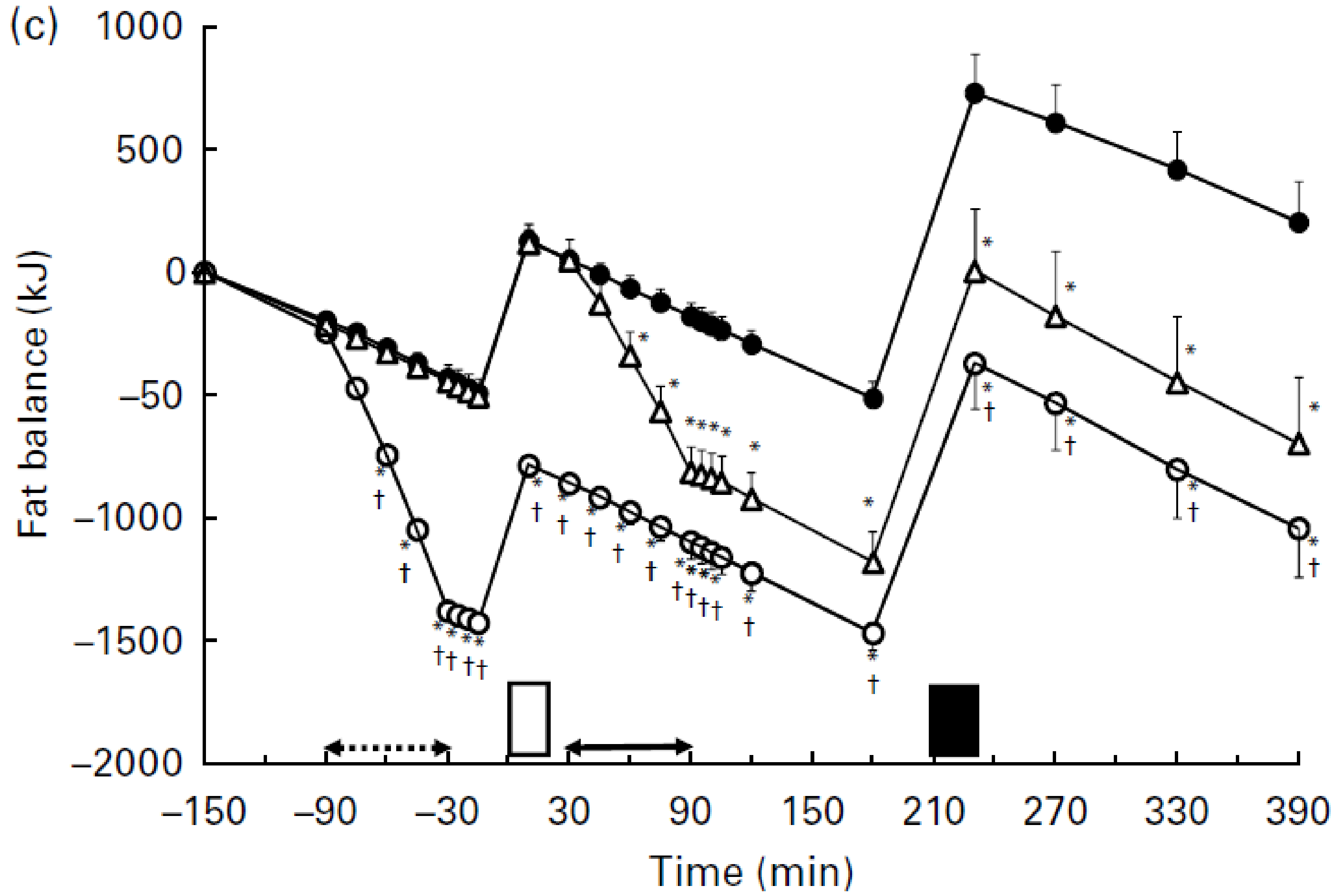
