Modeling the Future Burden of Stroke in the Netherlands
Impact of Aging, Smoking, and Hypertension

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Background and Purpose—In the near future, the number of stroke patients and their related healthcare costs are expected to rise. The purpose of this study was to estimate this expected increase in stroke patients in the Netherlands. We sought to determine what the future developments in the number of stroke patients due to demographic changes and trends in the prevalence of smoking and hypertension in terms of the prevalence, incidence, and potential years of life lost might be.

Methods—A dynamic, multistate life table was used, which combined demographic projections and existing stroke morbidity and mortality data. It projected future changes in the number of stroke patients in several scenarios for the Dutch population for the period 2000 to 2020. The model calculated the annual number of new patients by age and sex by using incidence rates, defined by age, sex, and major risk factors. The change in the annual number of stroke patients is the result of incident cases minus mortality numbers.

Results—Demographic changes in the population suggest an increase of 27% in number of stroke patients per 1000 in 2020 compared with 2000. Extrapolating past trends in the prevalence of smoking behavior, hypertension, and stroke incidence resulted in an increase of 4%.

Conclusions—The number of stroke patients in the Netherlands will rise continuously until the year 2020. Our study demonstrates that a large part of this increase in the number of patients is an inevitable consequence of the aging of the population. (Stroke. 2005;36:1648-1655.)

Key Words: epidemiology ■ cigarette smoking ■ hypertension ■ scenario analyses ■ stroke

Stroke is a major disease in aging population subgroups. Not only the disease impact but also the healthcare impact of stroke are substantial.1–3 Stroke mortality is the third largest cause of death in the Netherlands. Overall, 8.5% of deaths in the Netherlands in 2001 were caused by stroke.4 As in most other developed countries, in the 1970s and 1980s a substantial decline in stroke mortality was observed in the Netherlands.5–6 Between 1974 and 1986, annual stroke mortality dropped by 2.7% for men and by 3.6% for women.6 From 1990 onward, the decline in mortality rates has leveled off. Stroke incidence rates have been stable since the 1980s.7 Likewise, the prevalence rates of stroke in the Netherlands have been stable during the last decade, although they showed a slight increase in the past few years.7

For health policy, it is important to have insight into the (future) trends in morbidity and mortality, because it enables priority setting in health care. It is particularly important in countries with an aging population, like the Netherlands. Insight into the future number of stroke patients allows healthcare policy makers to establish rational decisions about related healthcare needs, to plan healthcare facilities for stroke patients in the medium and long term, and to develop preventive measures for specific target groups, which can lead to new priority setting regarding the prevention and healthcare organization of stroke.

The future burden of stroke in the Netherlands has been studied previously, and future changes in stroke epidemiology were projected for the period 1985 to 2005 by using calculated trend values based on data from 1979 to 1989.8 However, from ~1990 onward, the calculated decline in stroke mortality and stroke incidence rates started to diverge from the observed trends in stroke mortality rates and stroke incidence rates. The divergence between the projections by Niessen et al8 and the observed trends during the period 1985 to 2005 can be explained by an unexpected leveling off of the decline in mortality rates and stroke incidence rates. Furthermore, the study by Niessen et al8 did not include trends in stroke risk factors (such as hypertension and smoking) in estimating the future number of stroke patients.
Hypertension is the most important modifiable risk factor for stroke for both men and women. A reduction of 10 to 12 mm Hg in systolic blood pressure and of 5 to 6 mm Hg in diastolic blood pressure results in a reduction of 38% in stroke incidence rates. Smoking is another major risk factor for stroke. In a meta-analysis, the overall relative risk of stroke associated with smoking was 1.5 compared with nonsmoking individuals. Therefore, a study investigating stroke associated with smoking was performed.

In Figure 1, the basic structure of the model is schematically presented. The boxes represent specific health states in the model, and the arrows represent transitions (eg, changes in smoking behavior or transitions from disease-free to stroke). The change in the annual number of stroke patients is the result of incident cases minus mortality numbers. Mortality consists of stroke mortality and mortality due to other causes. We calculated the PYLLs due to stroke for each age group (5-year age classes) by multiplying the number of deaths by the difference between mean life expectancy in each age and sex group and the mean age at death in each age and sex group. PYLLs correspond to the sum of the products obtained for each age and sex group.

