Incidence of Adverse Drug Reactions in Hospitalized Patients

A Meta-analysis of Prospective Studies

Jason Lazarou, MSc; Bruce H. Pomeranz, MD, PhD; Paul N. Corey, PhD

Objective.—To estimate the incidence of serious and fatal adverse drug reactions (ADR) in hospital patients.

Data Sources.—Four electronic databases were searched from 1966 to 1996.

Study Selection.—Of 153, we selected 39 prospective studies from US hospitals.

Data Extraction.—Data extracted independently by 2 investigators were analyzed by a random-effects model. To obtain the overall incidence of ADRs in hospitalized patients, we combined the incidence of ADRs occurring while in the hospital plus the incidence of ADRs causing admission to hospital. We excluded errors in drug administration, noncompliance, overdose, drug abuse, therapeutic failures, and possible ADRs. Serious ADRs were defined as those that required hospitalization, were permanently disabling, or resulted in death.

Data Synthesis.—The overall incidence of serious ADRs was 6.7% (95% confidence interval [CI], 5.2%–9.2%) and of fatal ADRs was 0.32% (95% CI, 0.23%–0.41%) of hospitalized patients. We estimated that in 1994 overall 2,216,000 (1,721,000–2,711,000) hospitalized patients had serious ADRs and 106,000 (76,000–137,000) had fatal ADRs, making these reactions between the fourth and sixth leading cause of death.

Conclusions.—The incidence of serious and fatal ADRs in US hospitals was found to be extremely high. While our results must be viewed with circumspection because of heterogeneity among studies and small biases in the samples, these data nevertheless suggest that ADRs represent an important clinical issue.

JAMA. 1998;279:1200-1206

METHODS
Definitions

One step we took to reduce heterogeneity was to exclude any data that did not use the following specific definitions:

Adverse Drug Reaction (ADR).—According to the World Health Organization definition, this is any noxious, unintended, and undesirable effect of a drug, which occurs at doses used in humans for prophylaxis, diagnosis, or therapy. This definition excludes therapeutic failures, intentional and accidental poisoning (ie, overdose), and drug abuse. Also, this does not include adverse events due to errors in drug administration or noncompliance (taking more or less of a drug than the prescribed amount). Using this conservative definition avoids overestimating the ADR incidence.

For editorial comment see p 1216.

Recently, some authors prefer the term adverse drug event (ADE), which is an injury resulting from administration of a drug. In contrast to the World Health Organization definition of ADR, the definition of ADE includes errors in administration. However, we have chosen the World Health Organization definition for ADR because of its frequent use in the studies that we analyzed, and because of our goal to estimate injuries incurred by drugs that were properly prescribed and administered. In those articles that did not use the World Health Organization definition (eg, ADE was used), we examined the raw data and removed adverse events due to errors in administration. However, this was not always feasible since a few articles may have included errors in administration but did not report them separately. Therefore, unfortunately, these latter articles added to the heterogeneity of our data.

PUBLIC ATTENTION is currently focused on adverse drug reactions (ADR) as evidenced by a recent bill passed by the US Senate requiring pharmaceutical companies to provide ADR information to consumers.1 Heightened interest in ADRs was stimulated by the thalidomide tragedy in the 1960s.2 To obtain an accurate estimate of ADR incidence in hospital patients, prospective studies were done, beginning in the 1960s, in which a defined population could be kept under close observation by monitors who recorded all ADR occurrences.3,4 These prospective studies have been done on 2 separate populations of patients; those admitted to the hospital due to an ADR (ADRd),5 and those experiencing an ADR while in the hospital (ADRn).6 We report here a meta-analysis of 38 of these prospective studies done in the United States over a period of 32 years from which we obtained ADR incidences for ADRn and for ADRd and an overall ADR incidence that combines these 2 groups. We focused mainly on serious and fatal ADRs since they represent the greatest impact of drug therapy. While recognizing the benefits of drug therapy, we chose not to compare benefits of drugs to the side effects of drugs.

From the Departments of Zoology (Mr Lazarou and Dr Pomeranz), Physiology (Dr Pomeranz), and Public Health Sciences (Dr Corey), University of Toronto, Toronto, Ontario.

