ORIGINAL ARTICLE

Outcomes of Adult Trauma Patients Admitted to Trauma Centers in Pennsylvania, 2000-2009

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Objective: To examine longitudinal trends in mortality for injured patients admitted to trauma centers.

Design, Setting, and Participants: Retrospective cohort design of 208 866 patients admitted to level I or level II trauma centers in Pennsylvania between 2000 and 2009 using the Pennsylvania Trauma Outcome Study database. Multivariate logistic regression was used to estimate the temporal trend for in-hospital mortality.

Main Outcome Measures: Patients were stratified by injury severity to estimate mortality trends in patients with low-severity, moderate, severe, and very severe injuries.

Results: Comparing 2000-2001 data with 2008-2009 data, the odds of mortality decreased by 29% (adjusted odds ratio [AOR]=0.71; 95% CI, 0.59-0.85) and the odds of major complications decreased by 32% (AOR=0.68; 95% CI, 0.57-0.81). Between 2000 and 2009, the mortality rate for patients admitted with moderate trauma decreased by 42% (AOR=0.58; 95% CI, 0.46-0.71) and the mortality rate for patients with severe trauma decreased by 51% (AOR=0.49; 95% CI, 0.40-0.60). Mortality rates for patients admitted with mild trauma or with very severe trauma did not change significantly during this period.

Conclusions: In-hospital mortality and major complications for adult trauma patients admitted to level I or level II trauma centers declined by 30% between 2000 and 2009. After stratifying patients by injury severity, the mortality rate for patients presenting with moderate or severe injuries declined by 40% to 50%, whereas mortality rates remained unchanged in patients with the least severe or the most severe injuries.

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The landmark Institute of Medicine report *To Err Is Human: Building a Safer Health System*[1] has focused widespread attention on the impact of medical errors on patient outcomes and the need for transformational change in health care delivery. In addition to the unsafe care documented in the Institute of Medicine report, influential reports from RAND have revealed that patients receive only about half of recommended care.[2,3] Less attention has been focused on the accumulating evidence that outcomes across a wide spectrum of medical and surgical conditions have actually improved substantially over time. For example, the mortality rate after myocardial infarctions has decreased by nearly 25% during the past 10 years.[4] The mortality rate for Medicare patients hospitalized for heart failure decreased 16% between 1993 and 2006.[5] Operative mortality rates for major cardiovascular procedures have declined 13% for aortic valve replacements, 21% for coronary artery bypass grafting, and 36% for abdominal aortic aneurysm repair during the last 10 years.[6] Similar improvements in mortality rates have been achieved for major cancer resections.[6]

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Trauma is the leading cause of years of potential life lost prior to age 65 years, exceeding heart disease and cancer.[7] Since the release of the Institute of Medicine report entitled *Accidental Death and Disability: The Neglected Disease of Modern Society*,[8] national attention has been focused on this "neglected epidemic." The extent to which those efforts have resulted in improved patient outcomes for injured patients is unknown. Unlike other medical and surgical populations, mortality trends for trauma patients have not been explored in great depth. Our goal in this study was to determine whether the mortality improvements reported for medical and surgical patients during the last 10

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years are also present in trauma patients. We examined longitudinal trends in the overall mortality of injured patients admitted to level I or level II trauma centers using population-based registry data from Pennsylvania. Because we hypothesized that temporal trends in mortality outcomes may vary depending on injury severity, we also performed secondary analyses stratified by injury severity.

METHODS

DATA SOURCE

This retrospective cohort analysis was performed using data from the Pennsylvania Trauma Systems Foundation from patients admitted to level I and level II trauma centers between 2000 and 2009. Pennsylvania includes rural and urban areas, and its population provides a representative case mix of trauma patients.[9] The Pennsylvania Trauma Outcome Study database is population based and includes data on all trauma admissions at accredited trauma centers meeting Pennsylvania Trauma Outcome Study inclusion criteria: admission to the intensive care unit or step-down unit, hospital length of stay longer than 48 hours, hospital admissions transferred from another hospital, and transfers out to an accredited trauma center.[10] Data elements in the Pennsylvania Trauma Outcome Study database include deidentified data on patient demographic characteristics, Abbreviated Injury Score codes, *International Classification of Diseases, Ninth Revision, Clinical Modification* codes, mechanism of injury (based on *International Classification of Diseases, Ninth Revision, Clinical Modification* E codes), comorbidities, physiology information, mechanisms of injury, in-hospital mortality and complications, transfer status, processes of care, and encrypted hospital identifiers. Data quality is assured through the use of standard abstraction software with automatic data checks, a data definition manual, and internal and external data auditing.[11]

