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# Wide range of socioeconomic factors associated with mortality among cities in Japan

**YOSHIHARU FUKUDA, KEIKO NAKAMURA and TAKEHITO TAKANO**
*Health Promotion/International Health, Division of Public Health, Graduate School, Tokyo Medical and Dental University, Bunkyo-ku, Tokyo, Japan*

## SUMMARY

*The aim of this study was to identify socioeconomic factors associated with mortality among cities in Japan. Sex-specific and age-adjusted mortality rates for 1990 and 1995 were calculated by 779 local administrative units across the nation. One hundred indicators related to socioeconomic factors were compiled and divided into eight categories: economy, education, living conditions, vegetation and open space, transport, preventive activities, medical care and demography. Composite socioeconomic indices were formulated using factor analysis of the socioeconomic indicators by category, and the association between the indices and mortality rates was examined by correlation analysis and multiple regression analysis. Nineteen composite socioeconomic indices were obtained from factor analysis, and all indices except educational expenditure-related index were significantly correlated with mortality rates. Unemployment, old housing, primary health resources and density were independently positively associated, and higher education, public library activity, health check-up participation and population growth were independently negatively associated with both 1990 and 1995 male mortality rates. For female mortality, higher income, unemployment, spacious dwelling, old housing, less vegetation, road facility, numbers of cars per population, primary health resources and density were independently positively associated, and higher education, public library activity and health check-up participation were independently negatively associated. The relationship between mortality and socioeconomic conditions was stronger in males than in females, and higher income and less vegetation were associated with higher mortality only for females. The present study demonstrated a close link between mortality and a wide range of socioeconomic conditions by using a number of indicators compiled from various data sources. The results promote a deeper understanding of socioeconomic health determinants and development of multi-sectoral health policy to improve population health.*

*Key words*: indicators; health determinants; mortality; socioeconomic factors

## INTRODUCTION

Health is recognized to be a multidimensional concept, and multiple factors are considered to affect population health (Durch *et al.*, 1997). Socioeconomic inequalities in mortality have been examined, and socioeconomic factors such as income level, income inequality, education and occupation have been reported to predict population health based on comparisons of national and regional aggregated statistics (Wilkinson, 1992a; Wilkinson, 1992b; Casas, 1993; Kennedy *et al.*, 1996). In addition to socioeconomic factors, population density (Mahoney *et al.*, 1990; Najem *et al.*, 1990), housing conditions and overcrowding (Johnson and Nelson, 1984; Alexander *et al.*, 1987; Carstairs and Morris *et al.*, 1989; Saito *et al.*, 1993), natural environments (Smith, 1974; Takano *et al.*, 2002), and social cohesion and level of trustworthiness in communities, so called social capital (Kawachi *et al.*, 1997), have been individually discussed as health determinants.

The impact of socioeconomic and environmental determinants of health has been well recognized, and multi-sectoral healthy policy is required to improve population health [World Health Organization (WHO), 1996; Tsouros and Farrington, 1999; Catford, 2002]. An integration-oriented perspective based on an understanding of the relations between health and socioeconomic health determinants would widen policy integration (Takano and Nakamura, 2001). In order to promote recognition of a wide range of health determinants, evidence of the association between population health and socioeconomic factors should be provided and accumulated, especially using data of the given population.

Life expectancy and disability-adjusted life expectancy in Japan are the highest in the world (WHO, 2000). Nonetheless, significant geographical variation in health levels is found even there. Life expectancy at birth by city has been found to vary from 70.1 to 79.5 years for males and from 79.4 to 87.9 years for females (Health and Welfare Statistics Association, 1998). Variations in health levels in Japan have been explained by the co-existence of multiple factors of demography, infrastructure, land-use, amenities, education, working conditions, economics, and medical and welfare services (Takeuchi *et al.*, 1995; Takano and Nakamura, 2001).

Studies have documented sex differences in the association between mortality and socioeconomic factors (Koskinen and Martelin, 1994; Borrell and Arias, 1995; Benach *et al.*, 2001), and demonstrated time trends in this association (Kunst *et al.*, 1990; Rodrigues and Lemkow, 1990; Marang-van de Mheen *et al.*, 1998). However, little is known about sex differences in the association between mortality and socioeconomic factors, and trends in Japan.

