The population of the United States, as of virtually all the world, is aging rapidly and with the greatest relative change in the oldest-old group. From 1960 to 1990, when the total U.S. population grew by 39%, the number of persons aged 65 or older increased by 89%, and those aged 85 or older increased by 232% (1). By 2030, older Americans aged 65 or older could represent 25% (12% currently) of the population, because the size of younger populations will have declined (2,3).

These demographic changes are of considerable importance, for although the oldest-old account even now for only 1.2% of the entire population and only 10% of those aged 65 or older, they disproportionately use the health care system, often at public expense. For example, Pawlson in 1994 calculated that the rate of nursing home institutionalization is 1,800% greater for those aged 85 or older than for those aged 65–74 (4).

Despite the importance of the aging population, there has been little research specifically aimed at the population aged 90 and older or 95 and older. Prior research often grouped subjects into an older than 85 category, despite some evidence of differences in the resource utilization of nonagenarians and centenarians compared with younger seniors. One study found that average total cost per hospitalization progressively declines after ages 70–79. In fact, it suggested that the oldest-old may be a select group of individuals who are healthier than the younger cohorts (5).

The division of the elderly population into three age groups—the young-old (often 65–74 years), the middle-old (75–85 years), and the oldest-old (≥85)—was suggested by Suzman and Riley (6), although they noted that to the threshold in the nineties, at which the structure of the aging process changes again. If true, this suggests a more advanced segment of the age continuum: a fourth era—the very oldest-old—consisting of those aged 95 or older.
**Methods**

In this study, we examined the relationship between the prevalence of selected conditions and age in those aged 80 to 105 years.

**Data**

We selected all individuals aged 80 or older from data representing all nursing home residents in seven states during 1992–1994. The states were New York, Kansas, Mississippi, South Dakota, Maine, Nebraska, and Pennsylvania. When we had multiple assessments of the same individual, we chose only the most recent assessment, i.e., each individual at the oldest age. All assessments were performed using the National Resident Assessment Instrument (RAI)/Minimum Data Set (MDS) mandated for use in virtually every nursing home in the United States (all homes eligible to receive federal funding under Conditions of Participation) on resident admission and significant change, and at least annually. The assessment is performed by facility staff, using all available sources of information, including the resident, staff, family, and the medical record.

The MDS, with more than 350 items, covers a broad set of domains, including physical and mental function, diseases, psychosocial status, mood and behavior disturbances, continence, and treatments (9). In multiple studies, most MDS items achieved good interobserver reliability (κ statistic > 0.6) and many—including measures of Activities of Daily Living (ADL) function and cognition—achieved excellent reliability (10). For example, the reliability of key indicators includes .88 for decision making, .92 for ADL self-performance items, and .63 for behavior problems. Only a few items had less than good reliability, although all achieved acceptable κ values (>0.4). We attribute these good results not only to the design of the instrument, but also to its purpose: to improve care through improved care plans. With a clinical rationale for its completion and pragmatic directions on how to use the information gathered, nursing home staff appear to perform accurate assessments (11).

**Measures**

We analyzed 34 measures selected a priori from a range of domains. The first domain addressed how elderly residents function in their environment and comprised indicators of ADL self-performance, decision making, and short-term memory loss. The second set addressed several aspects of the elderly residents’ adaptation to their situation, including manifested problem behavior (verbal abuse, physical abuse, and socially inappropriate behavior), demonstrated mood disturbance (anxiety, depression, and no involvement in facility activities), and the use of trunk restraints. We added a third set of items indicating clinical conditions and complications: falls (separately: <30 and 31–180 days prior), weight loss (5% in <30 days or 10% in <180 days), eating less, body mass index (used numerically), chewing problems, swallowing problems, incontinence (bowel and bladder), and catheter use. Finally, we considered diagnoses reflecting prevalent diseases of an elderly population (arthritis, cerebrovascular accident [CVA], cancer, diabetes, Alzheimer’s disease, other dementias, congestive heart failure, arteriosclerotic heart disease [ASHD], and hypertension). In all cases in which multiple levels were available, we examined the presence of the most dependent level. (Measures of the least dependent levels usually demonstrated relationships with age that were the mirror image of the most dependent levels, and intermediate levels were expectedly uninteresting.)

