

## VU Research Portal

### **Age- and sex-specific prevalences of diabetes and impaired glucose regulation in 13 European cohorts**

Tuomilehto, J.; Lindstrom, J.; Keinanen-Kiukaanniemi, S.; Hiltunen, L.; Kivela, S.L.; Gallus, G.; Garancini, M.P.; Schranz, A.; Bouter, L.M.; Dekker, J.M.; Heine, R.J.; Nijpels, G.; Pajak, A.; Castell, C.; Lloveras, G.; Tresserras, R.; de Pablos-Velasco, P.L.; Martinez-Martin, F.J.; Rodriguez-Perez, F.; Gabriel, R.

**published in**

Diabetes Care  
2003

**DOI (link to publisher)**

[10.2337/diacare.26.1.61](https://doi.org/10.2337/diacare.26.1.61)

**document version**

Publisher's PDF, also known as Version of record

[Link to publication in VU Research Portal](#)

**citation for published version (APA)**

Tuomilehto, J., Lindstrom, J., Keinanen-Kiukaanniemi, S., Hiltunen, L., Kivela, S. L., Gallus, G., Garancini, M. P., Schranz, A., Bouter, L. M., Dekker, J. M., Heine, R. J., Nijpels, G., Pajak, A., Castell, C., Lloveras, G., Tresserras, R., de Pablos-Velasco, P. L., Martinez-Martin, F. J., Rodriguez-Perez, F., ... Balkau, B. (2003). Age- and sex-specific prevalences of diabetes and impaired glucose regulation in 13 European cohorts. *Diabetes Care*, 26(1), 61-69. <https://doi.org/10.2337/diacare.26.1.61>

**General rights**

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal ?

**Take down policy**

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

**E-mail address:**

[vuresearchportal.ub@vu.nl](mailto:vuresearchportal.ub@vu.nl)

# Age- and Sex-Specific Prevalences of Diabetes and Impaired Glucose Regulation in 13 European Cohorts

THE DECODE STUDY GROUP

**OBJECTIVE** — To report the age- and sex-specific prevalences of diabetes and impaired glucose regulation (IGR) according to the revised 1999 World Health Organization criteria for diabetes in Europe.

**RESEARCH DESIGN AND METHODS** — A total of 13 studies from nine European countries with 7,680 men and 9,251 women aged 30–89 years were included in the data analysis.

**RESULTS** — In most of the study populations, the age-specific prevalences of diabetes were <10% in subjects younger than 60 years and between 10 and 20% at 60–79 years of age. Mean 2-h plasma glucose (2hPG) concentration increased linearly with age, but fasting plasma glucose (FPG) concentration did not. The increase in the prevalence of undiagnosed diabetes and IGR in the elderly was mainly a result of the large increase in 2hPG rather than FPG. Diabetes and impaired fasting glycemia defined by isolated fasting hyperglycemia was more common in men than in women 30–69 years of age, whereas the prevalence of isolated postload hyperglycemia, particularly impaired glucose tolerance, was higher in women than in men, especially in the elderly (individuals >70 years of age). More than half of the diabetes was undiagnosed in subjects younger than 50 years of age.

**CONCLUSIONS** — Most European populations have a moderate to low prevalence of diabetes and IGR. Diabetes and IGR will be underestimated in Europe, particularly in women and in elderly men, if diagnoses are based on fasting glucose determination alone.

*Diabetes Care* 26:61–69, 2003

Studies on the prevalence of diabetes in the last decades have broadened our knowledge about the impact of the disease and guided public health agencies in planning programs for diabetes care and prevention. There are, however, still problems related to the detection, diagnosis, management, and prevention of diabetes. Recently, the diagnostic cutoff value for fasting plasma glucose (FPG) has been lowered from 7.8 to 7.0 mmol/l (1,2). For epidemiological

studies and for routine clinical practice, the American Diabetes Association recommended using fasting glucose testing alone, and the use of the 2-h oral glucose tolerance test (OGTT) was not recommended (2), whereas the World Health Organization (WHO) Consultation still retained the OGTT (1). The impact of the changes on the prevalence of diabetes and on the reclassification of individuals has been studied in the DECODE (Diabetes Epidemiology: Collaborative Analysis of

Diagnostic Criteria in Europe) study populations (3,4). The results from the DECODE study (3,4) as well as from other studies (5–8) have clearly shown that fasting and 2-h glucose criteria do not identify the same group of individuals. Young and obese subjects are more likely to have diagnostic fasting glucose values than diagnostic 2-h glucose values (3–6,8,9).

It has been recognized that the prevalence of type 2 diabetes increases with age, especially in Europe (10,11). However, in most of the previous epidemiological studies, diabetes has mainly been defined by the 2-h glucose criteria alone (11). Whether the increase in prevalence is a consequence of increased fasting glucose or increased 2-h glucose concentrations is not known. Postload hyperglycemia reflects the acute increase in blood glucose after a glucose load, whereas fasting glucose is the glucose concentration after an overnight fast and reflects mostly hepatic glucose production. They represent physiologically different aspects of glucose metabolism and can probably be influenced differently by the aging process. This issue is of importance with regard to the improvement of diagnosis and medical care of elderly diabetic patients. The impact of sex is also an unresolved issue (10,11). In this report, the age- and sex-specific prevalence of diabetes and impaired glucose regulation (IGR), as well as the age- and sex-specific prevalence of isolated fasting or 2-h hyperglycemia, was assessed among some European populations.

## RESEARCH DESIGN AND METHODS

### Study population

The study populations and the methods used to recruit the participants have been reported in previous DECODE publications (3,4). Briefly, information on diabetic history and data on glucose measurements at fasting and 2 h after a standard 75-g OGTT were sent to the Di-

Members of the DECODE Study Group are listed in the APPENDIX.

Address correspondence and reprint requests to Dr. Qing Qiao, Diabetes and Genetic Epidemiology Unit, Department of Epidemiology and Health Promotion, National Public Health Institute, Mannerheimintie 166, FIN-00300 Helsinki, Finland. E-mail: qing.qiao@ktl.fi.

Received for publication 7 May 2002 and accepted in revised form 7 October 2002.

**Abbreviations:** 2hPG, 2-h plasma glucose; DECODE, Diabetes Epidemiology: Collaborative Analysis of Diagnostic Criteria in Europe; FPG, fasting plasma glucose; IFG, impaired fasting glycemia; IGR, impaired glucose regulation; IGT, impaired glucose tolerance; NHANES III, Third National Health and Nutrition Examination Survey; OGTT, oral glucose tolerance test; WHO, World Health Organization.

A table elsewhere in this issue shows conventional and Système International (SI) units and conversion factors for many substances.

