Comparing hierarchical modeling with traditional logistic regression analysis among patients hospitalized with acute myocardial infarction: Should we be analyzing cardiovascular outcomes data differently?

Peter C. Austin, PhD, a,b Jack V. Tu, MD, PhD, FRCP, a,b,c,d and David A. Alter, MD, PhD, FRCP a,e

Toronto, Ontario, Canada

Background Data in health research are frequently structured hierarchically. For example, data may consist of patients treated by physicians who in turn practice in hospitals. Traditional statistical techniques ignore the possible correlation of outcomes within a given practice or hospital. Furthermore, imputing characteristics measured at higher levels of the hierarchy to the patient-level artificially inflates the amount of available information on the effect of higher-level characteristics on outcomes.

Methods Conventional logistic regression models and multilevel logistic regression models were fit to a cross-sectional cohort of patients hospitalized with a diagnosis of acute myocardial infarction. The statistical significance of the effect of patient, physician, and hospital characteristics on patient outcomes was compared between the 2 modeling strategies.

Results The 2 analytic strategies agreed well on the effect of patient characteristics on outcomes. According to the traditional analysis, teaching status was statistically significantly associated with 5 of the 9 outcomes, whereas the multilevel models did not find a statistically significant association between teaching status and any patient outcomes. Similarly, the traditional and multilevel models disagreed on the statistical significance of the effect of being treated at a revascularization hospital and 3 patient outcomes.

Conclusions In comparing the resultant models, we see that false inferences can be drawn by ignoring the structure of the data. Conventional logistic regression tended to increase the statistical significance for the effects of variables measured at the hospital-level compared to the level of significance indicated by the multilevel model. (Am Heart J 2003;145:27-35.) See related Editorial on page 16.

Over the past 2 decades there has been an exponential growth in the publication of cardiovascular outcomes research. Many recent studies have examined the impact of hospital, physician, and process-related characteristics on outcomes for patients hospitalized with acute myocardial infarction (AMI). By virtue of their observational design, these studies rely heavily on the use of multivariate analyses to remove the effects of confounding variables. This allows one to examine the impact of isolated factors on outcomes after adjusting for differences in patient, physician, and hospital characteristics.

Data in health research frequently exist in hierarchical fashion. Specifically, patients are managed by physicians, and physicians practice within hospitals. Applying traditional multivariate techniques to multilevel or hierarchically structured data has 2 important limitations. First, traditional multivariate techniques treat observations as though they were independent. However, patients within a given practice or hospital may share characteristics, and their outcomes are unlikely to be truly independent of one another. For example, physicians may tailor their clinical practices

From the aInstitute for Clinical Evaluative Sciences, Toronto, Ontario, bDepartment of Public Health Sciences, University of Toronto, Toronto, Ontario, cClinical Epidemiology and Health Care Research Program, Sunnybrook and Women’s College site, Toronto, Ontario, dDivision of General Internal Medicine, Sunnybrook and Women’s College Health Sciences Centre and the University of Toronto, Toronto, Ontario, and eDivision of Cardiology, Schulich Heart Centre, Toronto, Ontario, Canada.

Supported in part by an operating grant from the Canadian Institutes of Health Research (CIHR). Dr Tu is supported by a Canada Research Chair in Health Services Research. The Institute for Clinical Evaluative Sciences is supported in part by a grant from the Ontario Ministry of Health and Long Term Care. The views expressed herein are solely those of the authors and do not represent the views of any of the sponsoring organizations.

Submitted September 13, 2001; accepted January 11, 2002.

Reprint requests: Peter Austin, Institute for Clinical Evaluative Sciences, G-160, 2075 Bayview Ave, Toronto, Ontario, M4N 3M5 Canada.

E-mail: peter.austin@ices.on.ca

Copyright 2003, Mosby, Inc. All rights reserved.

0002-8703/2003/$30.00 + 0

toward specific diseases, risk, or sociodemographic subgroups, and may have different practice styles. At the hospital level, the implementation of specific quality assurance programs (e.g., treatment protocols, critical care maps, and standing orders) may result in less heterogeneity in the use of evidence-based therapies for patients admitted to a particular institution. Ignoring the clustering present in hierarchical data may result in underestimating a variable’s standard error. Underestimating a variable’s standard error may result in a type I error: falsely assuming that a variable is significantly associated with an outcome when in reality it is not. Second, from a statistical standpoint, traditional multivariate analyses treat all variables as characteristics of the patient, as opposed to characteristics of the physician who treated them, or of the hospital in which they were treated. This results in an artificially inflated number of independent observations at the higher levels of the hierarchy, and an underestimate in the magnitude of the standard error for the effect of characteristics measured at higher levels of the hierarchy. Furthermore, the imputation of all such characteristics to the patient level may also have the paradoxical effect of creating unnecessarily conservative estimates (i.e., too low type I error probabilities) for patient factors.