PATIENT POPULATION

The study sample was limited to trauma patients older than 16 years admitted to either level I or level II trauma centers in Pennsylvania, after excluding patients with burns, hypothermia, isolated hip fractures, superficial injuries, unspecified injuries, and nontraumatic mechanism of injury and patients transferred out to another hospital. From this initial cohort of 226 283 patient observations, we excluded patients with missing information on transfer status (286 patients) and demographic characteristics (170 patients), patients with invalid Abbreviated Injury Score codes (12 662 patients), and patients transferred out (4299 patients). The final study cohort included 208 866 patients admitted to 28 level I and level II trauma centers. This study was approved by the institutional review board at the University of Rochester School of Medicine and Dentistry.

STATISTICAL ANALYSIS

Exploratory analyses were performed to examine trends in the prevalence of patient characteristics across 2-year periods using bivariate linear regression for continuous variables and logistic regression for categorical variables. In the main analysis, we used logistic regression to estimate the temporal trend for in-hospital mortality between 2000 and 2009. In this baseline analysis, we adjusted for injury severity using the Trauma Mortality Prediction Model,[12] modified by the addition of age, sex, mechanism of injury, transfer status, comorbidities, systolic blood pressure, the motor component of the Glasgow Coma Scale, and year of admission. Time was specified using separate indicator variables for each 2-year period. Missing values of the motor component of the Glasgow Coma Scale and the systolic blood pressure were imputed using the Stata implementation of the multiple imputation by chained equations (MICE) method described by van Buuren et al.[13] We also performed complete case analysis limiting model estimation to observations without missing data as a sensitivity analysis.

In our secondary analyses, we performed stratified regression analyses in patients with low-severity (Injury Severity Score <9), moderate (Injury Severity Score 9-14), severe (Injury Severity Score 15-24), and very severe (Injury Severity Score >24) trauma. In these analyses, we found that temporal improvements in outcomes were limited to patients with moderate or severe trauma. We then performed additional analyses in this patient group (moderate or severe trauma) stratified by the following: (1) the presence or absence of hypotension on admission (systolic blood pressure ≤90 mm Hg); and (2) the mechanism of trauma (blunt vs penetrating).

We also performed a separate analysis to determine whether decreases in mortality over time were accompanied by increases in major complications. We defined the composite complication outcome as any of the following having occurred after hospital admission: acute respiratory distress syndrome, acute myocardial infarction, acute respiratory failure requiring longer than 48 hours of ventilatory support after a period of normal nonassisted breathing (≥48 hours) or reintubation, aspiration pneumonia, pneumonia, pulmonary embolism, fat embolism syndrome, acute renal failure, central nervous system infection, progression of original neurologic insult, liver failure, sepsis, septicemia, empyema, dehiscence, gastrointestinal bleeding, small-bowel obstruction, compartment syndrome, arterial occlusion, and postoperative hemorrhage. We estimated the temporal trend for complications using the approach described for mortality.

Data management and statistical analyses were performed using Stata SE/MP version 11.0 statistical software (StataCorp LP). Robust variance estimators were used because patient observations were clustered by hospital.[14] All statistical tests were 2-tailed, and $P < .05$ was considered statistically significant. The discrimination of the logistic regression models used in the baseline analysis was assessed using the C statistic.

RESULTS

The study population consisted of 208 866 patients admitted to 28 level I or level II trauma centers between 2000 and 2009 (**Table 1**). Comparing 2000-2001 data with 2008-2009 data, the mean age increased from 44 to 52 years ($P_{trend} < .001$); the prevalence of low-severity trauma decreased from 34.5% to 30.0% (adjusted odds ratio [AOR] = 0.81; 95% CI, 0.79-0.84; $P < .001$), whereas the prevalence of severe injuries increased from 14.5% to 19.9% (AOR = 1.28; 95% CI, 1.23-1.33; $P < .001$); the prevalence of Glasgow Coma Scale motor scores of 3 or lower decreased from 9.5% to 7.3% (AOR = 0.75; 95% CI, 0.72-0.79; $P < .001$); and the prevalence of hypotension decreased from 5.4% to 3.9% (AOR = 0.69; 95% CI, 0.65-0.74; $P < .001$). Between 2000 and 2009, the prevalence of blunt trauma increased from 37.8% to 44.9% (AOR = 1.34; 95% CI, 1.30-1.38; $P < .001$); low falls increased from 12.1% to 16.8% (AOR = 1.46; 95% CI, 1.40-1.52; $P < .001$); motor vehicle crashes decreased from 30.9% to 21.0% (AOR = 0.60; 95% CI, 0.58-0.61; $P < .001$); gunshot wounds decreased from

