Forecasting the Number of Diabetic Patients in The Netherlands in 2005

ABSTRACT

Objectives. There is evidence from past decades that the number of diabetic patients has increased independently of changes in demography. A static model that takes into account only demographic changes is therefore unable to forecast the expected number of diabetic patients correctly.

Methods. We developed a dynamic model in which actual incidence, prevalence, and life expectancy data are used and alternative assumptions about future trends in these parameters can be incorporated.

Results. This dynamic model forecasts higher numbers of diabetic patients than the less sophisticated static model. According to the dynamic model, a 46% increase in the number of diabetic patients in The Netherlands can be expected, from 244 000 in 1990 to 355 000 in 2005 (about 2.5% annually). The static model forecasts a 22% increase.

Conclusions. Diabetes mellitus will become a more serious public health problem than can be expected from demographic changes only. In planning future health care, monitoring of trends in incidence, prevalence, remission, and mortality or life expectancy is a necessary prerequisite. (*Am J Public Health.* 1993;83: 989–995)

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Introduction

In planning future health care for an aging Western population, one of the main problems is the number of patients with chronic diseases expected in the next few decades. Diabetes mellitus is a major and growing cause of prolonged ill health and premature mortality that affects tens of millions of people in countries at all levels of development.[1] Therefore, diabetes mellitus was selected as a case study for further investigation in The Netherlands.[2,3]

The results of two prognostic models (static and dynamic) for computing the number of patients with diabetes mellitus expected in The Netherlands in 2005 are presented. The static model takes into account only actual prevalence data and demographic changes. The dynamic model also makes use of information about actual incidence as well as life expectancy data. The dynamic model was developed because there is evidence that in past decades type I (insulin-dependent) as well as type II (non-insulin-dependent) diabetes mellitus increased independently of demographic changes,[4–8] which makes the static model inadequate.

With a historic simulation procedure, it was possible to compute prevalence figures and compare them with actual prevalences. This procedure can be considered a validation of the dynamic model. Varying the actual incidence, prevalence, and life expectancy data on diabetic patients made it possible to test the sensitivity of the dynamic model in forecasting the number of diabetic patients in 2005 (sensitivity analysis).

To our knowledge this is the first study that uses more than demographic changes to compute the number of diabetic patients expected.

Methods

Description of the Two Models

Two distinct models are used to compute the number of patients expected in the year 2005. The first is called a "static" or "equilibrium" model. In this model the assumption is made that the age- and sex-specific prevalence of diabetes mellitus will remain constant over time. Apart from the prevalence, the only parameter of importance is demography (changing quantity and composition of the Dutch population until 2005). A simple multiplication of the age- and sex-specific prevalence by the population estimates at a certain moment yields the expected number of diabetic patients. This model makes it possible to determine the influence of demographic changes on the number of patients expected.

The second model is called a "dynamic" or "disequilibrium" model. In this model the age- and sex-specific prevalence is not presumed in advance to be