Table 1—Demographic data of the study population and the participation rate in the OGTT of those invited: the DECODE study

Study cohort (Code)	Mean age [range (years)]	Participated in OGTT [n (%)]		Blood glucose sample	Fasting time	Time of blood sampling	Glucose assay method	Years of screening	Location
		Men (%)	Men (%)						
MONICA-Sweden 1986 (1)	47 (30–64)	553 (78)	50.6	Plasma	Overnight	7:45–10:00	Glucose oxidase	1986	Suburban
MONICA-Sweden 1990 (2)	47 (30–64)	711 (63)	47.0	Plasma	Overnight	7:45–10:00	Glucose oxidase	1990	Suburban
MONICA-Sweden 1994 (3)	52 (30–74)	903 (62)	48.4	Plasma	Overnight	7:45–10:00	Glucose oxidase	1994	Suburban
MONICA-Finland (4)	54 (40–64)	1,841 (76)	45.4	Plasma	Overnight	8:00–10:00	Glucose dehydrogenase	1992	Urban
Oulu, Finland (5)	76 (70–89)	309 (78)	38.8	Capillary	10–12 h	8:00–10:00	Glucose dehydrogenase	1992	Urban
Hoom, Dutch (6)	62 (50–77)	2,364 (71)	46.4	Plasma	≥ 10 h	8:00–10:00	Glucose dehydrogenase	1989–1991	Urban
Newcastle, U.K. (7)	55 (30–76)	778 (91)	51.7	Plasma	Overnight	8:00–10:00	Glucose oxidase	1992–1994	Urban
MONICA-Poland (8)	58 (44–73)	359 (81)	47.9	Serum	12 h	8:00–11:00	Glucose oxidase	1992–1993	Urban
Cremona, Italy (9)	58 (40–89)	1,672 (87)	44.0	Plasma	≥ 12 h	8:30–10:30	Glucose oxidase	1990–1991	Urban
Viva, Spain (10)	50 (34–69)	1,948 (72)	45.2	Plasma	Overnight	8:00–9:00	Glucose oxidase	1996–1997	Urban and rural
Catalonia, Spain (11)	54 (30–89)	1,835 (93)	42.3	Capillary	12 h	9:00–11:00	Refractometric	1994	Urban
Guia, Spain (12)	55 (30–89)	588 (100)	44.6	Plasma	12 h	8:00–10:00	Glucose oxidase	1997	Island
Malta (13)	49 (30–87)	1,745 (73)	43.2	Capillary	Overnight	Morning	Glucose oxidase	1981	Island
Total	54 (30–89)	15,606	45.4						

abetes and Genetic Epidemiology Unit of the National Public Health Institute in Helsinki, Finland, for collaborative analyses. The inclusion criteria for the current study are 1) population-based studies, 2) studies performed after 1980, 3) studies including both men and women, 4) at least two decades of age, and 5) a standard 2-h 75-g OGTT in the morning after an overnight fast for at least 10 h according to WHO recommendations (12,13).

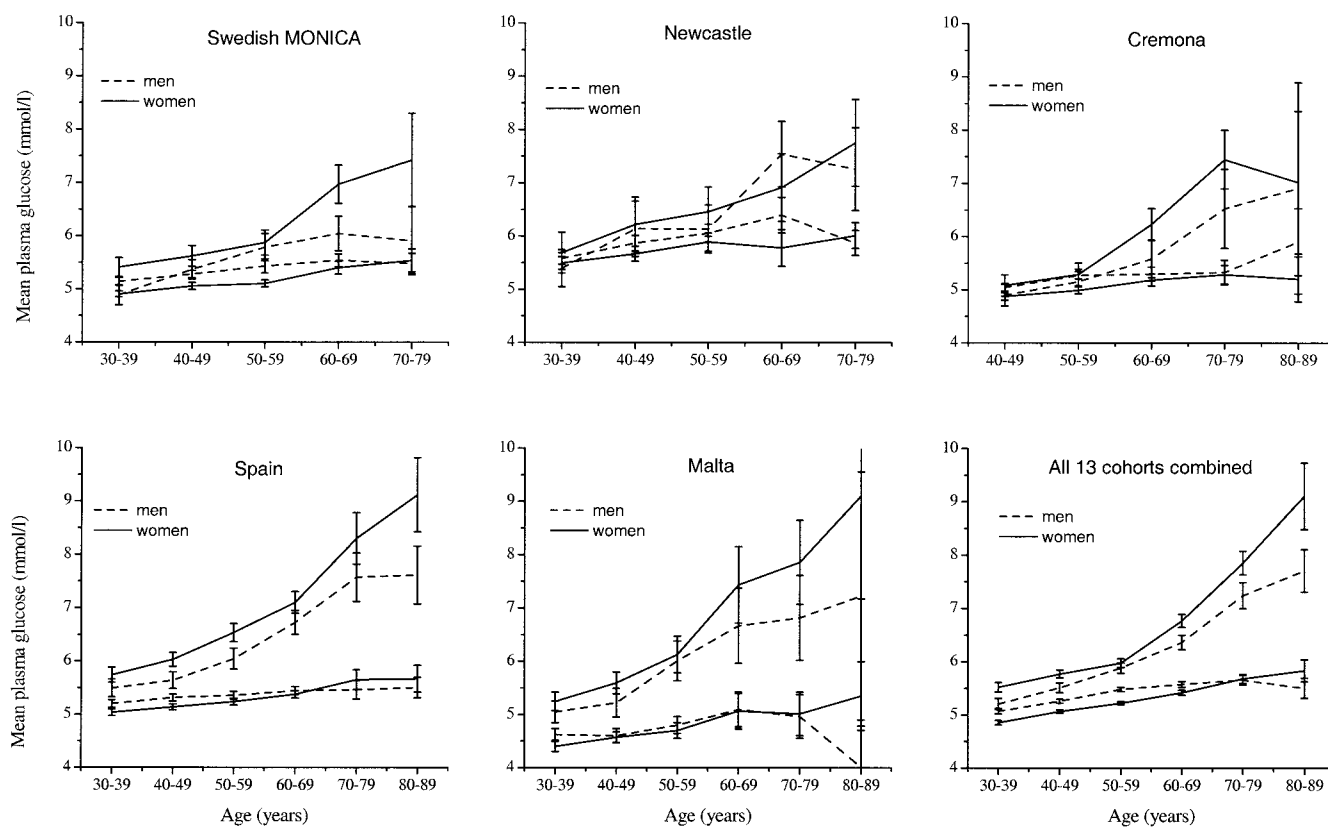
A total of 15,606 subjects (7,083 men and 8,523 women) who had no prior history of diabetes and 1,325 subjects (597 men and 728 women) who had a prior history of diabetes, from 13 studies in nine European countries, met the inclusion criteria for the current data analysis. The age range was 30–89 years. Demographic characteristics and information on the glucose tests for each study cohort are shown in Table 1. Age ranges and sample sizes varied between studies, but the age distribution was similar for men and women in each cohort. The proportion of female participants was slightly higher in most of the studies. The participation rate in the 2-h OGTT varied from 62 to 100%. Before data analysis, glucose concentrations of different kinds of blood specimens were all transformed to plasma glucose concentrations (APPENDIX).