The importance of higher-level variables in health services research cannot be understated given quality improvement initiatives aimed at evaluating the impact of hospital and physician process characteristics on outcomes. For example, many studies have evaluated many hospital ecological variables (e.g., teaching status, volume, on-site revascularization) to serve as surrogate measures of process. In so doing, investigators have incorporated traditional statistical techniques that ignore the hierarchical data structure and have often demonstrated significant outcome associations. Recently, based on research examining the association between patient-outcomes and annual hospital volume of AMI patients, it was suggested that where feasible, transporting patients directly to centers designated for the treatment of cardiac disease might result in decreased AMI mortality. We hypothesize that traditional methods overstate statistical significance and associations between hospital/physician-level variables and outcomes.

Multilevel statistical techniques have recently been developed as one solution to deal with data arranged in a natural hierarchy. While many studies have incorporated hierarchical methods, no study has evaluated its effects against a large set of cardiovascular outcomes. This study was undertaken to compare traditional multiple logistic regression techniques with multilevel hierarchical modeling methods for patients hospitalized with an AMI in Ontario, Canada. We hypothesized that the use of hierarchical multilevel modeling would result in inferences that are more conservative when compared with those using traditional multivariate analyses, particularly for variables at higher levels of the hierarchy (i.e., physician- and hospital-level characteristics).

Methods

Data sources

This study examined all Ontario patients admitted to hospital with a most responsible diagnosis of AMI (International Classification of Disease 9th Revision, [ICD-9] code 410) between April 1, 1994 and March 31, 1999. The accuracy of AMI coding in the Ontario Myocardial Infarction Database (OMID) has been previously validated through large province-wide chart audits. Creation of this linked, population-based administrative database is described in detail elsewhere. Briefly, hospital discharge abstracts compiled by the Canadian Institute for Health Information yielded data pertaining to the index admission, patient demographics, illness severity, comorbidity, inhospital procedure use, and mortality. Hospital readmissions were identified by use of longitudinal database linkages. Access to angiography and revascularization was determined both through the hospital discharge abstract database and from physician claims data obtained from the Ontario Health Insurance Plan. The Ontario Drug Benefit Program, which provides universal drug benefit coverage for all elderly residents aged ≥65 years, identified discharge rates of medical therapies for eligible patients. The Ontario Registered Persons Database allowed us to determine out-of-hospital deaths.

Between April 1, 1994 and March 31, 1999, 119,900 patients were discharged from Ontario hospitals with a most responsible diagnosis of AMI. We excluded patients who were not admitted to an acute care institution (0.1%), aged <20 years or ≥105 years (0.02%), who had an invalid county code (1.7%), with invalid Ontario Health Card numbers (1.6%), admitted to a noncardiac surgical service (0.4%), transferred from an acute care institution (6.5%), with an AMI coded as an inhospital complication (2.5%), discharged alive for whom the total length of hospital stay was ≤3 days (3.1%), and those patients with an AMI admission in the previous year (7.4%). Complete details regarding the OMID database and the rationale for these criteria have been published elsewhere. Given that data on postdischarge medical therapies were only available for elderly patients, we confined the analyses to patients in the OMID database aged ≥65 years (excluded 38.1% of patients in the original OMID cohort due to age restriction). AMI care in Ontario is delivered primarily by general practitioners/family physicians, general internists, and cardiologists. Because the vast majority of patients (92.4%) had attending physicians with 1 of these 3 specialties, the decision was made to exclude those patients whose attending physician did not belong to 1 of these 3 groups. Similar decisions have been reported elsewhere. Physicians who did not fall into 1 of these 3 categories tended to be subspecialists in internal medicine.