Reprints: Bruce H. Pomeranz, MD, PhD, Departments of Physiology and Zoology, University of Toronto, 25 Harbord St, Toronto, Ontario, Canada M5S 3G5 (e-mail: pomeranz@utoronto.ca).

1200 JAMA, April 15, 1998—Vol 279, No. 15

Adverse Drug Reactions in Hospitalized Patients—Lazarou et al
Possible ADR.—This is an ADR that follows a reasonable temporal sequence and for which the ADR is a known response to the drug, although the response may also be explained by the patient's clinical state.10 Possible ADRs were excluded from our study.

Serious ADR.—This is an ADR that requires hospitalization, prolongs hospitalization, is permanently disabling, or results in death. Serious ADRs include fatal ADRs, which were also analyzed separately.

Prospective Studies.—Patients were present during the study, and monitors were able to interview physicians, nurses, or patients at least once per week. All ADRs were confirmed prior to patient's discharge from the hospital.

Retrospective Studies.—Chart reviews were performed after the patient had left the hospital. These studies were excluded from our analysis.

Literature Search

Electronic databases were searched using the following key word strategy: adverse drug or adverse reaction or drug-related or drug-induced and hospital. Three MeSH (Medical Subject Headings) terms were also used where appropriate (ie, hospitalization, drugs, drug therapy/adverse effects) in combination with key words. Databases that we used were MEDLINE (1966-1995), Excerpta Medica (1980-1999), International Pharmaceutical Abstracts (1970-1999), and Science Citation Index (1989-1999). The reference sections of all retrieved articles were manually searched for additional studies. In addition, we sent letters to researchers in the field to request unpublished data in order to reduce publication bias.

Selection Criteria

The following criteria were used:

1. The patients studied were not selected for particular conditions or specific drug exposures.
2. Sufficient information was reported in the published study to calculate the incidence of ADRs.
3. English translations of the papers were available.
4. Prospective monitoring was used to identify ADRs.
5. Definitions used in the studies coincided with ours (see "Definitions" subsection for our definitions).

Quality of the Data

Rather than merely assessing the quality of each study,11 we chose instead to improve the quality of our database. First, we used prospective monitoring as an inclusion criterion to exclude the lowest-quality studies (ie, the retrospective studies). Second, ADRs classified as "possible" were excluded. Attributing causality is always a problem with ADR detection12 and, by excluding possible ADRs, we reduced the number of false positives in the data.

Heterogeneity

We dealt with heterogeneity among the studies in numerous ways: (1) we placed considerable emphasis on the 95% confidence intervals (CIs) to draw attention to the heterogeneity,13 (2) we used a random-effects model to do the analysis because it takes into account the heterogeneity of the various studies,13,14 (3) to reduce heterogeneity, we excluded ADRs caused by errors in administration, noncompliance, overdose, drug abuse, or therapeutic failures, (4) for additional ways to reduce heterogeneity, we excluded ADRs not fitting our strict definitions, possible ADRs, and retrospective data.

Data Extraction

We determined the incidence of ADRs in the hospital by extracting the total number of hospital patients in each study experiencing at least 1 ADR and dividing this value by the total number of hospital patients in each study. The ADR incidence was expressed as the percent of patients with an ADR. A data collection form was developed prior to the study for this purpose. Information on nonserious, serious, and fatal reactions was extracted. Other data extracted included the year of the study, ward and hospital type in which the study was performed, mean age, average length of hospital stay, average number of drug exposures for the patients included in the study, and the number of men and women in each study. To test for reliability of our extraction procedures a randomly selected subset of the data was extracted independently by 2 of us (J.L. and B.H.P.) and was found to be very consistent for the published ADR incidence for serious, fatal, and all severities (intraclass correlation coefficient ranging from 0.89 to 0.92).