### Classification of glucose abnormality

Subjects who had a prior history of diabetes were classified as having previously diagnosed diabetes. Other subjects were classified according to the 1999 WHO recommendations for the diagnosis of diabetes (1). Classifications of diabetes, impaired glucose tolerance (IGT), and normal glucose tolerance were made according to 2-h plasma glucose (2hPG) concentrations of  $\geq 11.10$ , 7.80–11.09, and  $< 7.80$  mmol/l, respectively. FPG concentrations of  $\geq 7.00$ , 6.10–6.99, and  $< 6.10$  mmol/l classified subjects into diabetes, impaired fasting glycemia (IFG), and normal fasting glucose. IGR according to the WHO 1999 recommendations (1) is either IGT or IFG.

### Statistical analysis

Mean FPG and 2hPG concentrations were calculated for subjects who had no prior history of diabetes by age-group, for populations with at least five 10-year age-groups. The age- and sex-specific prevalences of diabetes were calculated



**Figure 1**—Mean fasting (the two lower lines) and 2-h (the two upper lines) plasma glucose concentrations and their 95% CIs (vertical bars) for the five populations with at least five 10-year age intervals and for all 13 cohorts combined. The three Swedish cohorts were combined as one population, as were the three Spanish cohorts.

for six 10-year age intervals, from 30 up to 89 years, separately for subjects with and without diagnosed diabetes. The prevalence of diagnosed diabetes (Pkn) was calculated by dividing the number of diagnosed cases by the total number of subjects who had responded to the questions on the prior history of diabetes. Because there were nonparticipants in the OGTTs, the prevalence of undiagnosed diabetes = [(undiagnosed cases identified by the OGTTs/the number of individuals who attended the OGTTs)  $\times$  (1 - Pkn)]. The same rule was applied when calculating the prevalence of IGR. A  $\chi^2$  test was used to measure the differences in prevalence between men and women.

## RESULTS

### Age- and sex-specific plasma glucose concentration

The mean 2hPG concentration rose with age and increased more after 50 years of age in each study population (Fig. 1). Women had a significantly higher mean 2hPG concentration than men in each

age-group except in the fifth decade. The difference between men and women became larger in subjects older than 70 years of age. In men, the mean FPG concentration increased with age up to 69 years of age; thereafter, there was no further increase, whereas it rose with age in women (Fig. 1). The mean FPG concentration was higher in men than in women at 30–69 years of age; after 70 years of age, it was higher in women than in men.

### Age- and sex-specific prevalence of diabetes

The age-specific prevalence of diabetes rose with age up to the seventh and eighth decades in both men and women in each study population (Table 2, Fig. 2A). In most of the studies, the prevalence was <10% in subjects younger than 60 years of age and between 10 and 20% at 60–79 years of age. They were higher in Malta than in other populations, in each age-group for both sexes, and the prevalence of known diabetes was particularly higher. The prevalence of diabetes was also higher in elderly Finnish women in

Oulu and in elderly Spanish women in Guia, compared with most of the other populations.

As shown in Fig. 2A, the prevalence of isolated postload hyperglycemia (2hPG  $\geq 11.1$  mmol/l and FPG < 7.0 mmol/l) increased more with age than isolated fasting hyperglycemia (FPG  $\geq 7.0$  mmol/l and 2hPG < 11.1 mmol/l), especially in women.

### Age- and sex-specific prevalence of IGR

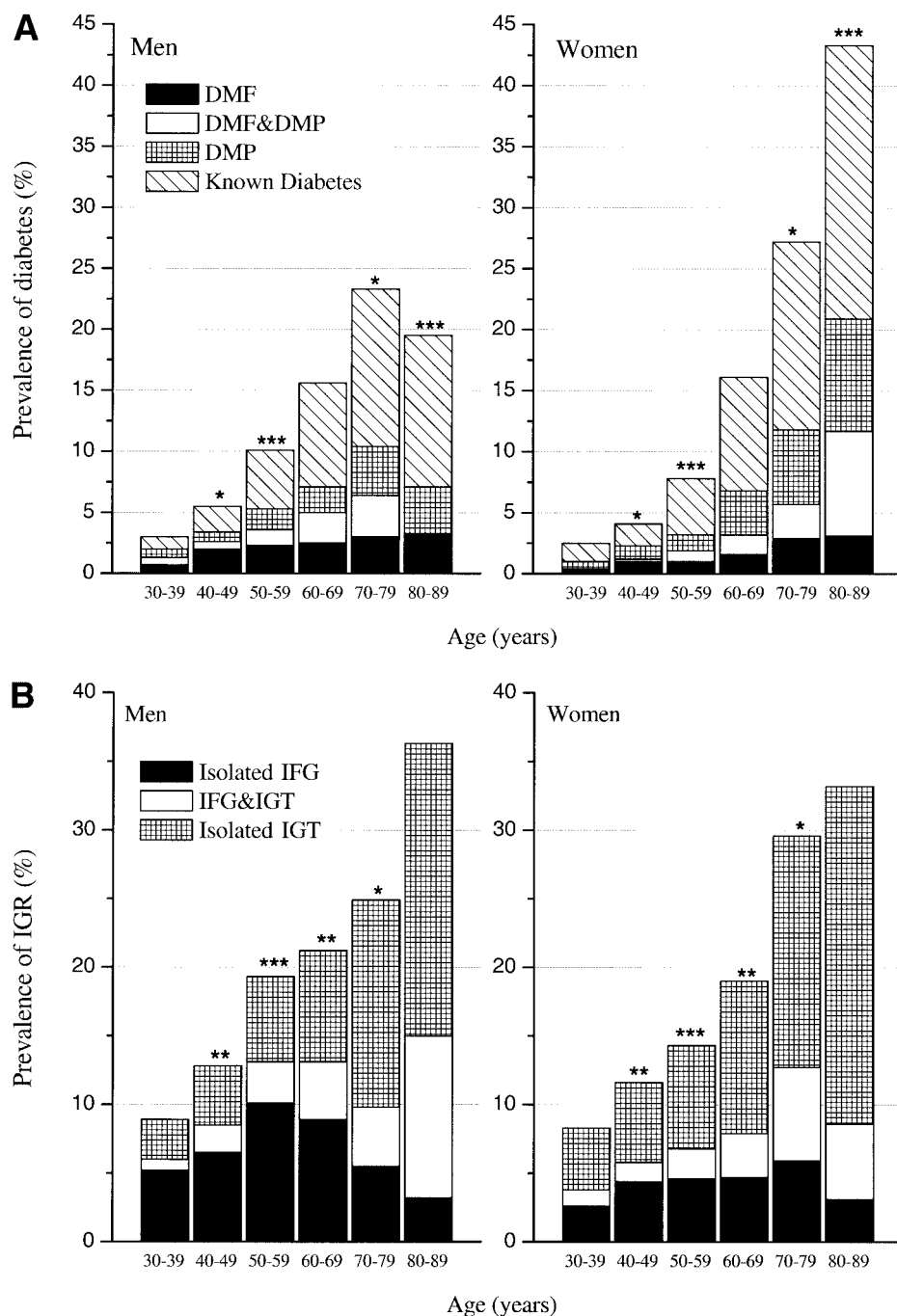
The prevalence of IGR rose with age in each study (Table 3 and Fig. 2B). In most of the study populations, the prevalence of IGR was <15% at 30–59 years of age and between 15 and 30% after 60 years of age. In each age-group, they were higher in Newcastle in the U.K., Poland, and Catalonia in Spain, compared with other populations. The elderly Finnish men and women in Oulu had the highest prevalence of IGR.