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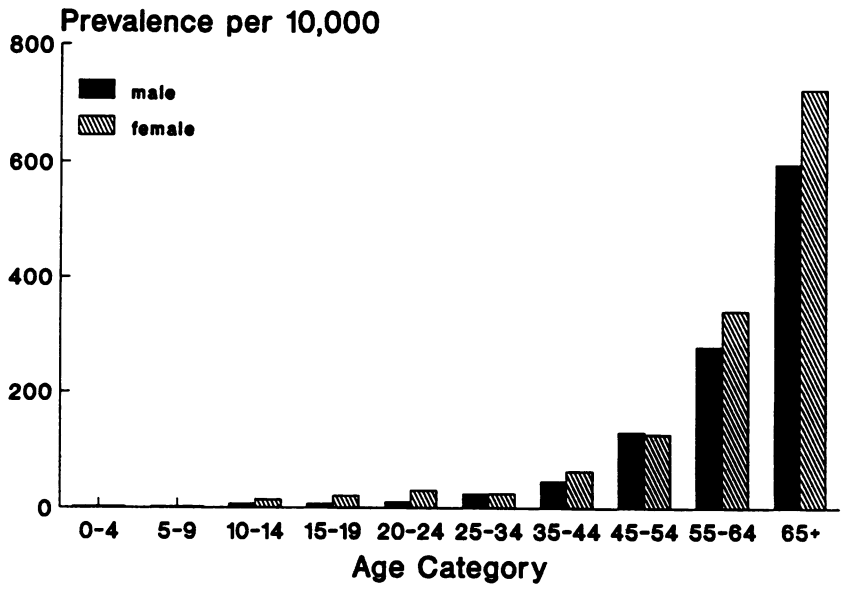
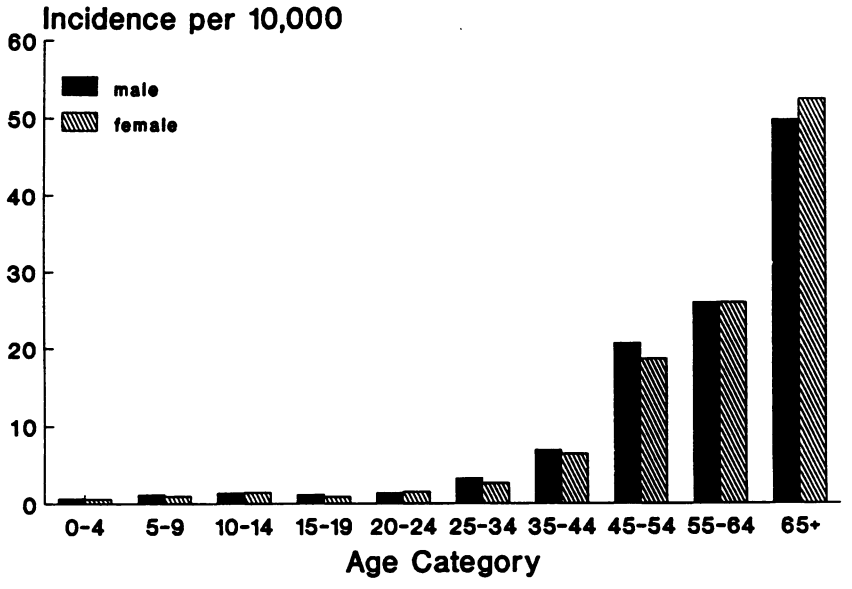


Source. Adapted from the Dutch Sentinel Practice Network[11] by Hoogenveen et al.[10]

FIGURE 1—Prevalence of diabetes mellitus per 10 000 inhabitants in The Netherlands in 1980, by age and sex.



Source. Adapted from the Dutch Sentinel Practice Network[11] and Vaandrager et al.[12]

FIGURE 2—Incidence of diabetes mellitus per 10 000 inhabitants in The Netherlands in 1980, by age and sex.

stable over time. Extra data are needed on the age- and sex-specific influx of new patients into and the age- and sex-specific efflux of known patients out of the pool of diabetic patients. The incidence represents the influx. The efflux is the sum of the diabetic patients who die and the diabetic patients who recover from the disease. In our model, data on the reduction of life expectancy from the moment diabetes mellitus is diagnosed, instead of mortality figures from death certificates, are used to define the efflux. Data based on death certificates are considered to be unreliable. On 25% to 77% of the death certificates of patients with diabetes mellitus, this disease is not mentioned at all.[9] Recovery from diabetes mellitus is not unlikely, but it is often temporary and medical care in terms of blood glucose and weight control is still recommended. Therefore the assumption is made that recovery does not occur.

In the dynamic model two variants are used. In the first variant the incidence remains constant over time; in the second variant a regular age- and sex-specific increase in incidence is taken into account. In both variants the reduction of life expectancy is kept constant over time, because in the literature there is no evidence that life expectancy has changed substantially for the majority of the patients (type II patients). The impact of improved survival, of type I patients only, on the projections would be limited. First, type I patients represent only 10% to 20% of all patients. Second, because of demographic changes in the period from 1980 to 2005 (i.e., the aging of the Dutch population), the absolute numbers of type II patients will strongly increase, while the proportion of type I patients will decrease. For a more detailed description of the models, see Appendix A and Hoogenveen et al.[10]

To start the dynamic model we had to estimate the age- and sex-specific distribution of the diabetic patients over the years of remaining life expectancy in the first year of the simulation period. A more detailed description of this precalculation procedure is given in Appendix B.