For two of the most important functional domains for nursing home care—ADLs and cognitive performance—we used known summary scales. The RUG-III ADL Index (12) succinctly summarizes residents’ self-performance in four late-loss ADLs: bed mobility, bed–chair transfer, eating, and toileting. From a range of 4 (independence in all four ADLs) to 18 (total dependence in all four), we examined the most impaired (i.e., values 14–18).

The MDS Cognitive Performance Scale (13) (CPS) summarizes the MDS cognitive measures. Five items are combined into a categorical functional scale that ranges from “totally functional” to “very severely impaired.” The CPS corresponds closely with scores from the Mini-Mental State Examination (MMSE) and the Test for Severe Impairment. We considered the two most severely impaired categories (severely and very severely impaired, MMSE score < 6). The category of severely impaired CPS corresponds to the highly impaired value of the MDS decision-making variable; the latter variable was thus dropped from the analysis.

**Analysis**

Initial examinations of the data considered average prevalence of each measure in the decades 65–74, 75–84, 85–94, and ≥95. For several variables, large differences were seen in the last two periods, encouraging more detailed examination of the very oldest-old. We computed the average prevalence of each measure at each individual age from 80 to 105. Changes in prevalence are similar to but not equivalent to the incidence of these conditions, because a person could acquire but be cured of a disease or die within the year (whether or not the death was related to the condition). Visual examination indicated that for younger ages (e.g., 80–90), the changes were relatively linear; for older ages, the increases were either linear with a larger slope or curvilinear with increasing slopes. To detect this change in slope, we employed piecewise regression models to examine how the prevalence of each measure changed with age (although many other models could have been used). For each measure, we optimized a model composed of two straight lines joined to form a continuous relationship, with a change in slope at a specified breakpoint. Similar models have been used by Chambers and Hastie (14). The model required fitting four parameters: the intercept and slope of the younger line segment (from age 80 to the breakpoint), the slope of the older line (from the breakpoint to age 106), and the breakpoint age (where the two lines are joined). We used weights proportional to the number of nursing home residents of each age, to accommodate for variance heterogeneity of the age-specific prevalence percentages. However, the primary results using weighted and nonweighted models were similar, and we report here the unweighted results. The optimal breakpoint value was estimated by “profiling the objective function” (15): for
each possible breakpoint (from 85 to 100), the best piecewise linear model was fit (two slopes and the intercept), using least squares. Then, across the range of breakpoints, the optimal model of this class was chosen to minimize the objective function: the sum of squared residuals. Assuming that the two-slope model adequately represents the prevalence by age, we tested the hypothesis of a change in slope at the breakpoint by comparing the residual sum of squares for a simple linear model and for the optimal piecewise linear model, using an F test. This test likely underestimates the hypothesis because there is also uncertainty in the estimation of the breakpoint. Given this and potential concerns about multiple comparisons, we chose a conservative threshold for the F statistic ($p = .01$). With our large samples, almost any comparison is statistically significant, so we considered whether contrasts were substantive rather than relying solely on statistical comparisons.

The models generally showed adequate goodness of fit in plotted residuals. We stress that our primary purpose was to demonstrate that there was a marked change in the slope around some approximate age, not that a linear model was sufficient to describe the relationship of prevalence with age, especially after any specific age. It may also be that a higher order (e.g., cubic) model might be fit across the entire age domain, but this would mask that the relationship for the younger ages was close to linear and that the older ages followed a different model. Finally, we do not suggest that the change in slope was cataclysmic at some particular age; rather, within some particular range of ages there was a change from a model of linear increase to one of accelerated prevalence.

**Results**

From 193,467 unique residents of at least age 80, we had 113,103 octogenarians, 74,209 nonagenarians, and 6,155 centenarians. Each individual age from 80 through 101 was represented by at least 1,700 individuals, and by 990, 664, 434, and 289 individuals, respectively, for ages 102, 103, 104, and 105.