The prevalence of IGT increased linearly with age, but the prevalence of IFG

Table 2—Prevalences of previously diagnosed and undiagnosed diabetes defined by 2hPG and FPG criteria in men and women in the DECODE cohorts

Cohort	Age (years)	Undiagnosed diabetes (mmol/l)						Diagnosed diabetes		Total diabetes	
		2hPG $\geq$ 11.1 and FPG < 7.0		2hPG < 11.1 and FPG $\geq$ 7.0		2hPG $\geq$ 11.1 and FPG $\geq$ 7.0		Men	Women	Men	Women
		Men	Women	Men	Women	Men	Women	Men	Women	Men	Women
MONICA 1986, Sweden	30–39	1.2	2.6	0	0	2.4	0	0.9	0.5	4.5	3.1
	40–49	0	1.3	0	0	0	0	2.5	1.5	2.5	2.8
	50–59	0	2.3	1.2	0	1.2	0	5.8	1.4	8.1	3.7
	60–64	2.3	5.6	2.3	0	0	0	15	9	19.6	14.6
MONICA 1990, Sweden	30–39	0	1.0	0	1.0	0	0	1.6	0.5	1.6	2.5
	40–49	0	0	1.0	0.9	0	0.9	2	1	3.0	2.8
	50–59	0	1.7	1.1	0	1.1	0.9	5.5	3.8	7.6	6.4
	60–64	0	3.7	3.2	1.8	3.2	0	7.2	5.9	13.6	11.4
MONICA 1994, Sweden	30–39	0	0	1.2	0	0	0	0.6	1.0	1.8	1.0
	40–49	1.9	1.9	0.9	1.0	0.9	0	1.5	1.5	5.3	4.4
	50–59	1.0	2.8	1.0	0.9	0	0.9	2.6	1.5	4.5	6.1
	60–69	3.1	5.7	2.3	1.6	2.3	2.4	6.1	4.5	13.9	14.3
MONICA, Finland	70–74	0	2.4	2.8	0	0	2.4	13.9	8.3	16.7	13.1
	40–49	1.2	1.2	1.9	1.8	0	0	1.6	0.8	4.7	3.8
	50–59	1.2	0.9	3.6	1.5	1.6	0.7	3.2	3.0	9.6	6.0
	60–64	1.2	1.7	2.3	0.9	1.7	0.9	4.1	4.4	9.2	7.8
Oulu, Finland	70–79	7.2	5.3	7.2	8.3	5.4	3.6	17.1	17.2	36.9	34.3
	80–89	3.6	9.1	7.1	6.1	0	13.7	0	25.8	10.7	54.6
Hoom, Dutch	50–59	1.5	0.7	2.2	1.8	2.1	0.5	2.2	1.4	8.0	4.4
	60–69	1.2	2.5	2.4	1.9	3.4	3.1	3.8	5.0	10.7	12.5
	70–77	2.9	4.3	3.5	2.6	5.7	4.7	4.0	8.1	16.0	19.7
Newcastle, U.K.	30–39	0	0	0	0	0	0	0	0	0	0
	40–49	1.2	1.2	4.8	0	2.5	1.2	1.3	1.3	9.7	3.7
	50–59	1.0	0	6.7	3.0	2.8	2.0	3.1	3.0	13.6	8.0
	60–69	1.0	2.1	7.9	6.4	4.9	2.1	3.3	3.3	17.1	13.9
MONICA, Poland	70–76	3.4	6.0	3.4	4.0	3.4	2.0	6.3	0	16.4	12.0
	44–49	2.4	0	4.9	2.6	0	0	2.1	0	9.5	2.6
	50–59	3.6	3.9	5.4	0	0	1.3	0	2.0	9.0	7.2
	60–69	7.4	4.8	2.9	1.6	2.9	0	2.5	11.3	15.7	17.7
Cremona, Italy	70–73	0	10.8	0	0	0	0	5.6	8.3	5.6	19.1
	40–49	0	0	0.9	0	0	0.9	3.2	1.2	4.1	2.1
	50–59	1.5	0.7	0.8	0	0.4	0.7	5.6	3.7	8.2	5.0
	60–69	1.9	1.8	2.4	0.7	1.0	1.1	12.9	9.4	18.2	13.0
	70–79	1.2	6.6	0	1.3	4.7	2.6	11.2	10.1	17.1	20.6
Viva, Spain	80–89	0	3.0	8.5	0	0	3.0	6.7	28.9	15.2	34.9
	34–39	0	1.1	0	0	0	0	0.4	2.2	0.4	3.3
	40–49	1.3	1.5	2.6	0.5	0.7	0.3	0.4	2.6	5.0	4.8
	50–59	3.0	1.9	1.9	0.3	0.8	1.6	1.8	3.6	7.5	7.4
Catalonia, Spain	60–69	2.5	4.0	1.8	1.5	1.8	0.5	4.3	4.2	10.4	10.3
	30–39	1.5	0.5	0.7	0.5	0	0	1.3	0.3	3.5	1.3
	40–49	0	1.4	2.4	1.8	0.6	0	1.7	1.7	4.6	4.8
	50–59	2.0	1.2	0.6	0.4	0	0	8.6	7.4	11.3	9.0
	60–69	4.0	5.9	1.3	1.5	1.3	0.4	12	17.5	18.6	25.3
	70–79	5.3	7.6	0.9	2.6	0	0.9	13.5	19.8	19.6	30.9
Guia, Spain	80–89	7.3	10.2	2.5	0	0	3.4	11.9	11.1	21.7	24.7
	30–39	0	0	0	0	0	0	0	0	0	0
	40–49	0	0	1.8	1.3	1.8	0	7.0	3.8	10.6	5.2
	50–59	3.9	2.8	2.0	1.4	0	2.8	12.2	10.9	18.2	17.9
	60–69	3.8	5.1	0	0	3.8	1.3	15.8	19.3	23.4	25.7
	70–79	7.1	11.6	0	0	1.7	0	13.3	32.2	22.2	43.8
Malta	80–89	0	18.7	0	0	0	6.2	15.6	31.6	15.6	56.5
	30–39	1.4	0.3	1.9	0.7	1.4	0	0.9	4.6	5.6	5.6
	40–49	1.1	1.6	2.2	1.2	1.1	0	7.1	4.5	11.6	7.4
	50–59	3.2	1.9	2.2	1.1	2.2	1.9	14.1	18.9	21.7	23.8
	60–69	0.7	5.4	2.0	1.8	4.7	2.4	25.5	36.3	32.9	45.8
	70–79	3.6	7.6	4.8	0	2.4	2.1	32.1	37.6	42.8	47.3
Total	80–87	5.9	8.3	0	4.2	0	8.3	35.3	33.3	41.2	54.2
	30–39	0.7	0.6	0.7	0.4	0.6	0*	1.0	1.5	2.9	2.5
	40–49	0.8	1.1	2.0	1.0*	0.6	0.2	2.1	1.8	5.4	4.2*
	50–59	1.7	1.3	2.3	1.0†	1.3	0.9	4.8	4.6	10.1	7.8*
	60–69	2.1	3.6‡	2.5	1.6	2.5	1.6	8.5	9.3	15.5	16.1
	70–79	4.0	6.1*	3.0	2.9	3.4	2.8	12.9	15.4	23.4	27.3*
80–89	3.9	9.2*	3.2	3.1	0	8.6‡	12.4	22.4*	19.5	43.3‡	