Analysis of ADR Incidence

We separately analyzed the incidence of ADR in and the incidence of ADR in and then combined the 2 groups to obtain an overall ADR incidence. We analyzed ADRs of all severities (which included nonserious and serious), ADRs that were serious (which included fatal), and ADRs that were fatal; however, we focused mainly on the serious and fatal ADRs. For each category, we analyzed the ADR incidences obtained from the different studies to determine the mean incidence and the 95% CIs. For this purpose we used a random-effects model for meta-analysis14 similar to the method used in the only previous meta-analysis of ADRs.15 This is the method of choice because it takes into account the heterogeneity of the various studies.16

When combining the incidence of ADR in and ADR in to obtain the overall incidence of ADRs, we avoided double counting patients who were admitted for an ADR and who then also experienced an ADR while in the hospital by assuming the 2 types of events to be independent and deriving an adjusted estimate using the following formula:

Adjusted Overall Incidence

= (Incidence of ADR in + Incidence of ADR in) - (Incidence of ADR in × Incidence of ADR in)

This provided a slightly smaller estimate of the ADR incidence. For example, the mean estimate for the overall number of serious ADRs per year (see "Results" section) would change by 83,000 patients, dropping from 2,249,000 (no adjustment) to 2,216,000 (our estimate using the adjustment).

When comparing groups, we used both parametric and nonparametric methods. The results were always the same for the 2 methods. Hence, for group comparisons, whenever possible, we reported the results of the more robust nonparametric Wilcoxon rank sum test.17 All statistical analyses were performed using the SAS statistical software package, version 6.11 (Statistical Analysis System, Cary, NC).

Number of Patients With ADRs

We estimated the number of hospital patients with ADR in the United States by using the incidence of ADRs in US hospitals derived from our data and multiplying this value by the number of hospital admissions in 1994 in the United States, obtained from published statistics.18 In 1994, there were 28,126,492 hospital admissions in the United States. We calculated the 1994 fatal ADRs as follows:

Number of Fatal ADRs in US Hospitals in 1994 (63,000) = Incidence of Fatal ADRs in Hospitals in the United States (0.0019) × Number of Hospital Admissions in the United States (33,125,492).

This estimate is based on the assumption that our sample is representative of the hospital population, and, hence, we examined representativeness at some length (see "Results" section).

RESULTS

Using our selection criteria, 39 of the 158 studies found in the literature were included in our meta-analysis. Features
Table 1.—Studies on ADRs in Patients While in the Hospital (ADRs)*

<table>
<thead>
<tr>
<th>Source, y</th>
<th>Words Studied</th>
<th>Study Size</th>
<th>All Serious</th>
<th>Serious</th>
<th>Fatal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basen et al. 1980†</td>
<td>1,7</td>
<td>378</td>
<td>8.3</td>
<td>0.9</td>
<td>0</td>
</tr>
<tr>
<td>Basen et al. 1980†</td>
<td>1,2</td>
<td>6031</td>
<td>4.4</td>
<td>1.5</td>
<td>0.36</td>
</tr>
<tr>
<td>Bouman et al. 1964‡</td>
<td>1</td>
<td>1064</td>
<td>15.3</td>
<td>1.1</td>
<td>0</td>
</tr>
<tr>
<td>Bases et al. 1980†</td>
<td>2, 6, 8</td>
<td>420</td>
<td>2.8</td>
<td>1.9</td>
<td>0</td>
</tr>
<tr>
<td>Szell et al. 1961‡</td>
<td>1</td>
<td>815</td>
<td>4.8</td>
<td>2.8</td>
<td></td>
</tr>
<tr>
<td>Mitchell et al. 1971‡</td>
<td>4</td>
<td>1868</td>
<td>16.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benner and Lipman, 1977‡</td>
<td>1, 9</td>
<td>122</td>
<td>7.2</td>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td>May et al. 1977‡</td>
<td>1</td>
<td>334</td>
<td>10.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Miller, 1973¶</td>
<td>4</td>
<td>11,520</td>
<td>22.5</td>
<td>2.4</td>
<td>0.29</td>
</tr>
<tr>
<td>McKenzie et al. 1973‡</td>
<td>4</td>
<td>1388</td>
<td>12.2</td>
<td>2.3</td>
<td>0.15</td>
</tr>
<tr>
<td>Wang and Tang, 1971‡</td>
<td>1, 9</td>
<td>825</td>
<td>14.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gardner and Watson, 1976‡</td>
<td>1</td>
<td>338</td>
<td>10.5</td>
<td>2.1</td>
<td>0.05</td>
</tr>
<tr>
<td>Borda et al. 1969‡</td>
<td>1</td>
<td>327</td>
<td>19.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sjod et al. 1967‡</td>
<td>1</td>
<td>714</td>
<td>13.9</td>
<td>0.8</td>
<td>0.42</td>
</tr>
<tr>
<td>Sjod et al. 1968‡</td>
<td>1</td>
<td>700</td>
<td>16.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ritchel 1965‡</td>
<td>1</td>
<td>600</td>
<td>6.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skorupka et al. 1964‡</td>
<td>1</td>
<td>1014</td>
<td>10.2</td>
<td>0.8</td>
<td>0.39</td>
</tr>
</tbody>
</table>