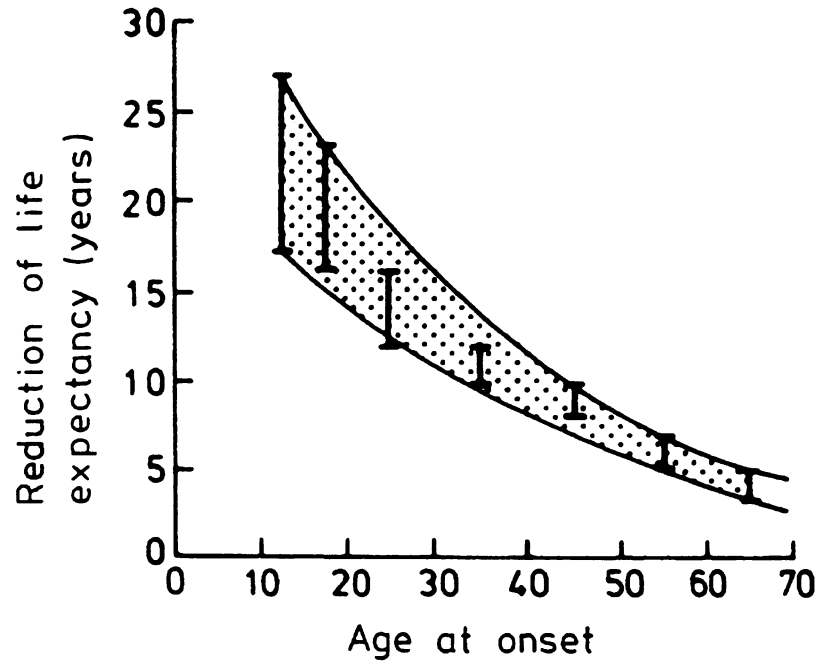
Data Used

As a baseline for computing the number of diabetic patients expected in 2005, the year 1980 was selected. The most reliable and representative data for The Netherlands stem from periods around this year. The age- and sex-specific prevalence in 1980 is presented in Figure 1. It represents known diabetic patients registered in 1980 in a Dutch sentinel network of general practitioners, distributed all over the country and covering about 160 000 inhabitants of all ages (1.2% of the Dutch population).[11] The incidence in 1980 is presented in Figure 2. The incidence for age categories older than 19 years was recorded in the period from 1980 through 1983; the data were obtained from the same study as the prevalence figures.[11] Although the sentinel network was covering about 160 000 inhabitants and 3 years were used to estimate the average annual incidence, the incidence of diabetes mellitus in the younger age categories is too small to obtain reliable figures. For the age categories from birth through 19 years, therefore, we used the nationwide retrospective study of children younger

than 20 years, which registered all new type I diabetic patients in the period 1978 through 1980.[12] The method chosen was a questionnaire distributed to all Dutch pediatricians and internists. To correct for undercount of cases, the same questionnaire was given separately to members of the Dutch Diabetes Association, employing the capture-recapture census method for calculating the ascertainment-corrected incidence figures.[13] Because diabetes in persons from birth through 19 years of age is almost entirely type I diabetes, the ascertainment-corrected annual incidence is presumed to represent all diabetic patients. Although ascertainment did not take place in the Dutch Sentinel Practice Network, prevalence and incidence figures are likely to be reliable because in The Netherlands every person has a general practitioner who records the patient's health problems, whether the patient will be treated by the general practitioner or by another doctor. Nevertheless, it is possible that newly diagnosed patients who will be treated by a specialist have not yet been recorded by the general practitioner. In that case the recorded incidence will be underestimated only slightly, because nearly 70% of all patients will be diagnosed by the general practitioner.[11]

The reduction of life expectancy for diabetic patients is presented in Figure 3.[14] These data, which have been used in the dynamic model, are taken from three longitudinal studies of diabetic patients.[15–17] Comparing these data and mortality data of the Dutch population from the Central Bureau of Statistics, we estimated the reduction of life expectancy for diabetic patients at onset to be 20% to 35%, depending on age at onset. For patients whose age at onset was in the category birth through 19 years and for those older than 79 years, the reduction of life expectancy was 30% to 35%; for patients aged 20 through 79 years the reduction of life expectancy was 20% to 30%, decreasing with age.

