Economic Trends from 2003 to 2010 for Perioperative Myocardial Infarction

A Retrospective, Cohort Study

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ABSTRACT

Background: Perioperative myocardial infarction (PMI) is a major surgical complication that is costly and causes much morbidity and mortality. Diagnosis and treatment of PMIs have evolved over time. Many treatments are expensive but may reduce ancillary expenses including the duration of hospital stay. The time-dependent economic impact of novel treatments for PMI remains unexplored. The authors thus evaluated absolute and incremental costs of PMI over time and discharge patterns.

Methods: Approximately 31 million inpatient discharges were analyzed between 2003 and 2010 from the California State Inpatient Database. PMI was defined using International Classification of Diseases, Ninth Revision, Clinical Modification codes. Propensity matching generated 21,637 pairs of comparable patients. Quantile regression modeled incremental charges as the response variable and year of discharge as the main predictor. Time trends of incremental charges adjusted to 2012 dollars, mortality, and discharge destination was evaluated.

Results: Median incremental charges decreased annually by $1,940 (95% CI, $620 to $3,250); P < 0.001. Compared with non-PMI patients, the median length of stay of patients who experienced PMI decreased significantly over time: yearly decrease was 0.16 (0.10 to 0.23) days; P < 0.001. No mortality differences were seen; but over time, PMI patients were increasingly likely to be transferred to another facility.

Conclusions: Reduced incremental cost and unchanged mortality may reflect improving efficiency in the standard management of PMI. An increasing fraction of discharges to skilled nursing facilities seems likely a result from hospitals striving to reduce readmissions. It remains unclear whether this trend represents a transfer of cost and risk or improves patient care.

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those that are clinically silent. Enhanced diagnosis in turn may lead to previous and/or more aggressive therapeutic interventions. In parallel, management of infarctions including coronary revascularization techniques has also evolved since the late 1990s: New surgical techniques have been introduced; angioplasty with drug-eluting stents (introduced 2002) and antiplatelet therapy with thienopyridines (late 1990s) are now widely used. Although not all are applicable in the context of PMI, they are predictably costly. For instance, a study by Fleisher et al.\textsuperscript{15} estimated a net increase of $15,000 in Medicare charges (2003 dollars) attributable to PMI. Increased direct cost of treatment may, though, be offset by shorter hospitalization and other savings, along with reduced mortality.\textsuperscript{15}

Our primary aim was to measure the trend in incremental hospital charges and in hospital mortality for PMI for the period of January 2003 to December 2010. Specifically, we tested the hypothesis that median and extremal (i.e., 10th and 90th percentiles of) incremental charges associated with PMI are increasing and that inpatient hospital mortality is decreasing. Second, we assessed trends in discharge destination, length of stay, total daily hospital charges, and incremental daily hospital charges.

Materials and Methods

We analyzed administrative data on approximately 32 million inpatient discharges from the 2003 to 2010 California State Inpatient Database.* In our analyses, all adult inpatients who had at least one surgical procedure were included. Because postdiagnosis care of PMI is approximately similar after cardiac and noncardiac surgery, we included both populations. Our primary outcome, total hospital charges, was mapped to 2012 U.S. dollars using the quarterly Consumer Price Index for Medical Care from the U.S. Bureau of Labor Statistics.† Patients with missing data on total hospital charges and/or baseline potential confounding variables were excluded from the analysis.

Perioperative myocardial infarction was defined as a nonpresent-on-admission (i.e., hospital acquired) diagnosis code for MI (\textit{International Classification of Diseases, Version 9, Clinical Modification}, diagnosis code of 410.xx) recorded for the discharge.

Baseline potential confounding variables included each patient’s diagnosis and procedure codes, age, sex, race, expected payer, as well as admission information such as source of admission, scheduled or unscheduled admissions, and weekend or weekday admission. Also used for potential confounder adjustment was the present-on-admission risk (POARisk) index. This is an all-purpose risk index for in-hospital mortality that incorporates age, sex, present-on-admission diagnoses, principal diagnosis, principal procedure, and secondary procedures that occurred on days leading up to the date of the principal procedure.\textsuperscript{16} Because POARisk incorporates all such diagnoses and procedures, it provides a granular and robust risk assessment.

To account for potential confounding, we matched each PMI patient to a non-PMI patient \textit{via} a propensity-matching procedure (see Statistical Analysis). Propensity scores were based on POARisk index, age, sex, race, scheduled (\textit{vs.} unscheduled) admission, primary expected payer, weekend (\textit{vs.} weekday) admission, and do-not-resuscitate order status. Successful matches were restricted to those with common year/quarter of discharge, common principal diagnosis code (\textit{International Classification of Diseases, Version 9, Clinical Modification} diagnosis code, truncated to the “base code” consisting of the first three digits), and common principal procedure code (\textit{International Classification of Diseases, Version 9, Clinical Modification} procedure code, truncated to the “base code” of two digits).