Patient-, physician-, and hospital-level characteristics

Data were organized into 3 levels to reflect the natural hierarchy of the data: patient-, physician-, and hospital-level
characteristics. Patient-level characteristics consisted of age, sex, and disease severity. Disease severity was derived by use of the Ontario AMI mortality prediction rules for 30-day and 1-year mortality.25 The prediction rule comprised the variables of cardiac severity (eg, congestive heart failure, cardiacogenic shock, arrhythmia), and comorbid status (eg, diabetes mellitus, stroke, acute and chronic renal disease, and malignancy), as derived from the ICD-9 codes present in the 15 secondary diagnostic fields of the hospitalization database. The prediction rule was derived on a subset of the OMID database (ie, all AMI patents admitted between April 1st 1994 and March 31st 1997) with areas under the receiver operating curve of 0.78 for 30-day mortality and 0.79 for 1-year mortality (with age and sex included in the model). The prediction rule has been independently validated in 4836 and 112,234 patients with AMI from Manitoba and California, respectively.26

Physician-level characteristics consisted of the attending physician specialty: cardiology, internal medicine, and general practice. We examined 2 hospital-level characteristics: academic affiliation (teaching vs nonteaching status), and the presence or absence of on-site revascularization facilities. There were 4 institutions that had on-site angiography-only facilities, comprising 3.9% of the sample population, which were excluded from the analysis because of a small sample size.

Outcomes

Outcomes were classified into 3 categories: (1) fatal, (2) nonfatal outcomes, and (3) processes of care. Fatal and nonfatal outcomes consisted of mortality and recurrent angina admissions at 1-year postdischarge, respectively. Processes of care outcomes consisted of utilization rates of coronary angiography at 1-year, myocardial revascularization at 1-year, discharge rates of evidence-based therapies (ie, aspirin, β-blockers, angiotensin-converting enzyme inhibitors, statins), and utilization of calcium-channel blockers at 90-days. Recurrent angina admissions were restricted to those patients who were discharged alive after the index admission. Postdischarge drug utilization outcomes were restricted to all patients who were discharged alive after the index admission, and who were not discharged to a chronic care facility. Due to the lack of clinical detail in the administrative data that was used, we were unable to determine both patient eligibility for these therapies and the presence of clinical contraindications to therapy.

Statistical analyses

We fitted a conventional logistic regression model to the data for each of the 9 outcomes. Patient, physician, and hospital characteristics were entered into a traditional multivariate logistic regression model23 to examine their association with the outcome. Patients’ age and illness severity were treated as continuous variables. The conventional logistic regression model imputed physician and hospital characteristics to the patient. Patients treated by the same physician, or within the same hospital were treated as independent observations. The conventional logistic regression models were fit using SAS v8 (SAS Institute Inc, Cary, NC).

The above analyses were repeated using multilevel logistic regression model techniques.17,19 Such models are also known as random effects models or hierarchical regression models. The relationships between patient-, physician-, and hospital-level characteristics were examined for each of the outcomes. A multilevel analysis allows one to correctly incorporate variables measured at different levels of the hierarchy, and to take into account the fact that the outcomes of 2 patients under the care of a single physician, or within the same hospital may be correlated. The multilevel model assumed a normal distribution of physician- and hospital-specific effects.

The proportion of residual variance attributable to variations between units of the 3 levels of hierarchy was determined for each outcome, using methods described elsewhere.17 This is equal to the proportion of the unexplained variation in outcomes due to unmeasured characteristics at each of the 3 levels. The multilevel models were fitted using 2nd order penalized quasi-likelihood (PQL) methods and the MLwiN version 1.10.0006 software package.25

In each model, physician speciality was treated as a 3-level categorical variable. It was represented by 2 indicator variables, 1 denoting a general internist, and 1 denoting a cardiologist. Hence, at the physician-level, general practitioners/family physicians (GP/FP) was the reference category. The effect of being treated by either a general internist or a cardiologist was compared to the effect of being treated by a GP/FP. Similarly, at the hospital level, revascularization hospitals were compared with nonrevascularization hospitals, and teaching hospitals were compared with nonacademic hospitals.

Statistical significance was defined as $P < .05$ for all analyses.

Results

The cohort consisted of 51,046 patients admitted to 204 hospitals, who were cared for by 4502 physicians. The average age was 76.1 years (SD 7.2); 45.4% were female. The number of AMI admissions ranged from 1 to 1329 across the population of hospitals. The median number of patients admitted to a given hospital was 133 (1st quartile, 50.5; 3rd quartile, 402.5). The number of patients treated by a specific physician at a specific hospital ranged from 1 to 227. The median number of patients treated by a specific physician at a specific hospital was 3 (1st quartile, 1; 3rd quartile, 9). The number of physicians practicing in a given hospital ranged from 1 to 112. The median number of physicians per hospital was 16 (1st quartile, 9; 3rd quartile, 31.5).