Data are %. \* $P < 0.05$ , † $P < 0.001$ , ‡ $P < 0.01$ , for the difference between men and women.



**Figure 2**—Age- and sex-specific prevalence of diabetes (A) and IGR (B) for all studies combined. DMF: Diabetes determined by FPG  $\geq 7.0$  mmol/l and 2hPG  $< 11.1$  mmol/l; DMP: Diabetes determined by 2hPG  $\geq 11.1$  mmol/l and FPG  $< 7.0$  mmol/l; DMF&DMP: Diabetes determined by FPG  $\geq 7.0$  mmol/l and 2hPG  $\geq 11.1$  mmol/l; Isolated IFG: FPG 6.1–6.9 mmol/l and 2hPG  $< 7.8$  mmol/l; Isolated IGT: 2hPG 7.8–11.0 mmol/l and FPG  $< 6.1$  mmol/l; IFG&IGT: FPG 6.1–6.9 mmol/l and 2hPG 7.8–11.0 mmol/l. \* $P < 0.05$ , \*\* $P < 0.01$ , \*\*\* $P < 0.001$ , for the difference in the total prevalence between men and women.

did not (Fig. 2B). The concordance between the two was poor.

### Sex difference in prevalence of diabetes, IFG, and IGT

In most of the study cohorts, the age-specific prevalences of previously undiagnosed diabetes and IGT defined by isolated postload hyperglycemia were higher in women than in men, but the prevalences of undiagnosed diabetes and

IFG diagnosed by isolated fasting hyperglycemia were higher in men than in women (Tables 2 and 3). The sex difference in the prevalence of undiagnosed diabetes and IFG defined by isolated fasting hyperglycemia was statistically significant in subjects younger than 70 years of age. IGT was more prevalent in women than in men in all age-groups, although significantly different only in subjects younger than 70 years of age (Table 3). Undiag-

nosed diabetes defined by isolated postload hyperglycemia was more prevalent in women than in men after 60 years of age (Table 2).

The prevalence of previously diagnosed diabetes did not differ between men and women, except in the people aged 80 years or older, where the prevalence was higher in women (Table 2). The total prevalence of diabetes (Fig. 2A) was higher in men 40–59 years of age but

Table 3—Prevalences of IGT, IFG, and IGR defined according to 2hPG and FPG criteria (mmol/l) in men and women in the DECODE cohorts