An expected increase in incidence of 8% is assumed for the period 1980 through 2005 in the second variant of the dynamic model. This assumption is based on the average increase expected by 33 experts on diabetes mellitus in The Netherlands, one of the results of a Delphi investigation.[18] The demographic data come from the Dutch Central Bureau of Statistics. The assumptions of the middle variant of the Central Bureau of Statistics population forecasts are used to estimate the future number of inhabitants in The Netherlands.[19]



Note. The shaded area indicates the region between the highest and lowest estimates.
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FIGURE 3—Reduction of life expectancy for diabetic patients, by age at onset.

Historic Validation and Sensitivity Analysis

Two validation procedures were performed to analyze the stability of the model, that is, whether the data on incidence, prevalence, and reduction of life expectancy due to diabetes mellitus and the assumption of no remission result in a state of relative equilibrium of the dynamic model. The first validation procedure was a historic simulation of the prevalence between 1955 (specific demographic data before 1955 are lacking) and 1980, assuming time-independent relative incidence and reduction of life expectancy to forecast the 1980 absolute prevalence. We compared the calculated prevalence with the 1980 data. This historic simulation also made it possible to subdivide the prevalence for those older than 64 years into the more specific age categories 65 through 79 years and 80 years and older. The actual data gave just one prevalence for all those older than 64 years.

The second validation procedure was a sensitivity analysis. We analyzed the impact on the forecast prevalence in 2005 of variations in some main model parameters (i.e., the 1980 prevalence, incidence, and reduction of life expectancy data for diabetic patients). For the incidence and prevalence, two variants were used: a 5% increase and a 5% decrease in each age- and sex-specific category compared with the actual data for 1980. For the reduction of life expectancy, a 25% increase and 25% decrease were used. Also, one variant with a linear increase in incidence with age for those older than 64 years was used. For this age category the available empirical data yielded just one value for the incidence for men and one for women. These values were used in the dynamic models but may not be in accord with reality. The literature provides evidence that the incidence increases with age for those older than 64 years.[20] Therefore, in one variant a linear increase in incidence with age was assumed for those older than 64 years.

Results

Expected Number of Patients Predicted by the Two Models

The static model predicted an increase from 191 000 patients (1.35% of the population) in 1980 to 268 000 (1.65% of the population) in 2005, an increase of nearly 41%. Growth and aging of the Dutch population are responsible for increases of 15% and 25%, respectively. The dynamic model resulted in an increase to 339 000 patients (2.1% of the population) in 2005, that is, a total increase of 78% between 1980 and 2005. The extra increase of 37% over the prediction of the

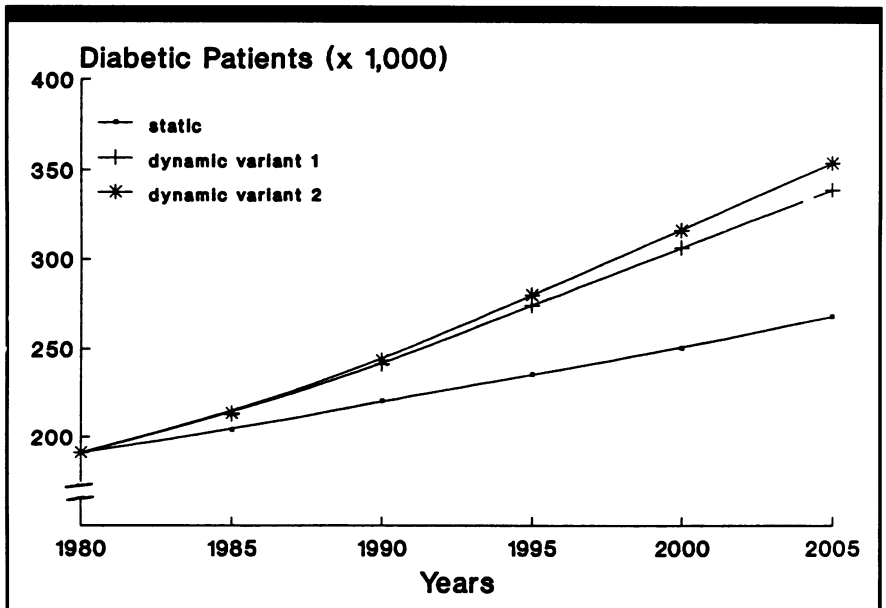

FIGURE 4—Expected increase in the number of diabetic patients in The Netherlands between 1980 and 2005, according to the static model and variant 1 and 2 of the dynamic model.