After matching, we defined incremental charges associated with PMI by calculating the difference in 2012 hospital charges adjusted to the medical rate of inflation between the PMI patient and the patient without PMI for each matched pair.

Statistical Analysis

After applying the above inclusion and exclusion criteria, we further removed all potentially matched control patients who did not share the distinct combination of year/quarter of discharge, primary diagnosis and primary procedure with at least one PMI patient, as these patients were ineligible for matching. Among the remaining patients, we estimated propensity scores\textsuperscript{17} using multivariable logistic regression. Restricted cubic splines were used in the propensity score model to flexibly relate continuous potential confounders such as the POARisk index and age to the odds of PMI.

Patients with PMI were each matched 1:1 to a non-PMI control patient based on a greedy distance matching algorithm,\textsuperscript{18} restricting successful matches to common year/quarter of discharge, primary diagnosis and primary procedure, and similar propensity scores (i.e., within 0.01 propensity score units).

As an exploratory graphical analysis, quantile regression\textsuperscript{19} was used to display various quantiles (\textit{e.g.}, bottom 1%, first quartile, median, top 10%) of the distribution of 2012-adjusted hospital charges, separately for the matched PMI and non-PMI patients.

To evaluate our primary hypotheses—namely that median and extremal incremental charges associated with PMI are increasing over time—we developed another quantile regression model, this time with incremental charges as the response variable (again, defined as the difference in 2012-adjusted hospital charges among each
matched pair) and year of discharge as the main predictor. In this model, we adjusted for the total charges for the non-PMI patient as doing so increases statistical precision of the effect of interest. We also adjusted for any potential confounding variables exhibiting imbalance between matched PMI and non-PMI populations; “imbalance” for this purpose was defined as an absolute standardized difference score greater than 0.1. We used standardized difference scores to assess balance after matching due to the fact that our large sample sizes might have identified clinically unimportant imbalances as independent associations. Standardized difference scores are defined as the difference in means, mean rankings, or proportions divided by a pooled estimate of SD.20

For the secondary outcomes, we analyzed discharge destination using a multinomial logistic regression model (adjusting for the same potential confounding variables as in our other analyses, if any). Analysis of length of stay, total daily hospital charges, and incremental daily hospital charges incorporated the same approach as our primary outcome.

Model-based Wald tests21 incorporating nonparametric bootstrap-resampling-based standard error estimates22 were used to perform the tests of trend over time. R statistical software (The R Foundation for Statistical Computing, Vienna, Austria) was used for all analysis. The Bonferroni correction for three simultaneous comparisons (median, 10th percentile, and 90th percentile of incremental charges vs. time) was applied to maintain a study-wide type I error rate of 0.05.23

**Results**

There were a total of 31.8 million inpatient discharge records available in the California State Inpatient Database covering the years 2003 to 2010. Among these, 17.1 million were eligible for our study and 14.0 million were ultimately included after removing patients with missing data. An additional 8.6 million potential controls were ineligible for matching (see Statistical Analysis). Details of included and excluded patients are provided in figure 1.

Among all patients meeting inclusion criteria, the incidence of PMI was 0.60% (95% CI, 0.59 to 0.60%). Overall median (first quartile, third quartile) total hospital charges for patients with and without PMI (in 2012 U.S. dollars) was $154,180 ($85,910, $280,110) and $52,040 ($29,500, $91,100), respectively.

There were 32,396 patients with PMI available for matching. The propensity-matching procedure yielded 21,637 matched pairs, each with common year/quarter of treatment, principal diagnosis, and principal procedure. Balance among other potential confounding variables was very good (table 1), with all variables displaying an absolute standardized difference score of less than 0.1 between the two groups.

Figure 2 displays various quantiles of total hospital charges as a function of year of discharge, separately for the matched PMI and non-PMI patients. The figure indicates that total charges varied markedly but did not change appreciably over time. It, however, does not directly analyze the incremental charges associated with PMI. Figure 3 thus displays various quantiles of incremental charges (difference between matched pairs in charges, PMI minus non-PMI) as a function of year of discharge. Incremental charges also varied widely and were even negative for many of the matched pairs. The 99th percentile of incremental charges was estimated at $1 million and the 90th percentile was estimated at $500,000. On the other end of the distribution, charges in the matched PMI patient were decreased by more than $250,000 compared with the matched non-PMI patient for 10% of pairs and decreased by more than $500,000 compared with the matched non-PMI patient for 1% of pairs. Median (first quartile, third quartile) incremental charges were estimated at approximately $60,000 ($0, $180,000).