Table 1. Patient Characteristics

Characteristic	No. (%) 2000-2001	2002-2003	2004-2005	2006-2007	2008-2009
Hospitalizations, No.	32 533	36 152	41 423	47 535	51 223
Age, median (IQR), y[a]	44 (28-67)	45 (28-67)	46 (29-69)	48 (29-71)	52 (32-74)
Male[a]	20 800 (63.9)	22 932 (63.4)	26 550 (64.1)	29 970 (63.1)	31 086 (60.7)
Transferred in from other hospital[a]	7730 (23.4)	9003 (24.9)	11 039 (26.7)	13 436 (28.3)	15 522 (30.3)
Injury Severity Score					
<9[a]	11 221 (34.5)	12 275 (34.0)	13 158 (31.8)	14 709 (30.9)	15 380 (30.0)
9-14	11 306 (34.8)	12 347 (34.2)	14 325 (34.6)	16 359 (34.4)	18 043 (35.2)
15-24[a]	5298 (14.5)	6149 (17.0)	7639 (18.4)	9224 (19.4)	10 216 (19.9)
>24	4708 (14.5)	5381 (14.9)	6301 (15.2)	7243 (15.2)	7584 (14.8)
GCS motor component score					
≤3[a]	3083 (9.5)	3405 (9.4)	3769 (9.1)	3806 (8.0)	3740 (7.3)
4-5[a]	1598 (4.9)	1526 (4.2)	1605 (3.9)	1756 (3.7)	1922 (3.8)
6	26 375 (81.1)	29 212 (80.8)	32 726 (79.0)	37 394 (78.7)	42 554 (83.1)
Missing[a]	1477 (4.5)	2009 (5.6)	3323 (8.0)	4579 (9.6)	3007 (5.9)
Systolic blood pressure, mm Hg					
≤90[a]	1771 (5.4)	1792 (5.0)	1915 (4.6)	2055 (4.3)	1970 (3.9)
>90	30 446 (93.6)	33 812 (93.5)	38 296 (92.5)	43 513 (91.5)	48 892 (95.5)
Missing	316 (1.0)	548 (1.5)	1212 (2.9)	1967 (4.1)	361 (0.7)
Mechanism of trauma					
Blunt[a]	12 301 (37.8)	13 778 (38.1)	16 766 (40.5)	20 343 (42.8)	23 017 (44.9)
Motor vehicle crash[a]	10 039 (30.9)	11 229 (31.1)	11 295 (27.3)	11 954 (25.2)	10 759 (21.0)
Gunshot[a]	2203 (6.8)	2269 (6.3)	2571 (6.2)	2900 (6.1)	2579 (5.0)
Stab[a]	1323 (4.1)	1389 (3.8)	1616 (3.9)	1709 (3.6)	1892 (3.7)
Pedestrian trauma	2716 (8.4)	3006 (8.3)	3903 (9.4)	4294 (9.0)	4376 (8.5)
Low fall[a]	3951 (12.1)	4481 (12.4)	5272 (12.7)	6335 (13.3)	8600 (16.8)
Mortality, %[a]	7.2	6.8	6.6	6.1	5.7
Complications, %[a]	8.0	8.0	7.3	7.1	6.4

Abbreviations: GCS, Glasgow Coma Scale; IQR, interquartile range.
[a] $P_{trend} \leq .001$.