Cohort	Age (years)	Isolated IGT		Isolated IFG		IGT and IFG		IGR	
		2hPG 7.8–11.0 and FPG < 6.1		2hPG < 7.8 and FPG 6.1–6.9		2hPG 7.8–11.0 and FPG 6.1–6.9		IGT or/and IFG	
		Men	Women	Men	Women	Men	Women	Men	Women
MONICA 1986, Sweden	30–39	4.8	9.2	1.2	1.3	0	0	5.9	10.4
	40–49	7.4	7.6	2.4	0	0	1.3	9.8	8.9
	50–59	8.1	11.4	1.1	2.3	0	1.2	9.2	14.9
	60–64	2.3	11.0	4.6	2.7	2.3	0	9.2	13.7
MONICA 1990, Sweden	30–39	0	3.9	4.5	0	0	1.0	4.5	4.9
	40–49	2.0	6.1	14.6	0.9	2.0	0	18.5	7.0
	50–59	6.4	6.9	7.6	6.1	0	0.9	14.0	13.9
	60–64	0	11.1	12.8	11.1	0	3.7	12.8	25.9
MONICA 1994, Sweden	30–39	2.5	3.9	2.5	0	0	1.0	5.0	4.9
	40–49	0.9	2.9	2.8	3.8	3.8	1.9	7.6	8.6
	50–59	5.8	9.3	13.6	1.9	4.9	0.0	24.4	11.2
	60–69	7.0	13.1	7.0	2.4	3.1	1.6	17.1	17.1
	70–74	13.9	16.9	5.6	4.8	0	14.5	19.4	36.2
MONICA, Finland	40–49	4.6	4.9	11.9	6.1	3.4	0.9	20.0	11.8
	50–59	7.4	5.3	15.6	4.3	6.6	4.1	29.5	13.7
	60–64	7.4	11.6	14.3	4.3	5.2	5.5	26.9	21.4
Oulu, Finland	70–79	18.9	25.4	7.2	7.7	7.2	15.4	33.3	48.5
	80–89	35.7	25.7	7.1	6.1	21.4	6.1	64.2	37.9
Hoorn, Dutch	50–59	3.5	3.8	8.8	5.7	2.2	1.4	14.6	10.9
	60–69	5.8	9.9	12.9	5.6	3.1	2.5	21.7	18.0
	70–77	11.3	11.9	6.8	8.1	3.9	5.1	22.1	25.2
Newcastle, U.K.	30–39	3.0	3.6	11.9	9.1	4.5	1.8	19.4	14.5
	40–49	6.1	7.1	15.8	10.7	3.6	2.4	25.5	20.1
	50–59	1.9	8.0	31.4	16.0	2.8	6.0	36.1	30.0
	60–69	7.9	8.5	13.8	10.6	17.8	5.3	39.6	24.5
MONICA, Poland	70–76	17.1	12.0	11.9	8.0	3.4	14.0	32.3	34.0
	44–49	2.4	15.4	14.7	5.1	4.9	7.7	22.0	28.2
	50–59	14.3	20.7	16.1	1.3	8.9	3.8	39.3	25.8
	60–69	19.2	22.6	10.3	3.2	4.4	4.9	33.9	30.7
	70–73	0	16.1	18.9	0	0	10.8	18.9	27.0
Cremona, Italy	40–49	3.1	4.0	1.3	0.4	0.5	0.9	4.9	5.2
	50–59	3.4	3.3	7.5	0.7	1.5	1.2	12.4	5.2
	60–69	7.3	8.0	3.4	2.5	1.5	2.2	12.2	12.7
	70–79	9.5	17.7	2.4	0.6	3.6	1.3	15.5	19.7
	80–89	25.5	20.8	0	0	17.0	0	42.5	20.8
Viva, Spain	34–39	3.8	2.1	9.6	2.5	0	1.6	13.3	6.2
	40–49	5.2	3.3	4.9	4.0	1.3	1.3	11.4	8.6
	50–59	9.0	10.9	4.9	5.1	0.8	1.3	14.7	17.3
	60–69	7.9	9.5	4.9	4.0	3.1	2.5	15.9	16.0
Catalonia, Spain	30–39	4.3	7.4	7.2	4.4	1.5	2.5	13.0	14.3
	40–49	6.5	9.3	5.9	9.6	3.5	2.8	15.9	21.7
	50–59	9.3	12.2	11.3	9.4	5.3	4.9	26.0	26.5
	60–69	14.9	13.8	7.9	5.9	5.3	4.9	28.1	24.6
	70–79	22.9	17.7	3.5	9.3	7.1	6.7	33.6	33.8
	80–89	12.2	30.8	4.9	3.4	7.3	6.8	24.5	41.0
Guia, Spain	30–39	6.3	7.5	6.3	3.8	0	1.3	12.6	12.6
	40–49	5.4	11.8	3.5	2.6	1.8	2.6	10.7	17.0
	50–59	14.0	19.5	11.9	0.0	3.9	4.2	29.8	23.7
	60–69	11.5	15.3	9.6	3.9	3.8	5.1	24.8	24.3
	70–79	19.4	11.6	3.6	3.9	3.6	0	26.5	15.5
	80–89	16.9	12.5	0	0	13.5	12.5	30.4	24.9
Malta	30–39	0.9	3.0	1.4	2.0	0.9	0.3	3.2	5.2
	40–49	2.7	5.4	2.2	2.2	0	0.3	4.9	7.9
	50–59	5.9	7.1	1.4	1.5	0	0.4	7.3	8.9
	60–69	6.7	8.9	1.3	2.4	3.4	0	11.4	11.3
	70–79	10.7	17.2	1.2	3.2	1.2	0	13.2	20.5
	80–87	23.6	20.9	0	0	0	4.2	23.6	25.1
Total	30–39	2.9	4.5*	5.2	2.6†	0.8	1.2	8.9	8.3
	40–49	4.3	5.8*	6.5	4.4†	2.0	1.4	12.7	11.6†
	50–59	6.2	7.5*	10.1	4.6†	3.0	2.2	19.2	14.3‡
	60–69	8.1	11.1†	8.9	4.7†	4.2	3.2	21.2	19.0‡
	70–79	15.1	16.9	5.5	5.9	4.3	6.8*	24.8	29.6
	80–89	21.3	24.6	3.2	3.1	11.8	5.5	36.2	33.2

Data are %. \* $P < 0.05$ , † $P < 0.01$ , ‡ $P < 0.001$ , for the difference between men and women.

lower in men over 70 years of age, compared with women. The similar age and sex pattern for the prevalence of IGR was also observed (Fig. 2B).

### Proportion of previously undiagnosed diabetes

The percentage of subjects with undiagnosed diabetes varied with age and sex. For all studies combined, the proportions of undiagnosed diabetic cases were 0.70, 0.60, 0.50, 0.50, 0.40, and 0.40 in men and 0.39, 0.58, 0.41, 0.42, 0.43, and 0.48 in women, respectively, at 30–39, 40–49, 50–59, 60–69, 70–79, and 80–89 years of age. In men, the proportion was high in young age-groups and decreased with age, whereas there was not a clear prevalence pattern with age in women.

**CONCLUSIONS**— The prevalences of diabetes and IGT according to the WHO 1985 criteria have been reported previously for all of the individual studies (14–24), but the prevalence of diabetes and IGR according to the revised WHO 1999 criteria (1) have not been fully reported. In the current article, the age- and sex-specific prevalences of diabetes and IGR as well as their components according to the revised diagnostic criteria were investigated in each of the individual studies and in all studies combined. We found that the 2hPG concentration increased linearly with age, but the FPG concentration did not. The increase in the prevalence of undiagnosed diabetes and IGR in the elderly population resulted mainly from the large increase in postload hyperglycemia rather than fasting hyperglycemia. In addition, we found that there was a distinct sex difference in the prevalence of diabetes, IFG, and IGT. Undiagnosed diabetes and IFG defined by isolated fasting hyperglycemia was more common in men than in women at 30–69 years of age, whereas the prevalence of isolated postload hyperglycemia was higher in women than in men and was particularly higher in the elderly population (>70 years of age).

The finding that postload hyperglycemia was more prevalent in the elderly was consistent with a recent report from the Third National Health and Nutrition Examination Survey (NHANES III) (25). In that report, however, men and women were not studied separately. Our study further revealed that postload hyperglycemia, particularly IGT, was also more

prevalent in women of all ages than in men. This finding is consistent with a previous report that there are, worldwide, more women than men with IGT (11). Therefore, the prevalence of undiagnosed diabetes and IGR would be underestimated to a large extent in Europe, especially in female and elderly populations, if fasting glucose determination alone would be used, whereas the primary purpose of a population-based screening program for diabetes is to detect previously undiagnosed diabetes and IGR.