ADR indicates adverse drug reaction; ADRs, an ADR occurring in patients while in the hospital; and all episodes, class 4 or above.
†Words studied: 1, medical; 2, surgical; 3, parasitic; 4, pediatrics; 5, psychiatric; 6, internal medicine; 7, intensive care; and 8, gastro.
‡Incidence of ADRs (number of patients with ADRs/total patients studied) X 100.
¶This study performed by the Boston Collaborative Drug Surveillance Program was categorized as United States in our analysis since only 1,787 of the 11,583 patients were from hospitals outside of the United States.

Table 2.—Studies on Patients Admitted to the Hospital Due to an ADR†

<table>
<thead>
<tr>
<th>Source, y</th>
<th>Words Studied</th>
<th>Study Size</th>
<th>Incidence of ADRs, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nelson and Tabern, 1956‡</td>
<td>5, 7</td>
<td>450</td>
<td>9.3</td>
</tr>
<tr>
<td>Col et al. 1969 †</td>
<td>1</td>
<td>215</td>
<td>10.8</td>
</tr>
<tr>
<td>Michael et al. 1969 †</td>
<td>4, 5, 8</td>
<td>5649</td>
<td>10.9</td>
</tr>
<tr>
<td>Rigby et al. 1962 †</td>
<td>1</td>
<td>609</td>
<td>0.9</td>
</tr>
<tr>
<td>Leckie et al. 1969 †</td>
<td>1</td>
<td>634</td>
<td>4.2</td>
</tr>
<tr>
<td>Salter et al. 1965 †</td>
<td>5</td>
<td>41</td>
<td>12.2</td>
</tr>
<tr>
<td>Stewart et al. 1980 †</td>
<td>5</td>
<td>60</td>
<td>5.0</td>
</tr>
<tr>
<td>Frias et al. 1977 †</td>
<td>1, 2, 3, 4, 8</td>
<td>442</td>
<td>5.8</td>
</tr>
<tr>
<td>McKinney and Harrison, 1978 †</td>
<td>1</td>
<td>216</td>
<td>5.6</td>
</tr>
<tr>
<td>McKenney et al. 1974 †</td>
<td>4</td>
<td>2655</td>
<td>1.9</td>
</tr>
<tr>
<td>Carines et al. 1974 †</td>
<td>1</td>
<td>6025</td>
<td>2.0</td>
</tr>
<tr>
<td>Miller et al. 1974 †</td>
<td>1</td>
<td>492</td>
<td>3.3</td>
</tr>
<tr>
<td>Col et al. 1969 †</td>
<td>1</td>
<td>555</td>
<td>1.8</td>
</tr>
<tr>
<td>Raval et al. 1969 †</td>
<td>1</td>
<td>1025</td>
<td>3.0</td>
</tr>
<tr>
<td>Wesolowski et al. 1969 †</td>
<td>1</td>
<td>1185</td>
<td>5.9</td>
</tr>
<tr>
<td>Smith et al. 1968 †</td>
<td>1</td>
<td>2005</td>
<td>2.9</td>
</tr>
</tbody>
</table>