Figure 1 shows a plot typical for measures of functional impairment, here severely impaired cognition. As expected, the prevalence of severe impairment increases with age, representing an average gradual decline. Prevalence increases linearly from 22.6% at age 80 to mid-twenty percents in the late nineties, after which there is a shift in the annual change of prevalence, which rises to 34.6% by age 104. Fitting a piecewise model, also displayed, a slope change was found at approximately age 97. This model has an average increase of 0.2% per year (“younger” slope) for ages 80–97, but 1.1% per year from 97–105 (“older” slope). Thus, the fitted model indicates a slope change of 0.9% per year around age 97.

Many of the measures examined demonstrated these characteristics. Table 1 details the optimal model for each measure. The “younger” slope (e.g., the per year change in prevalence around age 80) for most conditions was of the expected sign, indicating increasing prevalence of the poorer outcomes. However, several measures had substantial and statistically significant age-specific changes toward lower prevalence of poor outcomes: depression, diabetes, hypertension, and CVA.

Seven measures demonstrated no significant slope changes from 80–105 years (as indicated by testing whether the piecewise-linear model was superior to simple linear model), including cancer, body mass index, falls 31–180 days prior, swallowing problems, and two behavior problems. For the remaining measures, we considered the magnitude of the slope change. Small to moderate slope changes were found for 18 measures, representing all the remaining clinical conditions and complications, all but one of the diagnoses, the remaining two behavior problems, and trunk restraint. Large late-life differences in the age-specific prevalence of conditions were seen for all measures of functionality, including all the ADL measures, incontinence, cognitive function, and a single diagnosis—arthritis. Some measures declined slightly in people in their eighties but increased in the late nineties: daily inappropriate behavior, falls (in 30 days), weight loss, and lack of involvement in activities. However, for most measures (including all the measures of functionality listed earlier), the nineties preserved a more substantial annual increment in prevalence.

The piecewise model also estimated the breakpoint—the inflection point between the two linear slopes. It is important to stress that our selection of the two-slope model was intended to depict the change in slope and not to focus on a particular age inflection point. Nevertheless, the breakpoints indicate the general range of ages after which the primary linear model fails to fit the data. The majority of the breakpoints are in the mid or late nineties. The six at the lower (age 85) or upper (age 100) bounds of the search indicated a relationship with slopes continually increasing or decreasing with age near these boundaries.

Finally, to address possible confounding with admission status, we divided our sample into those with stays >90 days and those relatively newly admitted. The results were virtually identical (data not shown).

**Discussion**

The prevalence of many adverse conditions in the elderly population increases every year of age after 80. Based on an almost unprecedentedly large sample, even of centenarians,
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these findings in nursing home residents extend those of others such as Kane and Kane (16), who found that in the general population the cross-sectional prevalence of disability, measured in several different ways, increases with age. However, we find that for many conditions the change in prevalence for each increasing year of age remains relatively constant until the mid-nineties, and thereafter the annual changes are substantively greater. Accelerated changes are seen for measures of how well an old person functions, including physical or mental functioning: dysfunction in ADL and cognitive performance (with the sole exception of short-term memory). In contrast, all measures of adaptation (behavior, mood, and restraint use) show small or no changes in slope, as do all clinical conditions and diagnoses (except arthritis). When detected, changes in slope generally occur in the mid-nineties. We are not aware of other studies detecting these changes.

Other of our results corroborate findings of other researchers, such as Smith (17), that the prevalence of certain diseases, including cancer, diabetes, and CVA, declines in late life. We expect that this is due to selective survival: these diseases are persistent and often directly or indirectly linked to mortality.