To elucidate the influence of a wide range of socioeconomic factors on population health, we examined the association between age-adjusted mortality rates and a number of socioeconomic indicators compiled from various data sources by local administrative units (cities) across Japan, focusing on sex differences and time-dependent changes in association.

## METHODS

### Study unit

In Japan, local governmental units are defined by Local Autonomy Law to be one of the following: Tokyo special ward-cities, cities designated by ordinance, cities, towns or villages. The cities designated by ordinance are further divided into wards for the purpose of administrative services. Many statistics are collected on the basis of these local-authority administrative units. In 1990, there were 786 local administrative units that derived from either Tokyo special ward-cities, wards in cities designated by ordinance and cities not designated by ordinance. In 1995, 802 local administrative units satisfied these criteria. Changes in the administrative boundaries and the new designation of cities by ordinance took place between 1990 and 1995 and, as a result, some units did not have statistics covering consistent geographic boundaries. A total of 779 local administrative units were coded with the same geographic boundaries both in 1990 and 1995, and used as study areas for this study. The 779 units comprised 23.3% of all local administrative units and the sum of the units' populations was 89.8 million, which amounted to 72.8% of the total population of all units in Japan in 1990.

### Age-adjusted mortality rates

The population in 1990 and 1995 [Statistics Bureau, Management and Coordination Agency (SBMCA), 1993; SBMCA, 1998], and the number of deaths by sex and age category of all the administrative units in 1989–1992 and 1994–1996 were individually compiled (Ministry of Health and Welfare, 1989–1992, 1994–1996). For the calculation of 1990 and 1995 age-adjusted mortality rates from all causes of death for males and females, direct age-standardization was applied using the 1985 model population of Japan and the average number of deaths in three consecutive years.

In 1995, 5488 people died as a result of the Hanshin-Awaji earthquake on January 17, 5447 of whom were residents of Hyogo prefecture. The death of 5447 people comprised 11.6% of all the annual deaths in Hyogo prefecture; thus, the calculated mortality of administrative units in Hyogo prefecture is not comparable to the mortality rates of other units. We excluded data from 30 units in the Hyogo prefecture from further analysis.

### Composite indices of socioeconomic factors

One hundred indicators related to socioeconomic factors from the following eight categories were used to formulate composite indices of different

aspects of social and physical conditions: economy, education, living conditions, vegetation and open space, transport, preventive activities, medical care and demography (Table 1). Indicators were selected and calculated using data from the following sources: 1990 Population Census of Japan (SBMCA, 1993), 1993 Housing Survey of Japan (SBMCA, 1996), 1991 Establishment Census of Japan (SBMCA, 1994), 1991 Indicators of Citizens' Income (Society for the Study of Municipal Taxation, 1995), 1989–1991 Annual Reports on Fires (Association of Fire Prevention, 1992–1994), 1990 Statistics of National Health Insurance (Ministry of Health and Welfare, 1994), 1990 National Consumption Survey Japan (SBMCA, 1992), 1993 Yearbook of Cities in Japan (Association of Mayors, 1993), 1990 Meteorological Data by Satellite Observation (Meteorological Agency, 1994), 1990 Forestry Census (Forestry Agency, 1993), 1990 Report on Atmospheric Monitoring Stations (Air Quality Bureau, Environment Agency, 1994), 1990 Basic Statistics for Community Medical Care (Health and Welfare Statistics Association, 1993), and 1990 Indices of Municipalities (SBMCA, 1995).

Principal component analysis with varimax rotation was performed by socioeconomic category to select factors for which the eigenvalue of the correlation matrix was >1.0. Indicators with factor loading of >0.5 in absolute value were listed and latent meanings representing individual factors were defined. We used factor scores of the selected factors as composite indices representing individual aspects of socioeconomic conditions of administrative units.

### Statistical analysis

Spearman's correlation coefficients between age-adjusted mortality rates and the composite indices of socioeconomic factors were calculated.

Multiple linear regression analysis was carried out using all the composite socioeconomic indices as independent variables, and male or female age-adjusted mortality rates in 1990 and 1995 as dependent variables. A step-wise procedure was used in the decision to include significant dependent variables.

Furthermore, a multiple regression model with selected composite indices as independent variables, which showed significant and strong association with age-adjusted mortality rates in the preceding regression analysis by sex and year, was applied to examine sex and year differences in the relationship between mortality and socioeconomic factors.