Scenarios
To estimate future numbers of stroke patients, we formulated the following 5 scenarios: (1) A baseline scenario, in which the incidence and prevalence figures for the year 2000 were calculated. This baseline scenario will be used as the reference scenario. (2) A demographic scenario, in which the future prevalence of stroke depends on past trends in the prevalence of hypertension. Future hypertension prevalence is calculated by means of trend exploration. (4) A smoking scenario, in which age- and sex-specific incidence rates depend on the trend in smoking prevalence. Future smoking prevalence is based on trend exploration. (5) A combined hypertension and smoking scenario, in which both risk factors are simultaneously taken into account.

Methods
Model
A dynamic, multistate life table was used to estimate future stroke incidence, prevalence, and mortality in the Dutch population during the period 2000 to 2020. An earlier version of the model was used to forecast the future burden of chronic obstructive pulmonary disease.

The model calculates the annual number of new patients by age and sex by using incidence rates, defined by age, sex, and major risk factors (hypertension and smoking). In the stroke model, demographic data, relative risks, and transition probabilities are used. The input data of the model consist of age- and sex-specific population numbers and age- and sex-specific input data on incidence rates, prevalence rates, and case fatality rates, which are estimated by using data from various sources. In addition, age- and sex-specific input data, relative risks, and transition probabilities for hypertension and smoking in the Dutch population were estimated. The input data, relative risks, and transition probabilities are described in Appendix 2, which is also available from the first author.

In Figure 1, the basic structure of the model is schematically presented. The boxes represent specific health states in the model, and the arrows represent transitions (eg, changes in smoking behavior or transitions from disease-free to stroke). The change in the annual number of stroke patients is the result of incident cases minus mortality numbers. Mortality consists of stroke mortality and mortality due to other causes. We calculated the PYLLs due to stroke for each age group (5-year age classes) by multiplying the number of deaths by the difference between mean life expectancy in each age and sex group and the mean age at death in each age and sex group. PYLLs correspond to the sum of the products obtained for each age and sex group.

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Scenarios 2 through 5 are based on the middle variant of the demographic prognosis of Statistics Netherlands. The results of the scenarios will be presented in terms of the incidence, prevalence, and PYLLs.

Sensitivity Analysis
In the combined hypertension and smoking scenario, the most elaborate scenario, we assessed the univariate sensitivity of the key variables related to (1) incidence, (2) prevalence, and (3) case fatality rates. In addition, we performed multivariate analyses to test the outside plausible range of the future number of stroke patients. We adjusted all assumptions in the same direction to create a best-case and worst-case scenario.

Results
Incidence
Figure 2 shows the number of incident stroke patients in 2000 (baseline scenario) and the 4 scenarios for 2020 for men and women, expressed as the number of patients per 1000.

The incidence of stroke in the year 2000 was 1.8 per 1000 for men, 2.5 per 1000 for women, and 2.2 per 1000 for the whole population (baseline scenario). Based on changes in
the size and composition of the population in the demographic scenario, the incidence will increase to 2.3 (+27%), 2.7 (+6%), and 2.5 (+15%) per 1000 for men, women, and the whole population, respectively, by the year 2020.

The figure shows that the effects of trends in the prevalence of hypertension are relatively small and result in similar incidence figures of 2.4, 2.6, and 2.5 per 1000 for men, women, and the whole population, respectively. By adding the trend in smoking prevalence to the demographic scenario, the incidence figures are estimated at 2.3, 2.8, and 2.5 per 1000 for men, women, and the whole population, respectively, for the year 2020. Projections in the smoking and hypertension scenario result in incidence figures of 2.3, 2.8, and 2.5 per 1000 for men, women, and the whole population, respectively. The incidence rate for men will increase more than for women. Hence, the total effects of demographic changes and the changes due to trends in hypertension and smoking behavior in the population result in an increase of incidence per 1000 of 17% for the whole population. The incidence rate for women is expected to rise to ≈24 000 incident cases by the year 2020 and to ≈20 000 incident cases for men if all risk factors are taken into account.