A Wald test evaluating whether there is a linear trend over time in the median of incremental charges revealed significant results ($P < 0.001$); annual decrease in median incremental charges was estimated at $1,940 (95% CI, $620 to $3,250). The 90th percentile of incremental charges declined faster than the median, with an annual decrease of $7,630 ($2,380, $12,870); $P < 0.001$. However, the bottom 10% of charges did not decrease significantly over time: annual change of $-130 [-750, +490]; P = 0.61$.

**Secondary Outcomes**

Estimated probability of discharge to the various destinations (routine, home health care, transfer, or death) as a function of year of discharge is displayed for the matched PMI and non-PMI patients separately in figure 4, while corresponding odds ratios comparing PMI with non-PMI patients are provided in figure 5.
Table 1. Present on Admission Risk Factors by PMI Status

<table>
<thead>
<tr>
<th>Factor</th>
<th>No PMI (N = 21,637)</th>
<th>PMI (N = 21,637)</th>
<th>ASD*</th>
</tr>
</thead>
<tbody>
<tr>
<td>POARisk (% chance of postoperative mortality, median [Q1, Q3])</td>
<td>3.5 [0.9, 17.0]</td>
<td>3.5 [0.9, 16.8]</td>
<td>−0.01</td>
</tr>
<tr>
<td>Admission source (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emergency department</td>
<td>62</td>
<td>64</td>
<td>0.04</td>
</tr>
<tr>
<td>Another hospital</td>
<td>6</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Another health facility/long-term care</td>
<td>4</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Court/law enforcement</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Routine/birth/other</td>
<td>27</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td>Scheduled admission (%)</td>
<td>22</td>
<td>22</td>
<td>0.00</td>
</tr>
<tr>
<td>Weekend admission (%)</td>
<td>19</td>
<td>20</td>
<td>0.02</td>
</tr>
<tr>
<td>Age (yr, mean ± SD)</td>
<td>72 ± 14</td>
<td>73 ± 13</td>
<td>0.07</td>
</tr>
<tr>
<td>Female sex (%)</td>
<td>49</td>
<td>48</td>
<td>−0.02</td>
</tr>
<tr>
<td>Race (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>65</td>
<td>65</td>
<td>0.06</td>
</tr>
<tr>
<td>Black</td>
<td>7</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Hispanic</td>
<td>18</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>Asian/Pacific Islander</td>
<td>8</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Do-not-resuscitate order (%)</td>
<td>9</td>
<td>10</td>
<td>0.01</td>
</tr>
<tr>
<td>Primary expected payer (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medicare</td>
<td>69</td>
<td>71</td>
<td>0.07</td>
</tr>
<tr>
<td>Medicaid</td>
<td>10</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Private insurance</td>
<td>17</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Self-pay</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>3</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>
| * ASDs defined as the difference in means, mean rankings, or proportions divided by a pooled estimate of SD are also given. An ASD >0.1 was considered as indicative of at least slight imbalance and any such factors were used for adjustment in subsequent analyses.
| ASD = absolute standardized difference; PMI = perioperative myocardial infarction; POARisk = present-on-admission risk. |

patients are given in figure 5, A–D. These figures indicate that, relative to non-PMI patients, PMI patients were progressively more likely to be transferred to another facility rather than discharged home. The probability of routine discharge declined over time, with a faster decline in the PMI population between 2005 and 2009 relative to the non-PMI population (as fig. 5A indicates). Discharge to home health care was stable in the PMI patients at approximately 13%, while this incidence rose from 9 to 13% between 2003 and 2006 for patients without PMI. Overall mortality incidences were stable over time at approximately 25 and 10% among matched patients with and without PMI, respectively.

Results for daily hospital charges, provided in figures 6 and 7, were largely similar to those obtained in our primary analysis measuring total charges for the visit. However, linear trends in daily charges were not statistically significant ($P = 0.28$, $P = 0.22$, and $P = 0.48$, respectively, for the median, 10th percentile, and 90th percentile of daily charges as a linear function of year of discharge).

Length of stay is summarized in figures 8 and 9. Median incremental length of stay associated with PMI decreased significantly over time (yearly decrease of 0.16 [0.10, 0.23] days; $P < 0.001$). The 90th percentile of incremental length of stay also decreased by 0.72 (0.45, 0.98) days per year ($P < 0.001$). However, the 10th percentile of incremental length of stay associated with PMI was not significantly related to year of discharge (yearly change of 0.00 [-0.08, +0.07] days; $P = 0.87$).

Discussion

Charges for patients with PMI (2012 values) were approximately $100,000 greater than those for patients without infarctions. However, incremental charges for PMI decreased each year, after adjusting for the medical component of inflation. The median-adjusted incremental charges decreased at a rate of $1,940 per year between 2003 and 2010, with the top 10% of charges decreasing even faster than the median. This decrease after adjustment indicates that charges increased less than inflation; in other words, charges in current dollars decreased over time.