Statistical analysis was conducted using the statistical software SPSS 10.0 for Windows.

## RESULTS

Age-adjusted mortality rates (per 100 000 population) for males and females in 1990 were 645.8 ± 63.8 and 497.5 ± 42.8 (mean ± standard deviation), respectively, and those in 1995 were 597.0 ± 58.6 and 431.8 ± 38.8, respectively.

Table 1 shows the results of factor analysis using a total of 100 indicators that were compiled and categorized. Finally we obtained 19 composite indices from eight categories: three economy-, three education-, two living conditions-, two vegetation and open space-, three transport-, one preventive activities-, three medical care- and two demography-related indices. It also shows the latent meaning of the indices, defined according to the indicators with factor loading >0.5.

Correlation coefficients between age-adjusted mortality rates and composite indices of socioeconomic factors are shown in Table 2. For males, unemployment, old housing, medical expenditure and density were positively and strongly ($r > 0.2$) associated, and higher income, economic growth, higher education and population growth were negatively and strongly ($r < -0.2$) associated with mortality rate, both in 1990 and 1995. For females, unemployment and density had a strong positive association ($r > 0.2$), while higher education and health check-up participation had a strong negative association ($r < -0.2$) with mortality rates in both years.

Correlation coefficients among the composite indices are shown in Table 3. There were strong significant correlations across the categories. In particular, higher income, spacious dwelling, less vegetation, and population growth were strongly ($r > 0.4$ or $< -0.4$) related to seven to eight indices.

Table 4 shows the results of multiple regression analysis of the relationship between mortality and composite indices of socioeconomic factors. Eight indices were significant independent variables for both 1990 and 1995 male mortality rates. Spacious dwelling was independently negatively associated with only the 1995 male mortality rate. For female mortality in 1990, six and three indices showed a positive and negative relationship, respectively. Among these indices, spacious dwelling, road facility and density were

**Table 1:** Result of factor analysis using indicators of socioeconomic factors by local administrative units in Japan

| Category[a] | Composite indices[b] | Percentage[c] | Indicators[d] |
|---|---|---|---|
| Economy | Higher income | 34.6 | Per capita income; taxable income per household; income differentials in households; financial index; sex ratio among workers; tertiary industry workers as percentage of total workforce |
| | Unemployment | 16.3 | Unemployment rate; unemployment rate among people aged 60–65 years; unemployment among people aged 20–24 years |
| | Economic growth | 9.0 | Growth rate of number of establishments; growth rate of total workforce |
| | Others | | Secondary industry workers as percentage of total workforce; sex ratio among employees; sex ratio among unemployed population; establishments per population; sex ratio among workers |
| Education | Higher education | 38.4 | Age-adjusted education level (males, females); education years among people aged 25–29 years (males, females) |
| | Public library activity | 24.3 | Number of rented books per population; number of books in library; ratio of book budge per total expenditure; ratio of registrants of library |
| | Educational expenditure | 19.3 | Per capita expenditure on education; per capita expenditure on school education; ratio of educational expense per total expenditure |
| Living conditions | Spacious dwelling | 48.0 | Average area of dwelling units per household; owner-occupied dwelling units as a percentage of all dwelling units; average area of dwelling units per population; percentage of dwelling units $\geqslant$ 1000 m from nearest medical facilities; percentage of dwelling units with direct sunshine $\geqslant$ 5 hours per day |
| | Old housing | 10.4 | Index for old dwellings; percentage of dwellings built pre-1975; percentage of houses abutted on narrow roads; percentage of wooden houses |
| | Others | | Percentage of households living in issued houses per dwelling; percentage of households living in issued houses per rented houses; number of outbreaks of fire per number of buildings; house rent per month; percentage of dwelling units on 6th floor and above |
| Vegetation and open space | Less vegetation | 64.9 | Normalized difference vegetation index area-average within a radius of 3 km; normalized difference vegetation index area-average within a radius of 10 km; normalized difference vegetation index area-average within a radius of 19 km; availability of sewerage |
| | Spacious city parks | 14.5 | Square kilometre of city park per square kilometre of habitable land; square kilometre of park per square kilometre of total land; square kilometre of city park per population; access to greenery and open space; forestry area as percentage of total land |