The coefficient estimates and 95% CIs, as derived from the traditional and multilevel models, are presented for the patient-, physician-, and hospital-level characteristics.

Patient-level factors

Table I contains the odds ratios and 95% CIs for the effects of patient age, sex, and illness severity, as derived from the conventional and multilevel logistic regression models, on cardiovascular outcomes. The im-
impact of patient-level factors on outcomes was virtually equivalent using multilevel and traditional statistical techniques. Increasing age, disease severity, and male sex were associated with higher mortality and lower angina readmission rates at 1-year after AMI after adjusting for baseline characteristics with either of the statistical techniques. Patients most likely to undergo cardiac interventions after AMI included those in lower age groups, males, and those with lower disease severity. Increasing age predicted lower use of evidence-based therapies after AMI. Females, compared with males, were more likely to be prescribed aspirin, β-blockers, and statins after AMI, after adjusting for all remaining baseline characteristics. In summary, when compared with traditional multivariate techniques, hierarchical modeling resulted in equivalent findings for patient-level characteristics.

Table 1. Effect of patient characteristics on outcomes after myocardial infarction

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Age</th>
<th>Female sex</th>
<th>Illness severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-year mortality</td>
<td>1.078 (1.075, 1.081)</td>
<td>1.012 (0.971, 1.055)</td>
<td>1.053 (1.051, 1.055)</td>
</tr>
<tr>
<td>1-year catheterization</td>
<td>0.879 (0.875, 0.882)</td>
<td>0.839 (0.800, 0.880)</td>
<td>0.971 (0.968, 0.973)</td>
</tr>
<tr>
<td>1-year revascularization</td>
<td>0.875 (0.872, 0.879)</td>
<td>0.836 (0.796, 0.878)</td>
<td>0.970 (0.967, 0.972)</td>
</tr>
<tr>
<td>1-year angina readmission</td>
<td>0.884 (0.880, 0.889)</td>
<td>0.834 (0.786, 0.884)</td>
<td>0.967 (0.963, 0.971)</td>
</tr>
<tr>
<td>90-day ASA use postdischarge</td>
<td>0.990 (0.985, 0.994)</td>
<td>1.244 (1.173, 1.319)</td>
<td>0.992 (0.988, 0.996)</td>
</tr>
<tr>
<td>90-day ACE use postdischarge</td>
<td>0.990 (0.985, 0.994)</td>
<td>1.243 (1.171, 1.319)</td>
<td>0.992 (0.989, 0.996)</td>
</tr>
<tr>
<td>90-day β-blocker use postdischarge</td>
<td>0.985 (0.982, 0.988)</td>
<td>1.020 (0.980, 1.063)</td>
<td>0.980 (0.978, 0.983)</td>
</tr>
<tr>
<td>90-day CCB use postdischarge</td>
<td>0.985 (0.982, 0.988)</td>
<td>1.019 (0.978, 1.062)</td>
<td>0.979 (0.976, 0.981)</td>
</tr>
<tr>
<td>90-day statin use postdischarge</td>
<td>1.006 (1.003, 1.009)</td>
<td>1.068 (1.026, 1.111)</td>
<td>1.043 (1.040, 1.046)</td>
</tr>
<tr>
<td>90-day revascularization</td>
<td>1.006 (1.003, 1.009)</td>
<td>1.065 (1.022, 1.109)</td>
<td>1.043 (1.040, 1.046)</td>
</tr>
<tr>
<td>90-day on-site revascularization</td>
<td>0.953 (0.950, 0.956)</td>
<td>1.043 (1.001, 1.087)</td>
<td>0.954 (0.952, 0.957)</td>
</tr>
<tr>
<td>90-day catheterization</td>
<td>0.951 (0.948, 0.954)</td>
<td>1.044 (1.001, 1.090)</td>
<td>0.951 (0.949, 0.954)</td>
</tr>
<tr>
<td>90-day mortality</td>
<td>1.003 (1.000, 1.006)</td>
<td>1.165 (1.118, 1.214)</td>
<td>0.993 (0.991, 0.996)</td>
</tr>
<tr>
<td>90-day mortality</td>
<td>1.004 (1.001, 1.007)</td>
<td>1.174 (1.125, 1.225)</td>
<td>0.993 (0.990, 0.995)</td>
</tr>
<tr>
<td>90-day mortality</td>
<td>0.915 (0.911, 0.919)</td>
<td>1.136 (1.080, 1.195)</td>
<td>0.987 (0.984, 0.990)</td>
</tr>
<tr>
<td>90-day mortality</td>
<td>0.909 (0.905, 0.913)</td>
<td>1.151 (1.092, 1.213)</td>
<td>0.983 (0.980, 0.987)</td>
</tr>
</tbody>
</table>

Values presented as the odds ratio (95% CI) derived from the conventional logistic regression model first, and the odds ratio (95% CI) derived from the hierarchical logistic regression model second.