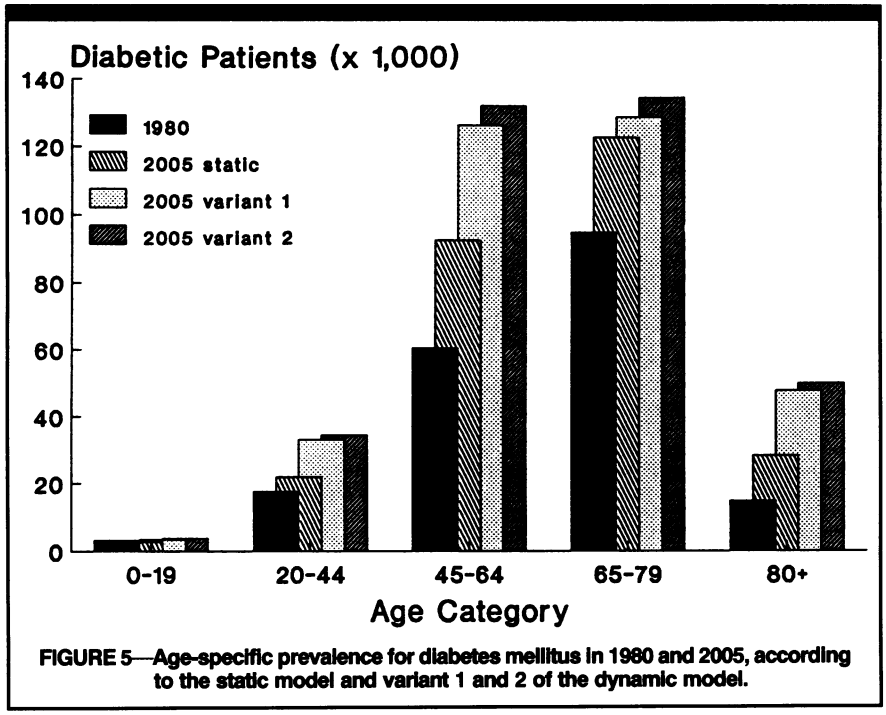

FIGURE 5—Age-specific prevalence for diabetes mellitus in 1980 and 2005, according to the static model and variant 1 and 2 of the dynamic model.

static model is the result of the disequilibrium between the influx and efflux of patients. The incidence exceeds the mortality. The second variant of the dynamic model resulted in an increase to 355 000 patients (2.2% of the population) in 2005, that is, an additional increase from 78% to 86%. In this variant the influx exceeds the efflux of patients even more.

The absolute increase in the number of diabetic patients in the period 1980 through 2005 according to the two models is presented in Figure 4. The estimated number of patients in 1990 predicted by the static model is 222 000 (1.5% of the population), compared with 242 000 (1.6% of the population) and 244 000 (1.6% of the population) predicted by the first and second variants of the dynamic model, respectively.

Age-specific analysis reveals that the expected absolute rise in the period 1980 through 2005 is most prominent in the age category 45 through 64 years (Figure 5). This applies to men as well as to women. Relatively, the most pronounced increase was found for the age category 80 years and older (in the dynamic model the number of patients in this category in 2005 is about 3.0 to 3.5 times the number in 1980, for both men and women).

TABLE 1—Projected Percentage Changes[a] in the Number of Patients in 2005, According to the Dynamic Model

Age- and Sex-Specific Change	Change in the Number of Diabetic Patients in 2005		
	Male	Female	Total
Prevalence			
+5	+0.2	+0.4	+0.3
−5	−0.2	−0.4	−0.3
Incidence			
+5	+4.8	+4.6	+4.7
−5	−4.8	−4.6	−4.7
Life expectancy			
+25	+2.3	+11.0	+7.1
−25	−9.0	−3.7	−6.1

[a]As a result of variation in age- and sex-specific prevalence, incidence, and life expectancy in 1980.