ADR indicates adverse drug reaction; ADRs, an ADR causing admission to the hospital; and all episodes, data not available.
†Use Table 1; the column "All Serious" is missing from Table 2 because all ADRs are classed as serious by definition.
†Words studied: 1, medical; 2, surgical; 3, parasitic; 4, pediatrics; 5, psychiatric; 6, internal medicine; 7, intensive care; and 8, gastro.
§Incidence of ADRs = (number of patients with ADRs/total patients studied) X 100.

of these 39 studies are given in Tables 1 and 2. These studies were excluded from our meta-analysis because one of our major goals was to determine representativeness of our sample in order to establish the accuracy of our summary statistics. Since we only had a sufficient number of studies from the United States to allow us to perform these tasks, we decided to exclude the remaining countries from our meta-analysis since a proper analysis for representativeness for any other country would be impossible to perform.

Incidence of ADRs

As shown in Table 3, the incidence of serious ADRs in 21% (95% CI, 19%-23%) of hospital patients, while the incidence of serious ADRs was 4.7% (95% CI, 3.1%.6%). The incidence of fatal ADRs was 0.4% (95% CI, 0.3%-0.6%) of hospital patients and the incidence of fatal ADRs was 0.1% (95% CI, 0.0%-0.2%). Combining ADR and ADRs, the overall incidence of serious ADRs was 6.7% (95% CI, 5.2%-8.2%) of hospital patients and the overall incidence of fatal ADRs was 0.8% (95% CI, 0.2%-0.4%). The incidence of ADRs in all severities (including nonserious and serious) was 10.9% (95% CI, 7.5%-13.9%) of hospital patients. The overall incidence of ADRs plus ADRs for all severities was 15.2% (95% CI, 12.0%-18.1%) of hospital patients.

Eight ADR articles included the proportion of type A (cis-dependent ADRs) and type B (idiosyncratic and/or allergic ADRs). Of the "all severities" ADRs, 75.5% (95% CI, 71.0%-79.9%) were type A reactions and 21.8% (95% CI, 16.9%-25.9%) were type B reactions. Unfortunately, none of these studies reported the proportion of type A and type B reactions for serious and fatal ADRs.

Number of Hospital Patients With ADRs

As shown in Table 4, we estimated that 702,000 (95% CI, 585,000-775,000) hospital patients in the United States experienced a serious ADR in 1984. We calculated that 1,547,000 (95% CI, 1,381,000-1,656,000) hospital patients experienced a serious ADR. Combining these values, overall 2,216,000 (95% CI, 1,701,000-2,711,000) hospital patients experienced a serious ADR in the United States in 1984. We calculated that there were 65,000 (95% CI, 41,000-85,000) fatalities due to ADRs and another 4,000 (95% CI, 1,600-7,100) deaths occurred in association with ADRs in the United States. Overall in 1984, we estimated that 106,000 (95% CI, 76,000-137,000) hospital patients were admitted to United States. Which could account for 35% (95% CI, 23.4%-46.6%) of the 2,288,000 recorded deaths from all causes during 1984 in the United States.Using the mean ADR incidence (106,000) or the more conservative lower lower 95% CI (78,000), we found that fatal ADRs ranked between the fourth and sixth leading cause of death in the United States in 1984.
Representativeness of Our Sample

Among the many factors possibly influencing ADR incidence, considerable research has identified average length of stay, age, gender, and drug exposure. Therefore, as shown in Table 5, we checked to see whether the population that we sampled was representative of the US hospital population. We vis-à-vis these 4 factors. We determined that the differences were significant for length of stay and gender but not for age. Unfortunately, we were unable to find values for the average number of drug exposures from national statistics. Possible biases in our ADR incidence that may have been caused by the differences in length of stay or gender are estimated in the “Comment” section.

Another possible source of sampling bias might be the year of study, as our meta-analysis spans 4 decades. Hence, we studied the relationship between ADR incidence and year of study using a random-effects linear regression model and found no significant correlation for ADR incidence (r = 0.57, P < 0.01) or for ADRs (r = 0.53, P < 0.01). The figure above shows these results graphically and indicates that no change in ADR incidence occurred over the span of our study. This result seems surprising since great changes have occurred over the last 4 decades in US hospitals that should have affected the incidence of ADRs. Perhaps, while length of hospital stay is decreasing, the number of drugs per day may be rising to compensate. Therefore, while the actual incidence of ADRs has not changed over the last 82 years, the pattern of their occurrence has, undoubtedly, changed.