Hospital-level factors

In one circumstance, the use of multilevel modeling would have resulted in a statistically significant relationship between cardiology specialty and angina readmissions (P = .008), whereas the use of traditional testing would not have (P = .0906). In summary, when compared with traditional multivariate techniques, hierarchical modeling resulted in stronger effect sizes, especially among cardiologists.

Figures 3 and 4 illustrate the point-estimates and 95% CIs for hospital teaching status and on-site revascularization capacity, respectively, and compare multilevel and traditional multivariate models for each of the 9 outcomes. In general, while the directions of effect were similar between the 2 statistical methods for the vast majority of outcomes, multilevel modeling led to wider confidence intervals for each of the 9 outcomes examined. Specifically, the relationship between teaching status and outcomes met criteria for statistical significance in 5 of the 9 outcomes (angina readmissions, aspirin, β-blockers, calcium-channel blockers, and statins) using traditional methods, and in none of the 9 outcomes using hierarchical modeling techniques. The relationship between on-site revascularization facilities and outcomes met criteria for statistical significance in 4 of the 9 outcomes (cardiac catheterization, revascularization procedures, angiotensin-converting enzyme inhibitors, and β-blockers) using traditional methods, and in only 1 of the 9 outcomes (cardiac catheterization) using hierarchical modeling techniques.
mary, the increased width of confidence intervals with hierarchical compared with traditional statistical multivariate techniques resulted in 8 statistically significant associations becoming nonsignificant trends.

Unexplained variation

The percent of residual or unexplained variation attributable to variations between patients, physicians, and hospitals is summarized in Table II for each of the 9 outcomes using multilevel models. Unmeasured differences between patients accounted for the largest proportion of the variability not explained by the model. Unmeasured physician characteristics and unmeasured hospital characteristics accounted for 1.8% to 12.6% of the variability in patient outcomes not explained by the model. The proportion of residual variation that was due to unmeasured differences between physicians and unmeasured differences between hospitals was greatest for process of care measures, less so for fatal outcomes, and least for nonfatal outcomes after AMI. In contrast to multilevel models, the traditional regression model assumed that all of the residual variability was due to unmeasured variation between patients.

Discussion

Our study compared 2 analytic techniques of evaluating cardiac outcomes data: hierarchical versus traditional multivariate methods. We demonstrated that the effects of physician and hospital-level characteristics were sensitive to the analytic method chosen. If one were to base inferences on the presence or absence of statistical significance (ie, \( P < .05 \)), hierarchical methods would have led to different conclusions 44% (8/18) of the time when examining the impact of hospital factors on outcomes after AMI. Whereas hierarchical modeling led to less statistically significant results for hospital characteristics, it led to more greater-effect sizes when examining the impact of physician characteristics on outcomes after an AMI. In contrast to physician- and hospital-level characteristics, the 2 statistical methods showed excellent agreement when examining the impact of patient-level characteristics on outcomes. While none of the unexplained variation was attributable to unmeasured physician or hospital factors when using traditional statistical models, unmeasured physician and hospital factors accounted for as much as 12.6% of the unexplained variation when incorporating hierarchical techniques. In short, traditional statistical methods for multivariate analyses tended to overestimate the statistical significance of hospital factors and, at the same time, underestimate the magnitude of the effects of physician specialty on AMI outcomes when compared with hierarchical methods.
Our results are consistent with those published elsewhere: for example, Bennett examined 950 children attending primary school in the United Kingdom and demonstrated a significant relationship between teaching style and educational progress using traditional multivariate techniques. Upon a reanalysis of the data, Aitkin et al accounted for the clustering of students in classes and schools by using hierarchical modeling and concluded that the association was no longer significant.