Historic Validation and Sensitivity Analysis

The historic simulation showed a 10% higher prevalence in 1980 than the empirical numbers. This difference is statistically significant ($P < .001$). The calculations also showed that the prevalence for the oldest category (80+ years) in 1980 (2.8% for men, 5.8% for women) was lower than that for the 65- through 79-year-old category (6.0% for men, 7.3% for women).

The results of the sensitivity analysis for the dynamic model (first variant) are presented in Table 1. A 5% change in the age- and sex-specific prevalence in 1980 changes the total number of patients in 2005 by less than 1%. For the incidence, a 5% change in each age- and sex-specific category results in a similar 5% change in the total number of patients in 2005. When the reduction of life expectancy is changed by 25%, the total number of patients in 2005 changes by 6% to 7%. For men, a decrease in life expectancy influenced the results more than an increase; for women, the opposite applied. If instead of one value for all those older than 64 years, a linear increase in incidence is used, a decrease of 9000 patients (2.7%) is found in 2005 (not presented in Table 1).

Discussion

Two models were used to compute the projected number of diabetic patients:

a static model and a dynamic model. The static model forecasts 268 000 patients in 2005; the dynamic model (second variant), 355 000. These estimates include all classes of diabetes mellitus.[1] Type II diabetes represents about 80% to 90% and type I diabetes represents about 10% to 20% of all diabetic patients.[21,22]

Of the two models, the dynamic model is considered to be the more valid. For the static or equilibrium model, the assumption was made that the age- and sex-specific prevalence remains constant over time. This type of model for chronic diseases can be used only if the age- and sex-specific incidence and life expectancy of diabetic patients are constant during a long period. For diabetes this is unlikely, because an increasing incidence has been reported in the literature.[4-8] Our historic simulation procedure supports this observation. It appeared that the forecasted prevalence for 1980 was about 10% higher than the actual registered prevalence in 1980.

In the dynamic or disequilibrium model, it appeared that the influx of new patients was higher than the efflux of known patients, particularly in the second variant, in which an increasing incidence was assumed. There is no reason to assume that the past increase in incidence, as reported in the literature, has stopped. Furthermore, there are no indications of a significant change in life expectancy for the majority of the diabetic population (type II patients). Therefore, this parameter was kept constant. Consequently, the second variant, which resulted in a total increase of 86%, is viewed as the more valid. On the other hand, it is quite obvious that the increase in incidence contributes relatively little to this total increase in the number of diabetic patients in 2005 (8%). In contrast, changes in demography (static model) and the disequilibrium between influx and efflux in the first variant of the dynamic model caused increases of 41% and 37%, respectively.

As stated earlier, the dynamic model was validated by a historic simulation procedure. This procedure resulted in a lower prevalence for persons aged 80 years and older in 1980 than for persons aged 65 through 79 years. This finding may be a consequence of the use of just one incidence for those older than 64 years. Empirical age-specific incidence data for those older than 64 years were nonexistent. Therefore we may have underestimated the incidence for those aged 80 years and older and, as a consequence, we may have underestimated the prevalence for this age category in 1980. In the second place, the estimated number of patients dying in this age category may be too high (the reduction of life expectancy has been overestimated), thereby underestimating the prevalence for those aged 80 years and older in 1980. On the other hand, the lower prevalence in the oldest age category has been confirmed by several empirical studies.[8,23-25]

The sensitivity analysis revealed that the dynamic model is most sensitive to variations in incidence and is relatively insensitive to variations in prevalence. (This applies to all diseases characterized by a prevalence that increases with age.) The majority of the diabetic patients in 1980 were older than 64 years of age and most of them will not survive until 2005; almost all of the diabetic patients in 2005 will represent incident patients diagnosed in the period 1980 through 2005. The validity of the prevalence and incidence data used is considered in the Methods section.