**Prevalence**

Figure 3 shows that the prevalence of stroke in the year 2000 was estimated at 7.7 per 1000 for men, 7.2 per 1000 for women, and 7.5 per 1000 for the whole population. The prevalence was estimated at 118 500 (60 500 for males and 58 000 for females). In the demographic scenario, the prevalence rate per 1000 is estimated to increase to 8.2, 8.9, and 8.6 per 1000 by the year 2020. The prevalence rates per 1000 for women will increase more than for men. This difference is due to the higher numbers of women in older age classes than men during the aging process in the coming 20 years in the Netherlands.

When the trends in prevalence of hypertension and smoking are also taken into account, the prevalence rate per 1000 will increase to 8.7 per 1000 by the year 2020 (risk factor scenario). The effects of the major risk factors on the prevalence figure are fractionally small compared with the effects of demographic changes. In total, the prevalences increase to 71 000 stroke cases in men and to 81 000 stroke cases in women by the year 2020.

**Potential Years of Life Lost**

Figure 4 shows the PYLLs for the years 2000 to 2020 for the combined smoking and hypertension scenario, including the changes in size and composition of the population. Based on our input data, in 2000, almost 250 000 life-years were lost owing to premature death among patients with stroke. The projection in the combined hypertension and smoking scenario leads to an increase of ≈30%, to 335 000 PYLLs by the year 2020. Compared with the general population, a female stroke patient loses, on average, 8.9 year of life expectancy, whereas a male stroke patient loses, on average, 8.4 year of life expectancy (not shown in Figure 4).

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**Figure 3.** Stroke prevalence in 2000 and projections for 2020 in different scenarios for men, women, and the total population in the Netherlands.

**Figure 4.** Life years lost due to stroke for men, women, and the total population in the Netherlands, 2000 to 2020.
Sensitivity Analysis
We found that estimates of the future number of stroke patients were not particularly sensitive to variations in case fatality rates and the changes in transition rates, in the prevalence of hypertension, and in smoking prevalence. The single effect of a 10% change in transition rates for hypertension or smoking was at most 2% in incidence, prevalence, and mortality. A 10% decrease in case fatality rates for all age and sex classes resulted in an increase of 8% in the total number of prevalent stroke cases in 2020. The future number of patient estimates appeared to be more sensitive to variations in the incidence and prevalence rates of stroke in the Netherlands. When we applied the lowest incidence and prevalence stroke rates from Dutch general practitioner registries in the combined hypertension and smoking scenario, the effect was a 20% decrease in the total number of stroke incident cases and an 18% decrease in prevalent stroke cases by the year 2020. However, when we applied the highest incidence and prevalence stroke rates, the incidence and prevalence will increase by 19% and 16%, respectively.

Discussion
This study aimed to predict the future burden of stroke in the Netherlands. Besides the effects of demographic changes, we estimated the effects of trends in 2 major risk factors for stroke, ie, hypertension and smoking, in terms of incidence, prevalence, and PYLLs.

The dynamic, multistate life-table approach demonstrated that changes in the size and composition of the population will result in an increase of stroke incidence from 1.8 per 1000 in 2000 to 2.3 per 1000 in 2020 for men (28%) and from 2.5 per 1000 to 2.8 per 1000 for women (12%). The stroke prevalence was also estimated to increase substantially in the near future, ie, from 7.7 per 1000 in 2000 to 8.2 per 1000 for men (7%) and from 7.2 per 1000 to 8.9 per 1000 for women (24%).

The trend in prevalence of hypertension has a fractionally smaller effect on both the incidence and prevalence for stroke in both men and women. The input data of hypertension may have contributed to the marginal effects on the future number of stroke patients. Patients who use antihypertensive medication are no longer defined as hypertensives when normal blood pressure levels are achieved in our input data. Therefore, current improved detection and treatment of hypertension may have diminished the effect of hypertension. The trend in smoking prevalence in the Dutch population also has a relatively small effect on the future number of stroke patients in the medium term. This is caused by the large time lag between the decrease in smoking prevalence in society and its effect on stroke incidence rates. Current high stroke prevalence rates for men and lower prevalence rates for women are mainly due to past trends in smoking behavior. The higher increase in stroke prevalence rates for women in 2020 in our projections are due to past smoking behavior, with women showing a smaller decrease in smoking prevalence than men in the last few decades.