| | | | |
|---|---|---|---|
| Transport | Number of cars per road | 44.5 | Number of buses per kilometre of road; number of trucks per kilometre of road; number of private cars per kilometre of road; ratio of paved roads |
| | Road facility | 22.0 | Length of road per total land area; length of road per habitable land area |
| | Number of cars per population | 14.3 | Number of registered cars per population; number of cars per population; number of buses per population |
| Preventive activities | Health check-up participation | 57.4 | Participation rate in general health check-up; participation rate in stomach cancer screening; participation rate in lung cancer screening; participation rate in uterus cancer screening |
| Medical care | Primary health resources | 40.6 | Number of dental clinics per population; number of clinics per population; number of clinics and hospitals per population; number of dentists per population; number of pharmacists per population; number of medical doctors per population; number of public nurses per population |
| | Secondary health resources | 14.9 | Number of beds in general hospitals and clinics; number of comprehensive hospitals per population; number of beds in hospitals and clinics; number of nurses per population; number of midwives per population; number of emergency hospitals per population |
| | Medical expenditure | 8.3 | Medical expense per admitted patient; medical expense per patient; care expense per admitted patient; number of general hospitals per population |
| | Others | | Capacity of facilities for the elderly; capacity of day services; capacity of short-stay services; number of home-helpers per population |
| Demography | Density | 28.9 | Density of households; population density; percentage of private one-person households; percentage of households with elderly residents; percentage of foreigners |
| | Population growth | 24.9 | Sex ratio; population growth rate; population |
| | Others | | Percentage of nuclear family households; percentage of population aged ⩽15 years (males, females); percentage of population aged ⩽15 years (males, females); ratio of daytime population to night population; percentage of population aged ⩾65 years (males, females) |

[a]Indicators were divided into eight categories and factor analysis was performed for each category.
[b]Factors for which the eigenvalue of correlation matrix was >1.0 were selected and the latent meanings were defined.
[c]Proportion of variant.
[d]Indicators with factor loading of at least 0.5 in absolute value.

**Table 2:** Correlation coefficients between age-adjusted mortality rates and socioeconomic composite indices by local administrative units in Japan

| Socioeconomic indices[a] | Males | | Females | |
|---|---|---|---|---|
| | 1990 | 1995 | 1990 | 1995 |
| Higher income | −0.27 | −0.26 | NS | 0.07 |
| Unemployment | 0.44 | 0.40 | 0.24 | 0.20 |
| Economic growth | −0.36 | −0.31 | −0.22 | −0.19 |
| Higher education | −0.46 | −0.46 | −0.27 | −0.23 |
| Public library activity | −0.15 | −0.13 | NS | NS |
| Educational expenditure | NS | NS | NS | NS |
| Spacious dwelling | −0.13 | −0.12 | −0.18 | −0.18 |
| Old housing | 0.42 | 0.38 | 0.22 | 0.19 |
| Less vegetation | NS | NS | 0.17 | 0.20 |
| Spacious city parks | 0.08 | NS | NS | NS |
| Number of cars per road | 0.11 | 0.09 | 0.16 | 0.14 |
| Road facility | −0.20 | −0.18 | NS | NS |
| Number of cars per population | −0.21 | −0.18 | NS | NS |
| Health check-up participation | −0.10 | −0.11 | −0.24 | −0.23 |
| Primary health resources | NS | NS | NS | 0.07 |
| Secondary health resources | 0.08 | NS | NS | −0.08 |
| Medical expenditure | 0.32 | 0.27 | NS | NS |
| Density | 0.25 | 0.22 | 0.27 | 0.22 |
| Population growth | −0.43 | −0.39 | −0.09 | NS |

Correlation coefficients were significant ($p < 0.05$) except where indicated [non-significant (NS)].
[a]Socioeconomic composite indices were obtained from factor analysis using 100 indicators of socioeconomic factors divided into eight categories.

not associated with the 1995 female mortality rate, while old housing, less vegetation and number of cars per population were significantly associated with only 1995 mortality.

Table 5 shows the results of multiple regression analysis for a model with seven selected composite indices, which showed significant and strong association with mortality rates (standardized regression coefficient $>0.2$ or $<-0.2$) in any model of preceding regression analysis. There was no difference in significant variables between the 1990 and 1995 male mortality rates. For females, spacious dwelling and density were not significant for 1995 mortality, but were for 1990 mortality. Higher income and less vegetation showed a significant association with only female mortality. The coefficient of determinants ($r^2$) was higher for males than for females, and higher in 1990 than in 1995.