The prevalence of previously undiagnosed diabetes, according to a FPG level of  $\geq 7.0$  mmol/l alone, for U.S. adults aged  $\geq 20$  years was estimated in the NHANES III (26). At a comparable age range of 40–59 years, the prevalence of undiagnosed diabetes according to the same fasting glucose criteria was lower in most of the female populations and in about half of the male European populations, compared with the U.S. non-Hispanic white population, but they were all lower than those of Mexican American subjects.

Age- and sex-specific prevalences of diabetes (known plus unknown cases defined according to 2hPG  $\geq 11.1$  mmol/l) in selected populations worldwide have been assembled using aggregate data and were reported by King et al. in 1993 (11). However, in that report, only two small European studies from Poland and Finland were included, and the old WHO 1985 criteria were used (13). In the current study, age- and sex-specific prevalences of diabetes and IGR according to the recently revised WHO 1999 diagnostic criteria were reported for 13 European cohorts based on the individual data. At comparable age ranges of 30–69 years, the prevalences of diabetes, estimated using the same 2-h glucose criteria, in most of the European populations were lower than most of the other populations worldwide, but higher than those in the Bantu in Tanzania and the Chinese in Da Qing (11). About half of the male European populations had higher and half had lower prevalences of diabetes than U.S. non-Hispanic men, whereas U.S. non-Hispanic white women had higher prevalences than most of their female European counterparts in all age-groups. Europeans have a moderate to low prevalence of diabetes compared with most of the other racial and ethnic groups worldwide

where age- and sex-specific prevalences of diabetes have been reported.

The ratio of prevalences of glucose abnormality between men and women has been estimated in many studies, but so far there has been no consistent trend (11,26). The previous WHO estimate (11) was based on aggregate data with age-standardized rates rather than on individual subject data with age-specific rates. The major limitation of using aggregate data is that detailed analysis using the same strategy cannot be made. In addition, an age-standardized estimate does not represent the true population prevalence because it depends not only on the actual age-specific rates in the study sample but also on the age distribution of the chosen standard population. Our study showed a clear sex pattern in the prevalence of postload hyperglycemia and the prevalence of fasting hyperglycemia. This pattern was similar to the sex patterns of the population distributions of age-specific FPG and 2hPG concentrations. The findings may be important for planning treatment strategy, designing screening programs, and improving diabetes care.

The DECODE study is based on collaborative analysis of the existing population-based databases. It is an economic and efficient way to maximize and optimize the use of survey databases. During the data analysis, the same diagnostic criteria and strategy could be used in all studies, and thus, results could be compared directly between studies. However, because the individual surveys have been carried out independently, there were differences in study design, participation rate, and classification of known diabetes and no centralized glucose assays, despite the application of uniform inclusion criteria. Nevertheless, there were many similarities between studies, such as the number of hours of fasting, the time for blood sampling, and the method for glucose assay. Moreover, the findings were also homogeneous among the DECODE populations in terms of the age-specific glucose concentrations and the sex difference in prevalence of fasting and postload hyperglycemia. This suggests the findings are valid.

In conclusion, the prevalence of diabetes and IGR in Europe was moderate to low compared with other worldwide reports. The prevalence of isolated postload hyperglycemia (diabetes and IGT) in-



creased with age, but the prevalence of isolated fasting hyperglycemia (diabetes and IFG) did not. The former was more common in women of all ages and in elderly men, and the latter more prevalent in young and middle-aged men. Diabetes and IGR will be underestimated in Europe, particularly in women and in elderly men, if diagnosis of diabetes is based on FPG determination alone.

**Acknowledgments**—This analysis was carried out with the help of grants from Novartis Pharma, Basel, Switzerland, and from the Finnish Academy (grants 46558, 76502, and 77618). The DECODE study was initially funded by Novo Nordisk, Bagsvaerd, Denmark.

**APPENDIX**—The DECODE study was started in 1997 on the initiative of the European Diabetes Epidemiology Group.

#### Investigators and study centers included in this analysis

**Finland:** FIN-MONICA: Jaakko Tuomilehto, Pekka Jousilahti, Jaana Lindström, Department of Epidemiology and Health Promotion, National Public Health Institute, Helsinki, Finland; Oulu Study: Sirkka Keinänen-Kiukaanniemi, Liisa Hiltunen, Sirkka-Liisa Kivelä, Department of Public Health Science, University of Oulu, Oulu, Finland. **Italy:** Cremona Study: Giuseppe Gallus, Maria Paola Garancini, Institute of Medical Statistics, University of Milan and Epidemiology Unit, S. Raffaele Institute, Milan, Italy. **Malta:** Malta Study: Antoine Schranz, Diabetes Clinic, St Luke's Hospital, M'Gania, Malta. **The Netherlands:** The Hoorn Study Research Group: Lex M. Bouter, Jacqueline M. Dekker, Robert J. Heine, Giel Nijpels, Coen D.A. Stehouwer, Institute for Research in Extramural Medicine, Vrije Universiteit Medical Center, Amsterdam, the Netherlands. **Poland:** POL-MONICA Study (Krakow): Andrzej Pajak, Department of Clinical Epidemiology and Population Studies, Institute of Public Health, Collegium Medicum, Jagiellonian University, Krakow, Poland. **Spain:** The Catalonia Study: Conxa Castell, Goncal Lloveras, Ricard Tresserras, Department of Health and Social Security, The Autonomous Government of Catalonia, Catalonia, Spain; The Guía Study: P.L. de Pablos-Velasco, F.J. Martinez-Martin, F. Rodriguez-Perez, En-

docrinology Department, Hospital de Gran Canaria Dr Negrin, Las Palmas University, Las Palmas, Spain; The Viva Study: Rafael Gabriel, M. Serrano-Rios, M. Pladevall, J. Muniz, Hospital De La Princesa, Madrid, Spain. **Sweden:** The Northern Sweden MONICA Study (three cohorts): Mats Eliasson, Birgitta Stegmayr, Vivan Lundberg, Department of Medicine, Institution of Public Health and Clinical Medicine, University of Umeå, Umeå, Sweden. **U.K.:** Newcastle Heart Project: Nigel Unwin, Naseer Ahmad, K. George, M.M. Alberti, Louise Hayes.

#### Secretariat

Knut Borch-Johnsen, Steno Diabetes Center, Gentofte, Denmark; Johan Eriksson, Qing Qiao, Jaakko Tuomilehto, Department of Epidemiology and Health Promotion, National Public Health Institute, Helsinki, Finland.

#### Data analysis

Qing Qiao, Gang Hu, Department of Epidemiology and Health Promotion, National Public Health Institute, Helsinki, Finland; Beverley Balkau, INSERM U258, Paris, France.