Combining the effects of the trends in hypertension prevalence and smoking prevalence results in an additional increase of 4% in stroke prevalence in 2020. Our model projection shows that the slightly advantageous effects of the trend in prevalence of hypertension in the Dutch population are overshadowed by the adverse effects of the trend in prevalence of smoking in the Dutch population, especially in women. Our model demonstrates that the increase in prevalence is associated with an increase of PYLLs of >30% in the period 2000 to 2020. The annual amount of PYLLs increases by a stable percentage in each different time period.

Comparing our results during the period 2000 to 2020 with the results of an earlier study for the period 1985 to 2005 revealed that they differ considerably for stroke incidence rates. Niessen et al projected for the period 1985 to 2005 a 19% decline in the absolute numbers of stroke incident cases for men (current study, an increase of 28% per 1000 between 2000 to 2020, which corresponds to an increase of 39% in stroke incident numbers) and an ~17% decline for women (current study, increase of 12% per 1000 between 2000 and 2020, which corresponds to an increase of 20% in absolute incident stroke numbers). Niessen et al estimated an annual decline in stroke incidence rates based on calculated trend values, but empirical data up to the year 2000 have not confirmed this decline. Also, the effects of ongoing aging of the population are different for the 2 time periods (1985 to 2005 vs 2000 to 2020), which in turn leads to different effects on the number of incident stroke cases. Finally, the effects of trends in risk factors, as accounted for in the current study, will result in a growing number of stroke patients. However, these effects do not have a great impact on the future number of new stroke patients.

Our study predicts an increase in stroke prevalence rates of 24% per 1000 for women, which corresponds to an increase of 40% in absolute prevalence rates. This increase is twice as large as that predicted by Niessen et al (an increase of 19%). However, the increase in prevalence rates for men in the current study (an increase of 7% per 1000, which corresponds to an increase of 18% in absolute stroke numbers) is comparable with the results of Niessen et al (an increase of 25%). The larger increase in women observed in our study is related to the different number of incident cases and the differences in stroke mortality rates used in the 2 studies. Niessen et al predicted an annual decline in stroke mortality rates, but this prediction has not been confirmed by empirical data. The study of Niessen et al did not calculate the PYLLs, so a comparison with the current study cannot be made.

Some remarks need to be made. In our model, assumptions were made to fill gaps in knowledge. However, when applying the maximum and minimum values of the most sensitive variables, the projections in our model are robust in terms of incidence, prevalence, and PYLLs. Using the Dutch general practitioner registries, we were limited in our ability to specify the subtypes of stroke. The Dutch general practitioner registries do not allow specification of the subtypes of stroke because they do not differentiate between ischemic stroke and hemorrhagic stroke. In reality, the risk profiles of ischemic stroke and hemorrhagic stroke differ, although hypertension and smoking are common risk factors for both stroke types. Differences between stroke subtypes may play an important role in projecting and understanding the dynamics of future stroke morbidity and mortality.
Furthermore, recent figures for the prevalence of hypertension in the Dutch population are lacking. Therefore, we used the most recent data available. Varying the prevalence rates of hypertension in our sensitivity analysis hardly affected the results in terms of incidence, prevalence, and PYLLs.

The number of stroke patients in the Netherlands will rise continuously until the year 2020. Our study demonstrates that a large part of this increase in the number of patients is an inevitable consequence of aging of the population. The increase in prevalence is larger for women (40%) than for men (18%). For the medium term, the increase in prevalence is marginally explained by expected changes in smoking behavior and changes in the prevalence of hypertension. Only a reduction of smoking and hypertension rates in the population will substantially reduce the prevalence of stroke in the long run. Such a population-based approach will be more effective in reducing the prevalence of stroke in the long run than current prevention strategies, which are only focused on individuals at high risk. Despite our conclusion that a large part of the increase in stroke patients is inevitable, we still believe that more attention should be paid to primary prevention. New priority setting regarding primary prevention of stroke is necessary to reduce the number of stroke patients in the long run.