## DISCUSSION

By using mortality and socioeconomic indicators at the city level across the nation in Japan, this study demonstrated that a wide range of socioeconomic factors, including living and environmental conditions, were related to mortality. In addition, the association and the trends showed significant sex differences.

With respect to sex differences in the univariate analysis, several socioeconomic indices significantly associated with male mortality rates (public library activity, road facility, number of cars per population and medical expenditure) did not show significance for females. In contrast, less vegetation, which was significantly associated with female mortality rates, did not show significance for male mortality rates. In the results of multiple regression analysis of each mortality model, population growth was not shown to be a significant independent variable for females but was for males, while higher income and less vegetation were not shown to be significant independent variables for males but were for females. The sex differences for higher income and less vegetation were confirmed by the results of regression analysis of the final model with selected indices.

Besides the kinds of socioeconomic factors associated with mortality, differences between

**Table 3:** Correlation coefficients among socioeconomic composite indices by local administrative units in Japan

| Socioeconomic indices[a] | Ec1 | Ec2 | Ec3 | Ed1 | Ed2 | Ed3 | L1 | L2 | V1 | V2 | T1 | T2 | T3 | P | M1 | M2 | M3 | D1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Higher income (Ec1) | | | | | | | | | | | | | | | | | | |
| Unemployment (Ec2) | – | | | | | | | | | | | | | | | | | |
| Economic growth (Ec3) | – | – | | | | | | | | | | | | | | | | |
| Higher education (Ed1) | 0.69 | −0.11 | 0.22 | | | | | | | | | | | | | | | |
| Public library activity (Ed2) | 0.26 | −0.09 | 0.13 | – | | | | | | | | | | | | | | |
| Educational expenditure (Ed3) | NS | −0.13 | NS | – | – | | | | | | | | | | | | | |
| Spacious dwelling (L1) | −0.60 | −0.31 | 0.10 | −0.49 | NS | | | | | | | | | | | | | |
| Old housing (L2) | −0.30 | NS | −0.66 | −0.32 | −0.21 | NS | – | | | | | | | | | | | |
| Less vegetation (V1) | 0.66 | 0.16 | 0.09 | 0.47 | 0.18 | NS | −0.74 | −0.21 | | | | | | | | | | |
| Spacious city parks (V2) | 0.16 | 0.15 | NS | 0.18 | NS | 0.13 | −0.36 | NS | – | | | | | | | | | |
| Number of cars per road (T1) | 0.45 | 0.20 | −0.11 | 0.31 | NS | 0.13 | −0.68 | NS | 0.55 | 0.40 | | | | | | | | |
| Road facility (T2) | 0.57 | NS | 0.16 | 0.51 | 0.12 | NS | −0.47 | −0.25 | 0.64 | NS | – | | | | | | | |
| Number of cars per population (T3) | 0.11 | −0.23 | 0.13 | −0.09 | 0.11 | NS | 0.21 | −0.28 | NS | NS | – | – | | | | | | |
| Health check-up participation (P) | −0.43 | −0.23 | NS | −0.29 | NS | 0.07 | 0.50 | NS | −0.47 | −0.11 | −0.31 | −0.36 | 0.08 | | | | | |
| Primary health resources (M1) | 0.13 | −0.09 | −0.15 | 0.26 | NS | 0.11 | −0.39 | 0.11 | 0.21 | 0.33 | 0.30 | 0.10 | −0.10 | −0.09 | | | | |
| Secondary health resources (M2) | −0.29 | −0.14 | −0.16 | −0.19 | −0.12 | NS | 0.20 | 0.11 | −0.31 | NS | −0.14 | −0.28 | NS | 0.14 | – | | | |
| Medical expenditure (M3) | −0.27 | 0.30 | −0.26 | −0.14 | −0.17 | NS | NS | 0.31 | −0.23 | 0.08 | NS | −0.21 | −0.18 | NS | – | – | | |
| Density (D1) | 0.48 | 0.23 | −0.33 | 0.38 | NS | 0.12 | −0.85 | 0.17 | 0.63 | 0.34 | 0.69 | 0.37 | −0.23 | −0.43 | 0.39 | −0.10 | 0.15 | |
| Population growth (D2) | 0.64 | NS | 0.57 | 0.46 | 0.27 | 0.09 | −0.27 | −0.73 | 0.53 | NS | 0.22 | 0.49 | 0.28 | −0.22 | −0.10 | −0.29 | −0.51 | – |