Our results should be interpreted critically, as our study has several limitations. One is the nature of the sample: our view is restricted to the population in nursing homes. Only 2% of those aged 65–74 live in a nursing home, but this percentage increases to 33% for those aged 90–94 and 47% for

### Table 1. Fitted Piecewise (Two-Slope) Linear Models

<table>
<thead>
<tr>
<th>Variable</th>
<th>Breakpoint</th>
<th>Younger</th>
<th>Older</th>
<th>$p$ Value*</th>
<th>Weighted Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short-term memory problem</td>
<td>0.67†</td>
<td>.062</td>
<td>66.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Verbally abusive (daily)</td>
<td>−0.03†</td>
<td>.227</td>
<td>3.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physically abusive (daily)</td>
<td>0.02†</td>
<td>.116</td>
<td>1.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fall: past 31–180 days</td>
<td>0.19†</td>
<td>.371</td>
<td>16.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body mass index (numeric index)</td>
<td>−0.10†</td>
<td>.249</td>
<td>22.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Swallowing problem</td>
<td>−0.03†</td>
<td>.020</td>
<td>10.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cancer</td>
<td>−0.09†</td>
<td>.071</td>
<td>7.8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* $p$ value for $F$-statistic testing if piecewise linear model is superior to simple (single-slope) linear regression model.
† Slope shown is that of a simple linear regression model.
‡ Slope of simple linear regression not significant ($p > .01$).
§ Piecewise linear model did not show clear optimality at threshold.
those aged 95 or older (18, 19). Although substantial proportions of persons older than 80 reside in nursing homes, and half of those in the oldest age groups, our sample cannot be representative of elderly persons living in the community. A combination of medical, cognitive, and functional problems, compounded with the behavior of informal and formal caregivers in recommending or accepting nursing home placement, causes certain individuals to enter nursing homes. Whether the same accelerated decline manifests itself in a community-based elderly population can only be conjectured. Second, we cannot infer causality (e.g., confirming the effects of selective survival). Our next step will be longitudinal analysis, following individuals across time, to measure the incidence of conditions and identify precipitating events. A third possible issue is the unknown effects of nursing home admission practices or quality of care. Fourth, there may also be unknown measurement effects that under- or overreport particular diseases or conditions in the very oldest-old. For example, the diagnosis of Alzheimer's disease or dementia may not be made in the very old, as it may be looked upon as to be expected, or the physician, family, or resident may avoid such designation or decision on etiology. This may be a reason for our different models for Alzheimer's disease and cognitive performance. Although MDS items have demonstrated good to excellent reliability, these studies have not been performed particularly on the oldest-old. Fifth, our findings may be a cohort effect rather than age-related changes in prevalence, a concern that can be addressed when we have data across a longer period of time or from other cultures. Sixth, we have not tested if the phenomenon is limited to a subset of the very oldest-old, such as females, or those with specific comorbidities; such analysis is currently under way. Finally, there may be technical issues with the analysis. The relationship between prevalence and age is unlikely to have a radical change at any specific age but rather can be expected to follow some higher order (and more complex) curve with a gradual accelerating prevalence. We observed a linear relationship in octogenarians and used our piecewise model to identify precipitation points have not been fully evaluated.

Nevertheless, although we acknowledge these possible problems, none provides a plausible explanation for the specific findings we focus on here—change in prevalence of broad measures of functionality in the mid-nineties in a large sample of institutionalized older persons. In this population, each additional acute or subacute problem over the years may have an accumulated effect, comparable to the cascade-breakdown phenomenon, in which more acute problems result in rapid terminal deterioration. The accumulated effects could compromise physiological reserves past the threshold needed for performance (20). Thus, the human body would wear out and experience a compressed period of change beyond the direct effects of disease.

Our results demonstrate that something different happens to elderly persons who survive into their mid-nineties—a more rapid rate of decline. Although this research does not provide an etiology of this change, it is associated with functionality rather than disease morbidity and is manifested in a very large and geographically broad population of institutionalized elderly persons. It was detected only by the availability of extremely numerous microdata on this population, which may only be available from large administrative data sets such as the MDS. The presence of this phenomenon provides justification for future efforts to examine centenarians separately: indeed, there appear to be differences between the very oldest-old and their younger counterparts. Physicians caring for the very oldest-old might take special care to understand functional deficits, which at times can be reversed or managed, rather than focusing on diseases that often cannot be cured.

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Address correspondence to Brant E. Fries, Ph.D., Institute of Gerontology, University of Michigan, 300 North Ingalls, Ann Arbor, MI 48109-2007. E-mail: bfries@umich.edu

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