Table 2. Adjusted Mortality Rates

Variable	2000-2001	2002-2003 AOR (95% CI)	2002-2003 P Value	2004-2005 AOR (95% CI)	2004-2005 P Value	2006-2007 AOR (95% CI)	2006-2007 P Value	2008-2009 AOR (95% CI)	2008-2009 P Value
All patients	1 [Reference]	1.02 (0.88-1.18)	.77	0.92 (0.80-1.06)	.24	0.79 (0.67-0.93)	.004	0.71 (0.59-0.85)	<.001
ISS									
<9	1 [Reference]	1.02 (0.68-1.54)	.91	0.92 (0.63-1.33)	.64	0.99 (0.66-1.49)	.96	0.79 (0.51-1.22)	.29
9-14	1 [Reference]	0.94 (0.79-1.12)	.49	0.84 (0.66-1.06)	.13	0.72 (0.57-0.91)	.006	0.58 (0.46-0.71)	<.001
15-24	1 [Reference]	0.90 (0.72-1.12)	.36	0.75 (0.63-0.89)	<.001	0.61 (0.49-0.76)	<.001	0.49 (0.40-0.60)	<.001
>24	1 [Reference]	1.09 (0.87-1.37)	.46	0.98 (0.79-1.22)	.88	0.84 (0.65-1.07)	.16	0.82 (0.63-1.07)	.15
Blood pressure, mm Hg[a]									
≤90	1 [Reference]	0.97 (0.66-1.42)	.87	1.10 (0.80-1.51)	.56	0.90 (0.64-1.26)	.54	0.98 (0.66-1.47)	.93
>90	1 [Reference]	0.92 (0.78-1.08)	.29	0.76 (0.65-0.90)	.002	0.64 (0.54-0.76)	<.001	0.49 (0.41-0.60)	<.001
Mechanism[a]									
Blunt	1 [Reference]	0.92 (0.78-1.08)	.30	0.78 (0.65-0.93)	.005	0.65 (0.54-0.78)	<.001	0.53 (0.44-0.63)	<.001
Penetrating	1 [Reference]	0.91 (0.64-1.30)	.60	1.04 (0.71-1.51)	.85	0.65 (0.44-0.97)	.04	0.55 (0.37-0.81)	.003

Abbreviations: AOR, adjusted odds ratio; ISS, Injury Severity Score.
[a] Analysis based on patients with an ISS between 9 and 24.

6.8% to 5.0% (AOR=0.73; 95% CI, 0.69-0.77; $P<.001$); and the proportion of patients transferred in increased from 23.4% to 30.3% (AOR=1.39; 95% CI, 1.35-1.44; $P<.001$). The unadjusted mortality rate decreased from 7.2% to 5.7% (AOR=0.78; 95% CI, 0.73-0.82; $P<.001$).

Comparing 2000-2001 data with 2008-2009 data, the odds of mortality decreased by 29% (AOR=0.71; 95% CI, 0.59-0.85; $P<.001$) (**Table 2**) and the odds of a major complication decreased by 32% (AOR=0.68; 95% CI, 0.57-0.81). Between 2000 and 2009, the mortality rate for patients admitted with moderate trauma decreased by 42% (AOR=0.58; 95% CI, 0.46-0.71; $P<.001$) and the mortality rate for patients with severe trauma decreased by 51% (AOR=0.49; 95% CI, 0.40-0.60; $P<.001$)

(**Figure 1**). Patients admitted with mild trauma (AOR=0.79; 95% CI, 0.51-1.22; $P=.29$) or with very severe trauma (AOR=0.82; 95% CI, 0.63-1.07; $P=.15$) had similar outcomes in 2008-2009 compared with 2000-2001.

In patients with either moderate or severe trauma, the mortality rate for patients presenting without hypotension decreased by 51% (AOR=0.49; 95% CI, 0.41-0.60; $P<.001$), whereas the mortality rate for patients presenting with hypotension did not change between 2000 and 2009 (AOR=0.98; 95% CI, 0.66-1.47; $P=.93$) (**Figure 2**). Patients with moderate or severe trauma and presenting with either blunt trauma (defined here as including motor vehicle crash, pedestrian trauma, and low falls) (AOR=0.53; 95% CI, 0.44-0.63; $P<.001$) or penetrating trauma (AOR=0.55; 95% CI, 0.37-0.81; $P=.003$) had similar reductions in mortality during the 10-year period (**Figure 3**).

Results obtained using only observations without missing data were similar to those based on the imputed data (results not shown). The risk adjustment models used in the baseline analysis for mortality and major complications exhibited very good to excellent discrimination, with C statistics of 0.96 and 0.80, respectively.