Appendix 1

Formal Description of the Stroke Model

The stroke model is a dynamic, multistate life table based on the life-table method. The model has a Markov property. This means that the likelihood of moving from 1 particular state to another state is independent of the preceding state and depends only on the present state defined by disease state, sex, and age. As a consequence, all relevant information for the transition probabilities must be included in the present state. Hence, the influence of duration and of past disease history is ignored in the model.24

The most important assumptions of the model are (1) conditional independence between transitions. The different transition rates are assumed to be mutually independent; ie, when a transition rate is changed, the other transition rates remain the same. Thus, the mortality rate of stroke patients does not depend on their risk factors, eg, whether or not they have hypertension. (2) homogeneity within states. Irrespective of duration of stay in the current state, past disease history is ignored in the model.24

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The stroke model is basically a combination of a demographic model and a disease model. For every 1-year time step, the demographic model calculates the mortality and migration (and birth) for different (sub)populations. The demographic model has the formula

\[
POP_{t+1} = POP_t - MORT_t + MIGR_t + B_t
\]

where \(POP_t\) represents the population numbers at the end of year \(t\), \(MORT_t\) represents the number of deaths due to stroke or other causes of death during year \(t\), \(MIGR_t\) represents the net migration during year \(t\), and \(B_t\) represents the number of newborns in year \(t\). The latter are irrelevant for the stroke model because stroke is a disease of the elderly.

**Estimation of Mortality**

Total mortality in the population is composed of 2 mortality rates: stroke mortality and mortality due to other causes. Formally the total mortality is

\[
MORT_t = MORT_stroke + MORT_other
\]

where \(MORT_t\) represents the case fatality and \(MORT_{stroke}\) represents the number of deaths due to all other causes of death in the disease-free population. The case fatality is again divided into 2 mortality rates: the "short-term case fatality" and the "long-term case fatality" and is calculated as follows:

\[
MORT_{stroke} = CF\times INC_t + CF\times PREV_t
\]

where short-term \(CF\) is the case fatality rate during the first year after the onset of stroke, \(INC_t\) is the incidence of stroke during year \(t\), \(CF\) is the yearly case fatality rate after the first year after the onset of stroke, and \(PREV_t\) is the number of stroke patients in year \(t\). The case fatality rates of stroke are estimated from data of 760 hospitalized stroke patients from the Research On Stroke Amsterdam study (ROSA). For detailed information of the study, please refer to van Straten et al25 and Scholte op Reimer26.

The curve estimation of the case fatality rate per day in ROSA is

\[
CF_t = 31 + 474 \times \left(1/1 + 6 \times \log(\text{age}) - 88 \times \log(\text{age})/t + 20\right)
\]

where \(t\) is the number of days after onset of stroke and age is the age at onset of stroke.

This formula enables us to calculate the case fatality rate after 365 days specified for age. A number of studies have reported case fatality rates, and these have a wide variation.27–34 We made a pooled estimate of case fatality found in the literature to compare it with our estimate of case fatality rates. After adjustment for age, case fatality rates from the ROSA were slightly higher than those reported in the literature.

Note that \(MORT_{stroke}\) represents total mortality among stroke patients and not mortality among stroke patients due to stroke alone. Stroke patients who die of causes other than stroke are also counted as case fatalities. The ROSA data do not allow us to know the cause of death of stroke patients. It is highly likely that the vast majority of deaths among stroke patients were the consequences of stroke.

The mortality numbers for the disease-free population (deaths due to other causes) are calculated as

\[
MORT_{other} = \text{mort}_{other} \times (POP_t + INC_t - PREV_t)
\]

where \(\text{mort}_{other}\) is the mortality rate for all other causes. The \(\text{mort}_{other}\) is derived from the cause-of-death registry of Statistics Netherlands.4 The cause-specific mortality rates were estimated for the total population. Stroke mortality was subtracted from overall mortality. Formally, overall mortality per 1000 is defined as

\[
\text{mort}_{other} = (N_{stroke} + N_{other})/POP_t - N_{stroke}/POP_t
\]

where \(N_{stroke}\) is the total number of deaths in the Netherlands in 2000 and \(N_{other}\) is the total number of stroke deaths in the Netherlands in 2000.

**Estimation of Stroke Prevalence**

The model describes the changes in disease prevalence numbers over time and specified by age and sex. The prevalence numbers change due to stroke incidence, mortality, and recovery. Annual changes in prevalence are calculated as

\[
\text{PREV}_{t+1} = \text{PREV}_t + \text{INC}_t - \text{MORT}_{stroke} - \text{REC}_{stroke}
\]

with \(\text{PREV}_t\) representing the number of stroke patients at the end of year \(t\), \(\text{INC}_t\) representing the incidence of stroke during year \(t\), \(\text{MORT}_{stroke}\) representing the case fatality during year \(t\), and \(\text{REC}_{stroke}\) representing the recovery of stroke patients during year \(t\).