The dynamic model was moderately sensitive to changes in life expectancy for diabetic patients. It is striking that for men a decrease in life expectancy influenced the results more than an increase. For women the opposite applied. This is probably due to the cutoff point: the year 2005. The explanation may be that the age of onset of diabetes is relatively lower for men than for women (Figure 2). Men diagnosed at the age of 45 years in 1980 will still be alive in 2005 if life expectancy remains unchanged or increases, but they may be dead in the event of an extra reduction of life expectancy. On the other hand, women diagnosed at the age of 65 years in 1980 will probably be dead in 2005 if life expectancy remains unchanged or decreases, but they may be alive in the event of an increase in life expectancy.

When a linearly increasing incidence for those older than 64 years of age was used, instead of one incidence, the predicted number of patients in 2005 decreased by 9000 (2.7%). The explanation is simple. First, a higher incidence in the oldest category results in a shorter duration of the disease. Those in the oldest category will die earlier. In the second place, the countervailing lower incidence for the age category 65 through 79 years, which is a larger group (denominator), will result in a larger absolute decrease in the number of diabetic patients.

The results presented in this paper relate only to the number of patients diagnosed. In the second National Health and Nutrition Examination Survey (1976–1980) in the United States, it was found that diagnosed patients represent only 50% of all diabetic patients.[26] Also, in The Netherlands it appears that many individuals suffer from undiagnosed disturbances in glucose metabolism.[27-29] Preliminary results of a cross-sectional study in The Netherlands of 2800 persons aged 50 through 74 years revealed that the prevalence of previously diagnosed diabetes was 4.8%. Diabetes was newly diagnosed by means of a glucose tolerance test in 5.3%.[29] Assuming that those results (roughly 50% undiagnosed patients) apply to the whole Dutch population and that all hitherto undiagnosed cases are diagnosed in 2005, an extra 355 000 diabetic patients can be expected in 2005. On the other hand, it is not unlikely that these patients represent a subcategory needing less intensive medical care.

Successful planning of future health care for diabetic patients depends on the availability of valid epidemiological data on trends in the incidence, prevalence, remission, and mortality or life expectancy for patients with this condition. Both the diabetes study of the Dutch Sentinel Practice Network and the registry of type I diabetes by all Dutch pediatricians and internists will be repeated—the former in the period 1990 through 1993, the latter retrospectively for the period 1988 through 1990. Therefore it will be possible to partly validate the models. Although the present computations concern diabetes mellitus in the Dutch population, the method is also relevant for other chronic diseases and other countries. The main restriction is the availability of valid data. It is therefore highly recommended that registries for diabetes mellitus and other chronic diseases be started and/or improved. □

Acknowledgments

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APPENDIX A—Static and Dynamic Models for Computing the Number of Patients Expected in the Future

	Static Model	Dynamic Model
Purpose:	Estimating changes in absolute prevalence numbers due to demographic changes	Estimating changes in absolute prevalence numbers due to demographic and epidemiologic changes
Definition:	Equilibrium: time-independent age- and sex-specific relative prevalence figures	Disequilibrium: time-dependent age- and sex-specific relative prevalence figures
Assumptions (age and sex specifically):	Influx equals efflux	(a) no remission (both variants) (b) time-independent reduction of life expectancy (both variants) (c) time-independent relative incidence figures (first variant) (d) time-dependent relative incidence figures (second variant)
Formulas:	(1), (2)	(3)–(6)

The static model projects actual relative prevalence figures on future population numbers. Formulas:

$$prev_{yr,s,a} = POP_{yr,s,a} \cdot PREVFR_{1980,s,a} \quad (1)$$

$$prev_{yr} = \sum_{s,a} prev_{yr,s,a} \quad (2)$$

where yr = time moment, s = sex, a = age, prev = absolute prevalence numbers, POP = absolute population numbers, and PREVFR = relative prevalence figures. Names in capitals are data, names in lowercase letters are model results. The interpretation of the formulas is as follows: (1) The absolute prevalence number in each age and sex category in a certain year is the product of the time-independent relative prevalence figure and the time-dependent population number in that specific category. (2) The total prevalence number in a certain year is the sum of all age- and sex-specific prevalence numbers in that year.