[a]Socioeconomic composite indices were obtained from factor analysis using 100 indicators related to socioeconomic factors divided into eight categories.
Correlation coefficients were significant ($p < 0.05$) except where indicated [non-significant (NS)].
–, there was no correlation among the indices of same categories because of varimax rotation in factor analysis.

**Table 4:** Results of multiple linear regression analysis with stepwise procedure on age-adjusted mortality rates with socioeconomic composite indices

| Socioeconomic indices | Males | | Females | |
|---|---|---|---|---|
| | 1990 | 1995 | 1990 | 1995 |
| Higher income | NS | NS | 0.35 | 0.26 |
| Unemployment | 0.27 | 0.25 | 0.10 | 0.09 |
| Economic growth | NS | NS | NS | NS |
| Higher education | −0.53 | −0.47 | −0.69 | −0.52 |
| Public library activity | −0.07 | −0.08 | −0.11 | −0.07 |
| Educational expenditure | NS | NS | NS | NS |
| Spacious dwelling | NS | −0.06 | 0.21 | NS |
| Old housing | 0.11 | 0.12 | NS | 0.26 |
| Less vegetation | NS | NS | NS | 0.22 |
| Spacious city parks | NS | NS | NS | NS |
| Number of cars per road | NS | NS | NS | NS |
| Road facility | NS | NS | 0.13 | NS |
| Number of cars per population | NS | NS | NS | 0.07 |
| Health check-up participation | −0.10 | −0.09 | −0.17 | −0.14 |
| Primary health resources | 0.09 | 0.08 | 0.11 | 0.15 |
| Secondary health resources | NS | NS | NS | NS |
| Medical expenditure | NS | NS | NS | NS |
| Density | 0.30 | 0.29 | 0.36 | NS |
| Population growth | −0.09 | −0.18 | NS | NS |
| Coefficient of determinant ($r^2$) | 0.55 | 0.47 | 0.34 | 0.26 |

Values represent standardized regression coefficients. Multiple linear regression analysis was carried out using sex-specific and age-adjusted mortality rates as dependent variables, and socioeconomic composite indices obtained from factor analysis as independent variables. The significant variables were selected by a stepwise procedure. Non-significant (NS) indices were not selected as significant independent variables.

**Table 5:** Results of multiple linear regression analysis on age-adjusted mortality rates with selected socioeconomic composite indices

| Socioeconomic indices | Males | | Females | |
|---|---|---|---|---|
| | 1990 | 1995 | 1990 | 1995 |
| Higher income | −0.08 | −0.08 | 0.33[a] | 0.26[a] |
| Unemployment | 0.28[a] | 0.25[a] | 0.12[a] | 0.09[a] |
| Higher education | −0.47[a] | −0.46[a] | −0.57[a] | −0.49[a] |
| Spacious dwelling | −0.02 | −0.04 | 0.18[a] | 0.04 |
| Old housing | 0.18[a] | 0.15[a] | 0.11[a] | 0.14[a] |
| Less vegetation | 0.02 | 0.04 | 0.15[a] | 0.23[a] |
| Density | 0.34[a] | 0.29[a] | 0.33[a] | 0.12 |
| Coefficient of determinant ($r^2$) | 0.53 | 0.45 | 0.31 | 0.24 |

[a] $p < 0.05$.
Values represent standardized regression coefficients. Multiple linear regression analysis was carried out using sex-specific and age-adjusted mortality rates in 1990 and 1995 as dependent variables, and selected socioeconomic composite indices obtained from factor analysis as independent variables. The indices were selected according to the results of previous regression analysis (see Table 4).

the sexes with respect to the extent of the association between socioeconomic factors and mortality were found. The relationship between mortality rates and several socioeconomic indices (unemployment, economic growth, higher education and old housing) was stronger in males than in females. Conversely, spacious dwelling, number of cars per population and health check-up participation showed a stronger relationship with female mortality rates than

male mortality rates. The results of the multiple regression analysis showed that the $r^2$ of male mortality models was larger than that of female mortality models. The finding that male mortality was predicted by socioeconomic factors more strongly than female mortality is supported by reports from other countries (Koskinen and Martelin, 1994; Sloggert and Joshi, 1994; Borrell and Arias, 1995).