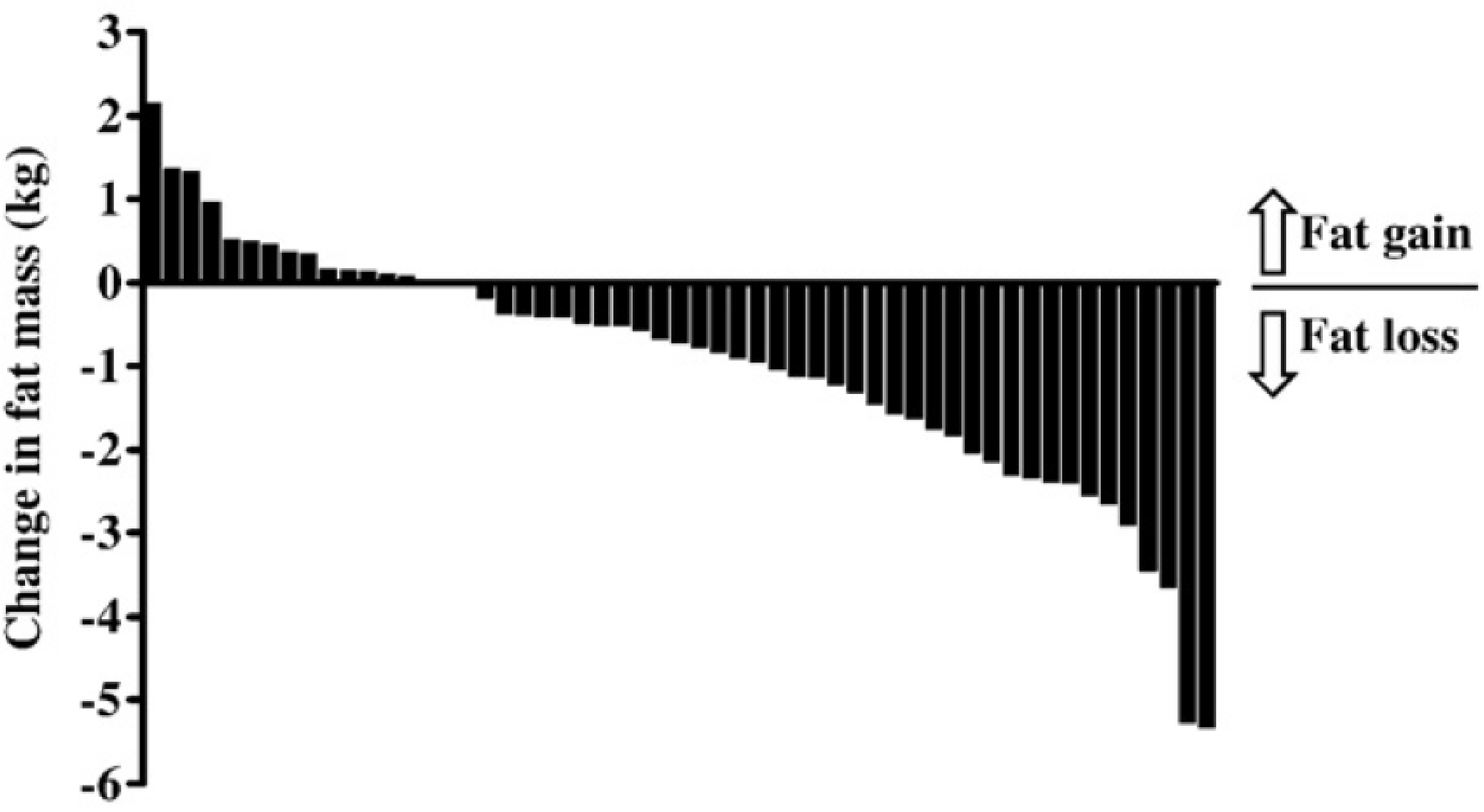