#### Writing Committee

Qing Qiao, Gang Hu, Jaakko Tuomilehto, Johan Eriksson, Diabetes and Genetic Epidemiology, Department of Epidemiology and Health Promotion, National Public Health Institute, Helsinki, Finland; Beverley Balkau, INSERM U258, Paris, France; Knut Borch-Johnsen, Steno Diabetes Center, Gentofte, Denmark.

#### References

1. WHO Consultation: Definition, diagnosis and classification of diabetes mellitus and its complications. I. Diagnosis and classification of diabetes mellitus. Geneva, World Health Org., 99:2, 1999
2. Expert Committee on the Diagnosis and Classification of Diabetes Mellitus: Report of the Expert Committee on the Diagnosis and Classification of Diabetes Mellitus. *Diabetes Care* 20:1183–1197, 1997
3. DECODE Study Group: Will new diagnostic criteria for diabetes mellitus change phenotype of patients with diabetes? Reanalysis of European epidemiological data. *BMJ* 317:371–375, 1998
4. DECODE Study Group: Is fasting glucose sufficient to define diabetes? Epidemiological data from 20 European studies.

*Diabetologia* 42:647–654, 1999

5. Qiao Q, Nakagami T, Tuomilehto J, Borch-Johnsen K, Balkau B, Iwamoto Y, Tajima N: Comparison of the fasting and the 2-hour glucose criteria for diabetes in different Asian cohorts. *Diabetologia* 43: 1470–1475, 2000
6. Shaw JE, Boyko EJ, Courten de M, Zimmet PZ: Impact of new diagnostic criteria for diabetes on different populations. *Diabetes Care* 22:762–766, 1999
7. Shaw JE, Zimmet PZ, de Courten M, Dowse GK, Chitson P, Gareeboo H, Hemraj F, Fareed D, Tuomilehto J, Alberti KG: Impaired fasting glucose or impaired glucose tolerance: what best predicts future diabetes in Mauritius? *Diabetes Care* 22: 399–402, 1999
8. Wahl PW, Savage PJ, Psaty BM, Orchard TJ, Robbins JA, Tracy RP: Diabetes in older adults: comparison of 1997 American Diabetes Association classification of diabetes mellitus with 1985 WHO classification. *Lancet* 352:1012–1015, 1998
9. Harris MI, Eastman RC, Cowie CC, Flegal KM, Eberhardt MS: Comparison of diabetes diagnostic categories in the U.S. population according to 1997 American Diabetes Association and 1980–1985 World Health Organization Diagnostic Criteria. *Diabetes Care* 20:1859–1861, 1997
10. King H, Aubert RE, Herman WH: Global burden of diabetes, 1995–2025: prevalence, numerical estimates, and projections. *Diabetes Care* 21:1414–1431, 1998
11. King H, Rewers M, WHO Ad Hoc Diabetes Reporting Group: Global estimates for prevalence of diabetes mellitus and impaired glucose tolerance in adults. *Diabetes Care* 16:157–177, 1993
12. World Health Organization: *WHO Expert Committee on Diabetes Mellitus: Second Report*. Geneva. World Health Org., 1980 (Tech. Rep. Ser., no. 646)
13. World Health Organization: *Diabetes Mellitus: Report of a WHO Study Group*. Geneva, World Health Org., 1985 (Tech. Rep. Ser., no. 727)
14. Vanhala MJ, Kumpusalo EA, Pitkääjärvi TK, Takala JK: "Metabolic syndrome" in a middle-aged Finnish population. *J Cardiovasc Risk* 4:291–295, 1997
15. Schranz A, Tuomilehto J, Marti B, Jarrett RJ, Grabauskas V, Vassallo A: Low physical activity and worsening of glucose tolerance: results from a 2-year follow-up of a population sample in Malta. *Diabetes Res Clin Pract* 11:127–136, 1991
16. Garancini MP, Calori G, Ruotolo G, Manara E, Izzo A, Ebbli E: Prevalence of NIDDM and impaired glucose tolerance in Italy: an OGTT-based population study. *Diabetologia* 38:306–313, 1995
17. Mooy JM, Grootenhuys PA, de Vries H, Valkenburg HA, Bouter LM, Kostense PJ,

- Heine RJ: Prevalence and determinants of glucose intolerance in a Dutch Caucasian population: The Hoorn Study. *Diabetes Care* 18:1270–1273, 1995
18. Unwin N, Harland J, White M: Body mass index, waist circumference, waist-hip ratio, and glucose intolerance in Chinese and European adults in Newcastle, UK. *J Epidemiol Community Health* 51:160–166, 1997
  19. Hitunen L, Luukinen H, Koski K, Kivela SL: Prevalence of diabetes mellitus in an elderly Finnish population. *Diabet Med* 11:241–249, 1994
  20. Castell C, Tresserras R, Serra J, Goday A, Lloveras G, Salleras L: Prevalence of diabetes in Catalonia (Spain): an oral glucose tolerance test-based population study. *Diabetes Res Clin Pract* 43:33–40, 1999
  21. Pajak A: Insulin sensitivity and coronary heart disease risk factors in a population based sample: XVII Congress of the European Society of Cardiology. *Eur Heart J* 16 (Suppl.):143, 1995
  22. de Pablos-Velasco PL, Martinez-Martin FJ, Rodriguez-Perez F, Ania BJ, Losada A, Betancor P: Prevalence and determinants of diabetes mellitus and glucose intolerance in a Canarian Caucasian population-comparison of the 1997 ADA and the 1985 WHO criteria: The Guia Study. *Diabet Med* 18:235–241, 2001
  23. Lorenzo C, Serrano-Rios M, Martinez-Larrad MT, Gabriel R, Williams K, Gonzalez-Villalpando C, Stern MP, Hazuda HP, Haffner SM: Was the historic contribution of Spain to the Mexican gene pool partially responsible for the higher prevalence of type 2 diabetes in Mexican-origin populations? The Spanish Insulin Resistance Study Group, the San Antonio Heart Study, and the Mexico City Diabetes Study. *Diabetes Care* 24:2059–2064, 2001
  24. Eliasson M, Lindahl B, Lundberg V, Stegmayr B: Diabetes and obesity in northern Sweden: occurrence and risk factor for stroke and myocardial infarction. *Scand J Public Health*. In press
  25. Resnick HE, Harris MI, Brock DB, Harris TB: American Diabetes Association diabetes diagnostic criteria, advancing age, and cardiovascular disease risk profiles: results from the Third National Health and Nutrition Examination Survey. *Diabetes Care* 23:176–180, 2000
  26. Harris MI, Flegal KM, Cowie CC, Eberhardt MS, Goldsten DE, Little RR, Wiedmeyer H-M, Byrd-Holt DD: Prevalence of diabetes, impaired fasting glucose, and impaired glucose tolerance in U.S. adults. *Diabetes Care* 21:518–524, 1998