In the model, there is the possibility that stroke patients will progress from a disease state to a nondisease state. However, we assumed that no stroke survivors will return to a nondisease state.
Therefore, the recovery rate in the stroke model was assumed to be zero. The annual changes in stroke prevalence in the model therefore become

\[ \text{PREV}_t = \frac{\text{INC}_t}{\text{H11001}} - \frac{\text{INC}_t}{\text{H11005}} + \frac{\text{INC}_t}{\text{H11001}} \times \text{MORT}_{\text{stroke},t} \]

\[ (8) \]

**Estimation of Stroke Incidence**

The incidence rate for nonsmokers is defined as the number of cases per 1000 people from the general practitioner registry and specified by age and sex. The incidence rates for smokers and former smokers are expressed as the incidence rate of nonsmokers multiplied by a relative risk. The relative risk for nonsmokers equals 1. The incidence risk for nonsmokers is calculated as the total observed incidence divided by the sum of relative risks multiplied by the relative sizes of all smoking classes. Formally, the incidence rate in smoking class k of a given age and sex is

\[ \text{INC}_k = \text{INC}_{\text{non}} \times \text{rr}(k) \]

\[ (9) \]

\[ \text{INC}_{\text{non}} = \frac{\text{INC}_s}{\sum \text{pop}(k) \times \text{rr}(k)} \]

\[ (10) \]

**Input Data and Transition Probabilities Within the Stroke Model**

<table>
<thead>
<tr>
<th>Arrow in Figure 1</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epidemiology</td>
<td>&lt;65 y</td>
<td>65–74 y</td>
</tr>
<tr>
<td>Stroke incidence (per 1000), no.</td>
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<td>7.87</td>
</tr>
<tr>
<td>Stroke prevalence (per 1000), no.</td>
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<td>45.06</td>
</tr>
<tr>
<td>First-year case fatality rate</td>
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<td>0.156</td>
</tr>
<tr>
<td>Long-term case fatality rate</td>
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<td>0.018</td>
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<tr>
<td>Excess mortality in disease-free population (per 100 000)</td>
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Hypertension

<table>
<thead>
<tr>
<th>Prevalence (transition probability)</th>
<th>Category 1 (&lt;120 mm Hg)</th>
<th>Category 2 (120–139 mm Hg)</th>
<th>Category 3 (140–159 mm Hg)</th>
<th>Category 4 (160–179 mm Hg)</th>
<th>Category 5 (≥180 mm Hg)</th>
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</thead>
<tbody>
<tr>
<td>RR stroke</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Smoking

<table>
<thead>
<tr>
<th>Prevalence smokers</th>
<th>Stop probability</th>
<th>Restart probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category 1 (&lt;120 mm Hg)</td>
<td>0.313</td>
<td>0.028</td>
</tr>
<tr>
<td>Category 2 (120–139 mm Hg)</td>
<td>0.311</td>
<td>0.048</td>
</tr>
<tr>
<td>Category 3 (140–159 mm Hg)</td>
<td>0.276</td>
<td>0.047</td>
</tr>
<tr>
<td>Category 4 (160–179 mm Hg)</td>
<td>0.24</td>
<td>0.047</td>
</tr>
<tr>
<td>Category 5 (≥180 mm Hg)</td>
<td>0.026</td>
<td>0.030</td>
</tr>
</tbody>
</table>

RR indicates relative risk.

with \( \text{INC}_k \) being the incidence rate for smoking class k, expressed as the number of cases per 1000 in the group; \( \text{INC}_{\text{non}} \), the incidence rate for nonsmokers, also expressed as rate per 1000; \( \text{pop}(k) \), the fraction of the population belonging to smoking class k per 1000 in the group; and \( \text{rr}(k) \) the relative risk for smoking class k compared with nonsmokers.