For females, higher income was significantly positively related to mortality rates in multiple regression analysis. Recent studies pointed out the greater importance of relative income and income inequality over absolute income, especially in developed counties (Wilkinson, 1992a; Wilkinson, 1992b). A study showed the weak but significant relationship between poor self-rated health and wider health inequality at the prefecture level in Japan (Shibuya *et al.*, 2002), and further studies are required to elucidate the association between mortality and income inequality.

Higher education level was negatively and strongly associated with both male and female mortality rates. In addition, the index related to public library activity was independent of educational level and educational expenditure on schools, and it was correlated with lower mortality, even after adjustment for the effects of other socioeconomic factors. In 1996, there were ~2400 public libraries in Japan and >95% of the city governments had their own public libraries (Ministry of Education, Science, Culture and Sports, 1998). As these public libraries are established and managed by local government, the levels and contents of activities vary among communities. Indicators related to library activities have commonly been used as critical measurements of socioeconomic status of residential areas in Japan (Institute for Posts and Telecommunications Policy, 1997). Although the influence on mortality was not so strong (standardized regression coefficient = −0.07 to −0.11), library activities might independently contribute to residents' health through life-long education or community development, considering the weak correlations with other variables ($r$ = −0.21 to 0.27).

With respect to indices related to living conditions, spacious dwelling and old housing showed negative and positive correlations, respectively, with both male and female mortality rates. For environmental factors related to vegetation and open space, less vegetation was positively correlated with female mortality rates. According to the results of multiple regression analysis, old housing and less vegetation were significantly and positively related to higher mortality. The findings imply that improvement in living conditions and promotion of greenery should be prioritized for population health, as well as socioeconomic aspects such as education and economy.

The index related to health check-up participation was significantly related to lower mortality for both males and females. Health check-ups for community residents have been proposed mainly for persons aged ⩾40 years in each local administrative unit since 1983, when the Health and Medical Law for the Aged was established. There was marked variation in participation rates for these health examinations among prefectures, e.g. 26.2–61.1% for basic health check-ups and 5.9–38.9% for stomach cancer (Ministry of Health Welfare, 2000). The programs are inclusive of a health promotion program containing not only health check-ups, but also health counseling and health education. The results presented here suggest that the administrative units with more active community-based preventive activities had lower mortality.

Previous studies have demonstrated that the contribution of medical care to the geographical variation in health status has played only a small part compared with other socioeconomic factors in developed countries (Mackenbach *et al.*, 1990; Matterson *et al.*, 1998). In this study, the positive relationship between mortality and primary medical resources (i.e. local administrative units with more medical resources such as clinics and health professionals) suggests that the health system in Japan responds to greater need by greater provision of health services.

Among demography-related indices, density was positively related to male mortality rates and 1990 female mortality rate. The significant positive correlation between mortality rates and density indicated that overcrowded living conditions in urban areas had negative consequences on the health of urban dwellers.

The theoretical shortcomings of ecological analysis have been discussed previously (Greenland and Robins, 1994; Morgenstern, 1998; Greenland, 2001). While careful usage and interpretation are useful for identifying possible contextual effects and generating hypotheses, significant advantages compared with individual-level analyses have been claimed (Cohen, 1994;

Piantadosi, 1994; Schwartz, 1994; Pearce, 1996). The relationship between mortality and various socioeconomic factors at the city level across the country and time-dependent changes of the relationship could not be examined without ecological analysis.

In conclusion, this study has demonstrated a close link between mortality and a wide range of socioeconomic conditions by using a number of indicators compiled from various data sources. The results promote a deeper understanding and awareness of socioeconomic health determinants, including living and environmental conditions, which will contribute to the development of a multi-sectoral health policy to improve population health.

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*Address for correspondence:*
Keiko Nakamura
International Health
Division of Public Health
Graduate School, Tokyo Medical and Dental University
1-5-45 Yushima
Bunkyo-ku
Tokyo 113-8519
Japan
E-mail: nakamura.ith@tmd.ac.jp

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