COMMENT

This analysis of data from Pennsylvania shows that in-hospital mortality and major complications for adult trauma patients admitted to level I or level II trauma centers declined by 30% between 2000 and 2009. After stratifying patients by injury severity, we found that the mortality rate for patients with moderate or severe injury declined by 40% to 50%, whereas mortality rates did not improve significantly in patients with the least severe or the most severe injuries during this same period.

To our knowledge, this is the first large population-based study to examine temporal trends in outcomes for injured patients using comprehensive risk adjustment. A recent study based on data from Washington showed that the unadjusted in-hospital mortality rate decreased from 8% to 4.9% between 1995 and 2008.[15] However, this study did not control for injury severity or patient case mix. A second recent study also showed a decline in mortality rates among patients with severe injuries but not in patients with either the least severe or the most severe injuries.[16] However, that study was limited to patients from a single trauma center.

The exact mechanism for this substantial decline in trauma mortality over time is not known. Nathens et al[17] showed that the implementation of regional systems of trauma care was associated with reductions in motor vehicle crash mortality. There is also strong evidence that patients treated in trauma centers are less likely to die compared with patients treated in nontrauma centers.[18] The patients in our study cohort were all treated in trauma centers, eliminating regionalization of trauma care to specialized centers as a potential mechanism for the decline in mortality rates in Pennsylvania. Although there have been many changes in the management of critically ill trauma patients during the last 10 to 20 years, it is difficult to identify any single change in clinical practice that, by itself, may have led to the dramatic reductions in mortality observed in our study. Nonetheless, it is likely that many of the incremental advances in medical care, such as lung protection using low-tidal-volume ventilation,[19] early institution of enteral feedings,[20] and damage control surgery,[21,22] may together be responsible for some of the observed improvement in trauma outcomes during the last 10 years.

This study has several limitations that warrant discussion. Most importantly, because this study is limited

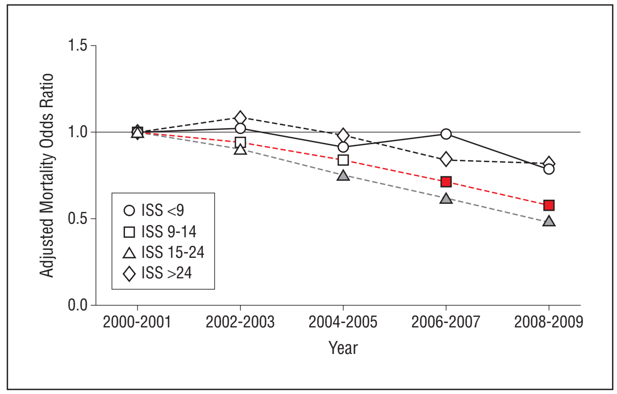

Figure 1. Trends in mortality rate as a function of injury severity. ISS indicates Injury Severity Score; solid symbols, $P<.05$.

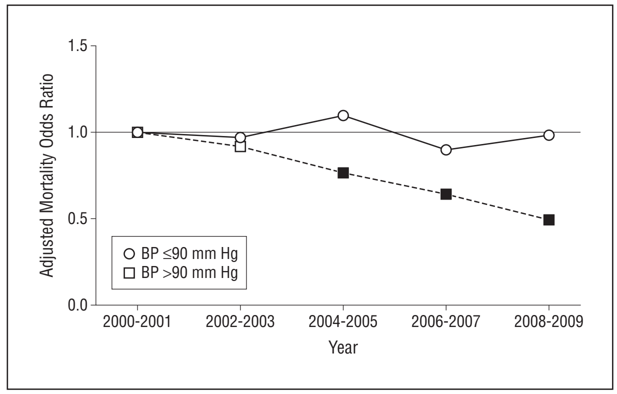

Figure 2. Trends in mortality rate as a function of hypotension for patients with an Injury Severity Score between 9 and 24. BP indicates blood pressure; solid symbols, $P<.05$.