It should be noted that additional factors have been proposed to have an effect on ADR rate: renal function, hepatic function, alcoholism, drug abuse, and severity of illness. Unfortunately, these factors were rarely reported in our sample of studies and, thus, could not be used to determine representativeness.

Medical wards are overrepresented in our database, and some articles in the literature suggest that ward type might have an effect on ADR incidence. Unfortunately, there is insufficient power in the 39 studies to calculate the incidence of ADRs for each ward type individually. Without these data, we cannot determine the possible effect that ward-type distribution might have on our ADR incidence. Nevertheless, in the “Comment” section, we estimate the possible bias due to ward type.

Similar to ward type, hospital type may also introduce bias into our results. It is thought that teaching hospitals contain more seriously ill patients than non-teaching hospitals, which may lead to a higher incidence of ADRs in teaching hospitals, but this has never been proven. Teaching hospitals are overrepresented in our sample. However, when we compared ADR incidence for teaching and nonteaching hospitals in our study, we found no significant differences. Thus, despite an overrepresentation of teaching hospitals in our sample, there may not be a major bias.

Finally, our letters to researchers in the field produced no evidence of publication bias.

**COMMENT**

We have found that serious ADRs are frequent and more so than generally recognized. Fatal ADRs appear to be between the fourth and sixth leading cause of death. Their incidence has remained stable over the last 30 years. There has been only one previous meta-analysis of ADR hospital studies, and it focused only on ADRs. Our article differs from the report in many respects: (1) we studied incidence of ADRs in US hospitals, (2) we combined ADRs and ADRs in order to obtain the overall incidence of ADRs, (3) we gave special emphasis to serious and fatal ADRs, (4) we improved the quality of the data by excluding retrospective studies and by excluding ADRs that were classified as “possible,” (5) we examined the representativeness of our sample, and (6) we estimated the total number of patients in US hospitals experiencing ADRs.

Recent studies have focused on ADEs, which include errors in administration. One of the goals of ADE research is to alert physicians about the preventability of many ADEs. In contrast, our study on ADRs which excludes medication errors, had a different objective: to show that there are a large number of serious ADRs even when the drugs are properly prescribed and administered.

We found that a high proportion of ADRs (76.2%) were type A reactions. This may suggest that many ADRs are due to the use of drugs with unavoidably
High toxicity. For example, warfarin often results in bleeding. It has been shown that careful drug monitoring in hospitals leads to a reduction of many of these ADRs, suggesting that some type A and type B ADRs may be due to inadequate monitoring of therapies and doses.35

Recent studies have shown that the costs associated with ADRs may be very high. Research to determine the hospital costs directly attributable to an ADR estimated that ADRs may lead to an additional $1.56 to $4 billion in direct hospital costs per year in the United States.35,36

Heterogeneity

As outlined in the “Methods” section, we dealt with heterogeneity in numerous ways. After taking these measures, we examined the remaining heterogeneity. We determined whether 4 factors thought to affect ADR incidence (age, gender, drug exposure, and length of stay) contributed to the remaining heterogeneity in our data using a linear regression version of the random-effects model.35 For ADR incidence, we found that the number of drug exposures and length of hospital stay jointly accounted for 43% of the variance (r = 0.66, P = .009, n = 18). For the rate of ADR, when age was included in the model, the variance was reduced by 27% (r = 0.68, P = .04, n = 14). Gender did not contribute to the variance. Thus, a great deal of the heterogeneity could be attributed to factors well known to affect ADR rates: number of drug exposures per patient, length of hospital stay, and the age of patients. This result indicates that much of the heterogeneity is due to variation in the populations examined in the various articles and, hence, only a portion of the variation could merely be attributed to inconsistent methods among the individual studies. For example, if the different investigators use different methods of ascertainment regarding what represents an ADR, they will find different rates. Another example of inconsistent methodology is the problem that some articles did not separate out administration errors. Methodological variation such as this is a limitation of meta-analysis.