Many studies have examined the effects of hospital and physician characteristics on cardiac outcomes after AMI, with the expectation that these ecological factors serve as surrogate markers for quality of care. For example, Thiemann et al demonstrated that mortality rates among patients admitted to large-volume hospitals in New York State were lower than those admitted to medium- and low-volume institutions. More recently, Allison et al determined that hospitals with teaching affiliation had better outcomes after AMI. Tu et al demonstrated that patients with AMI treated by admitting physicians with a high annual volume of patients with AMI had lower mortality than patients treated by low-volume physicians. Other studies have examined the relationship between physician characteristics (e.g., attending physician specialty, annual AMI patient volume, surgical volume) on outcomes among patients with cardiovascular disease. Some of these studies have led to changes in policy in jurisdictions and in hospitals. Despite their importance, few of these studies have incorporated hierarchical modeling when adjusting for confounding variables, opting instead for traditional multivariate techniques. Traditional multivariate regression models ignore the homogeneity that may exist in patient care within a single physician’s practice or within a single admitting institution. Ignoring this homogeneity may result in false inferences regarding the relationships between hospital or physician characteristics and outcomes.

Traditional logistic regression models impute physician and hospital characteristics to the patient-level, treating them as though they represented an inherent characteristic of the patients themselves. Accordingly, all of the unexplained variation in traditional models is assumed to be attributable to patient-related factors. Our results illustrate that this assumption may not be valid. Specifically, unmeasured physician and hospital factors accounted for modest proportions of the unexplained variability in outcomes using hierarchical techniques. Moreover, the degree to which unexplained variation was attributable to unmeasured physician and hospital factors was greatest for process of care-related
outcomes, suggesting that traditional logistic regression models may be sub-optimal when studying determinants of care. Moreover, traditional techniques artificially inflate the amount of independent information and may be invalid when examining data at higher levels of the hierarchy (at the hospital level). This likely explains why the confidence intervals were narrower with traditional than with hierarchical methods for hospital-related factors. Yet, our results also suggest that traditional models may underestimate the magnitude of the effect of physician-related characteristics on outcomes.

The results of the current study seem to suggest that if one is interested only in the effect of patient-level characteristics, then one may safely ignore the hierarchical structure of the data, and use conventional statistical models. Our findings indicate that this interpretation is true if one is interested only in the coefficient estimates associated with patient characteristics (e.g., age, sex). However, if one is interested in any function that involves the intercept, then conventional statistical models will produce different results than will hierarchical regression models. Research by the authors has shown that hierarchical regression models result in different hospital-specific risk-adjusted mortality rates than are obtained using conventional logistic regression (unpublished data), even though only patient-level characteristics are used in both models.

There are several noteworthy limitations of our study. First, limited clinical and process data were available. Because our study relied on administrative data, we were unable to adjust for all possible clinical factors that influence mortality, readmission, access to cardiac procedures, and secondary prevention. However, we did adjust for patient comorbidities, using a risk-adjustment model that has been independently validated in 2 jurisdictions. Second, we chose to examine each outcome as a dichotomous outcome within a given variable. Several of the outcomes are more appropriate for survival analysis that allows one to incorporate censoring. However, for computational reasons, this approach was not explored. Third, discharge abstract data did not allow us to link physicians across hospitals. Thus, the same physician practicing in 2 different hospitals was treated as 2 separate physicians. Ideally, physicians would be linked across hospitals, and cross-classified multilevel models would be used. However, these methods are computationally intensive, and could be potentially difficult to implement on a data set as large as the one used for the current study. Despite these limitations, our sample was large, comprehensive, and highly representative of the
We have examined the effect of patient, physician, and hospital characteristics on 9 different patient outcomes using a large, hierarchically structured data set. We have shown that conventional statistical methods tend to overstate the statistical significance of characteristics measured at the hospital-level. With the exception of 1-year mortality, either teaching status or the presence of revascularization facilities was associated with each of the outcomes using the conventional regression model, but not with the hierarchical regression model. We demonstrated that variations in patient outcomes were at least marginally due to unexplained differences between physicians and hospitals for each of the 9 outcomes. This leads us to conclude that, in general, there are hierarchical effects within data that are hierarchically structured. An empirical test for the presence of hierarchical effects would be to fit the 2 models and observe whether similar results were obtained. Furthermore, if 100% of the unexplained variation in outcomes was attributable to differences between patients, then one could safely ignore the hierarchical structure of the data.

In conclusion, researchers must be cognizant of hierarchically structured data sets. We suggest that hierarchical methods of multivariate analyses be routinely incorporated into the statistical analyses, in order to account for the hierarchical structure of the data. Fail-
ure to account for the structure of the data may lead to erroneous inferences.

References