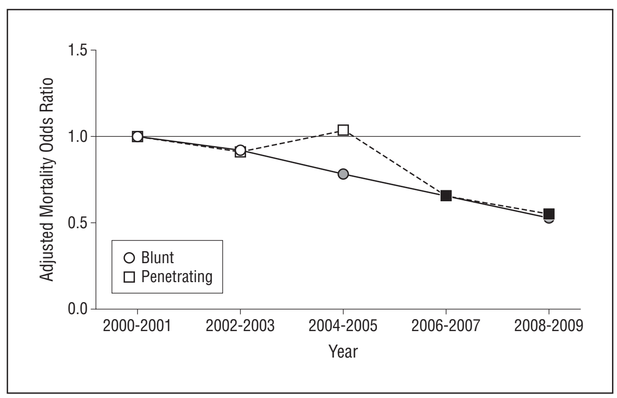

Figure 3. Trends in mortality rate as a function of mechanism of injury for patients with an Injury Severity Score between 9 and 24. Solid symbols indicate $P<.05$.

to patients admitted to trauma centers, it does not necessarily show that outcomes for all injured patients have improved during the last decade. Despite evidence that regionalization of trauma care results in better outcomes for severely injured patients, many patients with major trauma continue to be treated in nontrauma centers.[23] It is possible that the exclusion of severely injured patients who were initially admitted to nontrauma centers and then died may have led us to overestimate the size of the mortality reduction over time. Furthermore, trauma center closures in the United States are increasing at an accelerated pace, resulting in decreasing access to specialized trauma centers that are known to have the best outcomes.[24] In particular, this trend disproportionately affects the most vulnerable populations, such as African American individuals and people living in poverty.[24]

This study has other potential limitations as well. First, differences in patient case mix over time could account for our findings. We believe that this is highly unlikely given the comprehensiveness of the data from Pennsylvania and our use of a validated risk adjustment model that incorporates empirical measures of injury severity,[12] mechanism of injury, comorbidities, and patient physiology. The possibility of omitted variable bias is minimized by the excellent performance of our Trauma Mortality Prediction Model.[12] It is also unlikely that the use of imputed values for missing data affected our analysis because limiting our analysis only to patients without missing data yielded very similar findings. Second, this study examines trends in mortality and does not analyze other important dimensions of quality such as functional outcomes. It is possible that the observed improvements in mortality outcomes are associated with worse functional outcomes, limiting the actual patient benefit resulting from improvements in mortality rates. Third, the use of in-hospital mortality as opposed to 30-day mortality may have also led us to overestimate the magnitude of improvement in the mortality rate due to postdischarge deaths.[25] Finally, our study is based on Pennsylvania and may not necessarily be generalizable to other states.

In conclusion, we find that the mortality rate for trauma patients with moderate or severe injuries admitted to trauma centers has declined by more than 40% during the last 10 years. Although our results suggest that ongoing efforts to improve trauma care have led to significant improvements in trauma outcomes, there remains a large performance gap across hospitals caring for trauma patients.[26,27] This gap represents an opportunity to improve trauma outcomes even beyond the 40% reduction in mortality observed during the last decade. The challenge for the next 10 years is to narrow this performance gap by facilitating the diffusion of best practices from high-performing centers to lower-quality centers. The barrier to identifying best practices remains the lack of high-quality evidence on which to base clinical practice.[28,29] The trauma community must increase its efforts to systematically evaluate the effectiveness of both existing and innovative approaches to trauma care. Reducing unnecessary variation in trauma care through the implementation of best practices based on strong scientific evidence may be the key to achieving further large-scale reductions in trauma mortality rates during the next decade.

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Author Contributions: Dr Glance had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. *Study concept and design:* Glance, Osler, and Dick. *Acquisition of data:* Glance and Dick. *Analysis and interpretation of data:* Glance, Osler, Mukamel, and Dick. *Drafting of the manuscript:* Glance, Mukamel, and Dick. *Critical revision of the manuscript for important intellectual content:* Glance, Osler, Mukamel, and Dick. *Statistical analysis:* Glance, Osler, and Dick. *Obtained funding:* Glance and Dick. *Administrative, technical, and material support:* Glance and Dick. *Study supervision:* Glance and Dick.
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Correction

Error in Byline. In the article titled "Long-term and Perioperative Corticosteroids in Anastomotic Leakage: A Prospective Study of 259 Left-Sided Colorectal Anastomoses," published in the May issue of the *Archives* (2012;147[5]:447-452), there was an error in the byline. Dr Komen's name should have been listed as Niels Komen instead of Niels A. P. Komen. This article was corrected online.