Representativeness of Our Sample

In the “Results” section, we found that for the 5 factors examined 3 were possible sources of bias: length of stay, gender, and ward type. Thus, we have attempted to estimate the size of the sampling bias due to these 3 factors as follows. As seen in Table 5, we had a higher average length of hospital stay than the US national average (10.6 days vs 7.5 days).16 While the literature qualitatively reports a relationship between the incidence of ADR and length of stay,16,37 there are no quantitative estimates. Therefore, we performed a linear regression analysis on our own data using a random-effects model35 regressing the incidence of ADR on all severities on average length of stay to obtain a slope of 0.007 (P = .008) and deduced that increasing the length of hospital stay from 7.6 to 10.6 days would possibly cause the incidence of ADR of all severities to rise from the adjusted value of 8.7% to our value of 10.9%.

Also, as shown in Table 5, the proportion of female patients in our sample was lower than the national average (60% vs 66%). Using several studies reporting an increased incidence of ADRs among females, we were able to determine that, at most, the risk ratio for women vs men could be as high as 1.7 for both ADR incidence and ADR risk. Assuming the worst-case scenario, the adjusted value for the overall incidence of ADRs of all severities in the United States becomes 15.7% (95% CI, 12.7%-18.8%) compared with our value of 15.1% (95% CI, 12.0%-18.1%).

Finally, with regard to ward type, there was insufficient power in 39 studies to determine precisely the effect of ward-type discrepancies. Instead, we made a crude determination of the worst-case scenario of ward bias. If we assumed (1) that obstetrical wards have zero ADRs and (2) that we sampled zero obstetrical patients, and, since there are about 4 million obstetrical ward patients each year in the United States,8 of 38 million total hospital admissions,38 then the total number of ADRs occurring in the United States would be 0.33 lower than our estimates. Thus the overall number of fatal ADRs in the United States would drop from 106,000 (95% CI, 76,000-137,000) to 83,000 (95% CI, 67,000-121,000), which would make ADRs between the fourth and seventh leading cause of death in the United States rather than between the fourth and sixth leading cause as reported above. Regarding other ward types, psychiatric wards tend to have a higher ADR incidence and pediatric wards a lower ADR incidence than medical wards,39,40 so these 2 biases might cancel out. Thus, altogether, there probably is a small net upward bias in our ADR incidence due to our overestimation of medical wards.

CONCLUSIONS

Perhaps, our most surprising result was the large number of fatal ADRs. We estimated that in 1984 in the United States 106,000 (95% CI, 76,000-137,000) hospital patients died from an ADR. Thus, we deduced that ADRs may rank from the fourth to sixth leading cause of death. Even if the lower confidence limit of 76,000 fatalities was used to be conservative, we estimated that ADRs could still constitute the sixth leading cause of death in the United States, after heart disease (743,460), cancer (529,504), stroke (160,108), pulmonary disease (101,077), and accidents (90,523); this would rank ADRs ahead of pneumonia (76,719) and diabetes (53,894). Moreover, when we used the mean value of 106,000 fatalities, we estimated that ADRs could rank fourth, after heart disease, cancer, and stroke as a leading cause of death. While our results must be viewed with some circumspection because of the heterogeneity among the studies and small biases in the sample, these data suggest that ADRs represent an important clinical issue.

This work was supported by a grant (Dr Pomeranz) and a scholarship (Mr Lazarov) from the National Science Engineering Research Council, Ottawa, Ontario.

J. L. Lazarov did this work in partial fulfillment of his MSc degree at the University of Toronto, Ontario; B. H. Pomeranz, MD, PhD, was the principal investigator; and P. N. Corey, PhD, was the statistician who contributed to the conception, design, analysis, and interpretation of the data, and also participated in writing the manuscript.

A complete list of the 104 papers excluded from our meta-analysis is available on request from the authors.
References

52. Horwitz N. Pre-disposing factors in adverse drug reactions to drugs. BMJ. 1969;2:531-533.