For calculating the incidence rate for hypertensive individuals, the same procedure can be used. The incidence rate for hypertensives is expressed as the incidence rate for nonhypertensives multiplied by a relative risk. As a consequence, the relative risk for nonhypertensives is 1. The relative risk for hypertensives was derived from the literature. \( 35–38 \) The incidence rate for those with hypertension is

\[ \text{INC}_h = \text{INC}_{\text{nh}} \times \text{rr}(h) \]

where \( \text{INC}_h \) is the incidence rate per 1000 for the hypertension class, and \( \text{INC}_{\text{nh}} \) is the incidence rate per 1000 for those with no hypertension. Note that for nonhypertensives that \( \text{rr}(h) \) is again 1, so the \( \text{INC}_h \) for nonhypertension equals \( \text{INC}_{\text{nh}} \).

The incidence rate for hypertensive smokers slightly differs from the previous formulas. The incidence rate for people in smoking

\[ (11) \]
class k with hypertension is calculated as the incidence rate for smoking class k multiplied by the incidence rate for those with hypertension multiplied by a relative risk. The relative risk for hypertensive smokers was derived from the literature. So formally, the incidence rate for smoking class k with hypertension is

\[
INC_{k\text{,hyp}} = r(k, h) \times INC \times IRC_k
\]

Here \(INC_{k\text{,hyp}}\) is the incidence for hypertensive smokers, and \(r(k, h)\) is the relative risk for hypertensive smokers.

**Appendix 2**

**Input Data Model**

**Demographic Data**

Table 1 presents the input data, relative risks, and transition probabilities used in the stroke model. The age- and sex-specific demographic data for the year 2000 in the model, i.e., mortality numbers and birth and migration projections, were derived from Statistics Netherlands.

The incidence based on data from 5 general practitioner registries\(^{19,20,40–42}\) up to the year 2000 were combined into an age- and sex-specific average to obtain the most recent estimates for the incidence of stroke in the Netherlands. The same was done for data on stroke prevalence. Registries\(^{19,20,40–42}\) for which the year prevalence rates of stroke were available were used to estimate the prevalence rates of stroke in the Netherlands.

Age- and sex-specific case fatality rates were estimated with data from the Research On Stroke Amsterdam study (ROSA).\(^{26,44}\) This multicenter study followed up a large sample of hospitalized stroke patients (\(n = 760\)) for as long as 5 years after hospital admission. Data were collected at 6 months, 3 years, and 5 years after stroke and include the date of onset of stroke and date of death. After a goodness-of-fit test of the curve estimation for case fatality data, we calculated age- and sex-specific case fatality rates for the first year after the onset of stroke (hereafter referred to as the first-year case fatality) and for the subsequent years (hereafter referred to as the long-term case fatality).

**Risk Factors**

The age- and sex-specific prevalences of hypertension in the Netherlands were estimated on the basis of 2 studies and were used to determine the prevalence rates of hypertension in the Netherlands for a complete age range. The prevalence of hypertension up to the age of 65 years was estimated from the Monitoring Project on Risk Factors for Chronic Diseases (MORGEN-study), and the prevalence of hypertension for ages \(>65\) years was estimated from the Rotterdam Ergo study.\(^{46}\) The age-specific relative risks of hypertension for stroke were based on 4 studies.\(^{35–38}\) Results of these 4 studies were combined in an age-specific average relative risk (5-year age classes).

The age- and sex-specific prevalence rates for smokers and former smokers in the Netherlands were derived from the yearly population monitoring studies of the Foundation on Smoking and Health,\(^{47}\) for the time period 1997 to 2000, specified by sex and 5-year age classes and the 3 groups of never-smokers, former smokers, and current smokers. The age- and sex-specific start, stop, and restart rates were computed from the observed trends for the period 1997 to 2000.

The relative risks for former and current smokers were derived from several studies.\(^{15,48–51}\) The data from these studies were combined into an age- and sex-specific average (5-year age classes). The additional relative risks of stroke for individuals with the combination of hypertension and smoking were calculated on the basis of data from the 1 available study of Shaper.\(^{39}\)

Figure 1 shows the basic structure of the stroke model including possible health states (disease-free population, stroke population, and death) and possible transition rates, which are represented by arrows (number of arrows correspond to the numbers in Table 1).

**References**

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Jeroen N. Struijs, Marianne L.L. van Genugten, Silvia M.A.A. Evers, Andre J.H.A. Ament, Caroline A. Baan and Geertrudis A.M. van den Bos

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