Farah et al (2013) Br J Nutr 109: 2297-2307

Longer-term effects of exercise on body fat

Individual variability in weight loss response to exercise



Barwell et al (2009) Metabolism 58:1320-1328

Factors influencing individual variability of in weight loss response to exercise

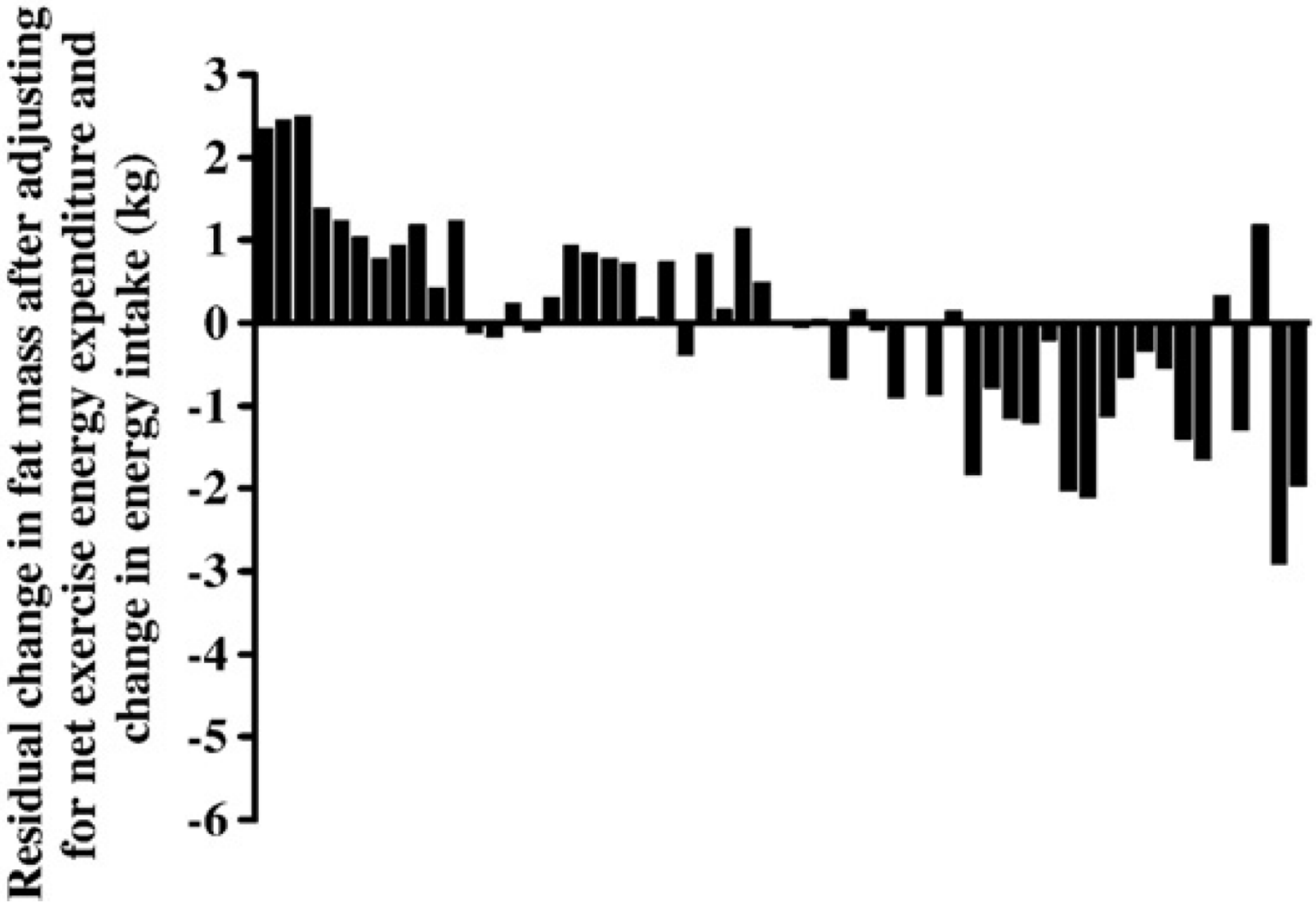
Differences in dietary compensation

King et al (2008) Int J Obes 32:177-84

Differences in physical activity compensation

Manthou et al (2010) Med Sci Sports Exerc 42:1221-1228

Individual variability in weight loss response to exercise



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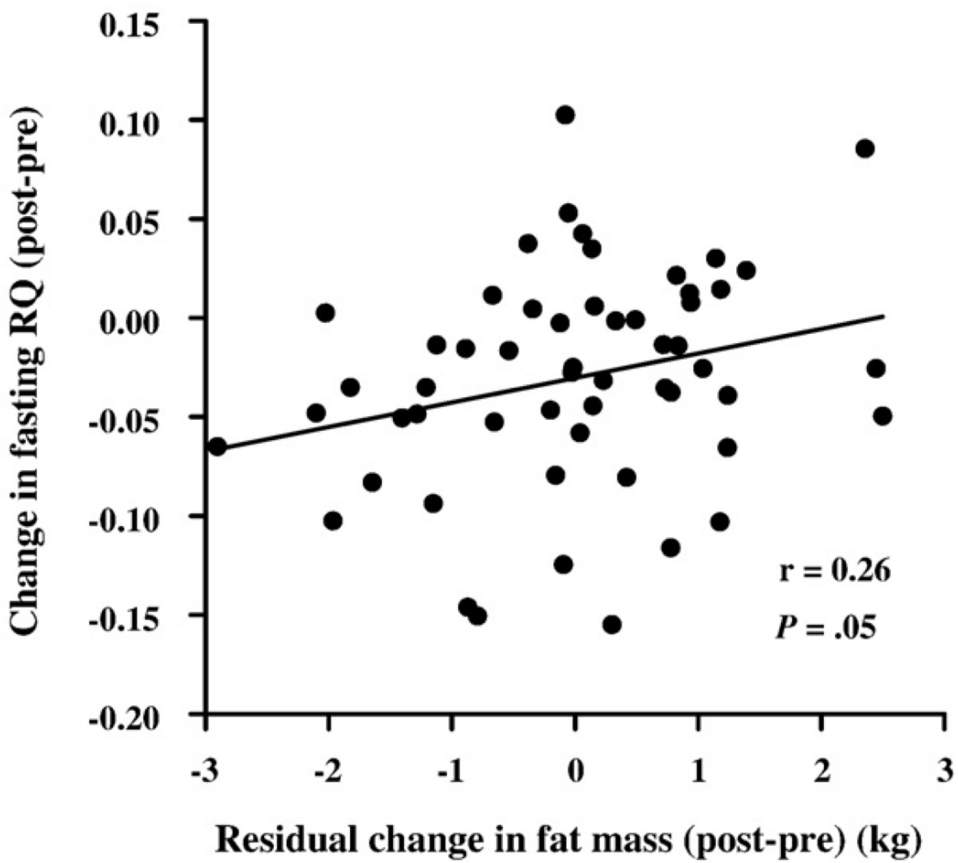

Barwell et al (2009) Metabolism 58:1320-1328

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- Dr Dilys Freeman
- Dr Ian Salt
- Dr Niall MacFarlane
- Dr Danny MacKay
- Dr Alex McConnachie
- Mr David Purves
- Mr John Wilson