The dynamic model is a Markov model. The Markov assumption is that the future behavior of an individual depends only on his or her actual state, not on his or her (disease) history. The main states being distinguished are health status—and, if a patient, remaining life expectancy—and age and sex. Formulas:

$$rle_{yr,s,a} := le_{yr,s,a} - LERED_{yr,s,a} \quad (3)$$

$$inc_{yr,s,a} := POP_{yr,s,a} \cdot INCFR_{yr,s,a} \quad (4)$$

$$prev_{yr+1,s,d} := prev_{yr,s,d+1} + \sum_a inc_{yr,s,a} \cdot (d = rle_{yr,s,a}) \quad (5)$$

$$prev_{yr,s,0} := 0 \quad (6)$$

where (see also above) rle = remaining life expectancy, le = normal life expectancy, LERED = reduction of life expectancy on age at onset, inc = absolute incidence numbers, INCFR = relative incidence figures, and d = remaining life expectancy. The interpretation of the formulas is as follows: (3) The remaining life expectancy is the difference between the normal and the reduction of life expectancy. (4) The absolute incidence number in each age and sex category in a certain year is the product of the time-independent relative incidence figure and the time-dependent population number in that specific category. (5) The absolute prevalence number at the end of each year is the sum of the prevalence number at the start of the year and the incidence number during the year. The remaining life expectancy of the prevalent cases who survive decreases with 1 year. (6) Patients die when their remaining life expectancy is zero.

APPENDIX B—Procedure for Estimating Age- and Sex-Specific Distribution of Patients over Years of Remaining Life Expectancy

To start the Markovian dynamic model, we had to estimate the age- and sex-specific distribution of the prevalence numbers over the remaining life expectancy in the first year of the simulation period (1980). We made two assumptions for this pre-calculation procedure. First, the absolute incidence number decreases with a constant multiplicative factor back in time. We had to make this assumption because of the lack of specific demographic data for the years before 1955. Second, the remaining life expectancy on the age at onset of diabetes is constant over time. The main formulas of this precalculation are as follows:

$$\mathrm{inc}_{1980,s,a} := \mathrm{POP}_{1980,s,a} \cdot \mathrm{INCFR}_{1980,s,a} \tag{1}$$

$$\mathrm{inc}_{yr,s,a} := 0.98 \cdot \mathrm{inc}_{yr+1,s,a} \tag{2}$$

$$\mathrm{prev}_{1980,s,a,d} := \sum_{yr<1980,a} \cdot \mathrm{inc}_{yr,s,a^*} \cdot (\mathrm{rle}_{1980,s,a^*} > [1980 - yr]) \cdot (a - a^* = 1980 - yr) \cdot (\mathrm{rle}_{1980,s,a^*} - d = 1980 - yr) \tag{3}$$

$$\mathrm{prev}_{1980,s,d} := \sum_a \{\mathrm{prev}_{1980,s,a,d} \cdot \mathrm{PREVFR}_{1980,s,a} \cdot \mathrm{POP}_{1980,s,a} / \sum_d \mathrm{prev}_{1980,s,a,d}\} \tag{4}$$

where (see also Appendix A) a = age in the year of prevalence (1980), a* = age in the year of incidence. The interpretation of the formulas is as follows: (1) The absolute incidence number in each age and sex category in 1980 is the product of the relative incidence figure in 1980 and the population number in that specific category in 1980. (2) The absolute incidence number in each age and sex category in a certain year before 1980 is the absolute incidence number in that specific category in the next year multiplied by 0.98. (3) The absolute prevalence number in 1980 is the sum of the incidence numbers during the years before 1980 that are still alive in 1980. The three multiplicative factors show the three conditions on the incidence numbers: survival to 1980, aging from age a* in the year of incidence to age a in 1980, and reduction of the life expectancy on the age at onset equal to the difference between the year of incidence and 1980. (4) The calculated prevalence numbers are scaled so that the age- and sex-specific numbers agree with the 1980 data. A sensitivity analysis showed that the prognostic model results (Appendix A) are not sensitive to the exact implementation of the precalculation procedure, that is, the choice of the multiplicative factor in equation (2), when the simulation period is about 25 years. A 5% change in this multiplicative factor changes the total number of patients in 2005 by less than 1%.