Daily hospital charges for PMI patients remained essentially unchanged between 2003 and 2010. For many postsurgical complications, charges far exceed the rate of inflation. Sepsis is just one example, as demonstrated in the study by Campion.24 Much of the cost increase for sepsis between 2000 and 2008 was explained by the implementation of new medications and treatment protocols with consequent improvements in mortality. Given the aging demographics of the inpatient surgical population, the observed stable rate of PMI may actually reflect a relative improvement in outcomes.

There was no increase in cost related to PMI, with the daily hospital charges between 2003 and 2010. As those who experience PMI generally have a higher risk of mortality, comparably sick controls would thus exhibit increased risk of mortality in turn. In part, this may be because concerns about bleeding cause procedural interventions to be reserved for PMI cases that are associated with cardiogenic shock or persistent symptoms. Consequently, conservative
Fig. 4. Probability of discharge to various destinations as a function of year of discharge, separately for perioperative myocardial infarction (PMI) and healthy patients. All probabilities were estimated from a multinomial logistic regression model. Note that routine discharge includes those who left against medical advice and those who were alive but had an unknown destination. Note also that in the figure, home healthcare discharges were denoted by HHC.

Fig. 5. (A–D) Odds ratios for discharge to four different destinations, comparing patients with perioperative myocardial infarction to patients without perioperative myocardial infarction. All odds ratios were estimated from a multinomial logistic regression model. Note that routine discharge includes those who left against medical advice and those who were alive but had an unknown destination.

**Fig. 7.** Quantiles of incremental daily hospital charges versus year of discharge. Charges adjusted to 2012 values using the Bureau of Labor Statistics’ Consumer Price Index (Division of Consumer Prices and Price Indexes. August 2012. Bureau of Labor Statistics, Washington, DC. Available at: www.bls.gov/CPI/cpifact4.htm. Accessed August 12, 2013.) for health care. Incremental daily charges were defined as the difference in daily charges among each respective matched perioperative myocardial infarction (PMI)/healthy pair. USD = U.S. dollars.
management using β-blockers, statins, and aspirin with deferred risk stratification is typically the primary strategy. Lack of new medical treatments for PMI have thus resulted in little impact on overall charges and, as might be expected, similarly little impact on mortality. The observed incremental annual decrease in charges between patients with and without PMI might reflect overall improvements in healthcare efficiency rather than specific improvements in the management of PMI per se.

Interestingly, the proportion of patients discharged to another facility increased significantly, with a compensatory reduction in discharges to home. A similar pattern has

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**Fig. 8.** Quantiles of length of stay versus year of discharge. PMI = perioperative myocardial infarction.

**Fig. 9.** Quantiles of incremental length of stay (LOS) versus year of discharge. Incremental LOS was defined as the difference in LOS among each respective matched perioperative myocardial infarction (PMI)/healthy pair.
been reported for sepsis and possibly reflects a general trend toward increased use of skilled nursing facilities. Such transfers may be wholly appropriate, given that patients with complications may require extended care and rehabilitation. With declining healthcare reimbursements, especially for Medicare patients, hospitals try to limit costs. If the receiving facilities can provide comparable eventual outcomes at lower cost relative to the acute care in inpatient facilities, then the overall healthcare system benefits by having reduced costs. By discharging patients to another facility, hospitals can potentially both reduce length of stay and reduce their costs for any given surgical episode. Medicare's recent implementation of financial penalties for hospitals with high rates of readmission will likely fuel this trend because transferring patients, particularly those at high risk of complications, possibly reduces readmissions. Increased transfers beginning in 2008 were observed among both groups. Continued monitoring of transfer trends for patients with and without PMI as future data become available will help ascertain whether or not the observed effects continue.

Using the California State Inpatient Dataset provides a large and diverse patient population for analysis. Further study regarding generalizability to the entire U.S. inpatient surgical population is warranted to confirm these findings. However, diagnosis, indications, and treatments in such data sets are not necessarily standardized and may have missing variables. Particularly, the data set may lack sensitivity for lesser infarcts, which plausibly have a different cost profile than those documented by an International Classification of Diseases, Version 9, Clinical Modification diagnosis code. And as in any retrospective study, it is impossible to know whether we have accounted for all material confounding variables. We did, though, use sophisticated risk-adjustment methodology to select well-matched groups. Due, in part, to our exacting criteria for suitable control patients for each case of PMI, one third of the patients with PMI were unmatched. We acknowledge nonetheless that there may be unrecognized systematic differences between these patients and those who were included in the analysis.

We could only include patients carrying a confirmed diagnosis of PMI. The overall incidence in our data set was just 0.6%. This is well below the previously reported rates, but lower incidence is at least partially explained because we included all adults having inpatient surgery, whereas previous studies evaluated older, high-risk populations; furthermore, patients in many previous studies were systematically screened for asymptomatic infarctions. It is therefore likely that we largely identified serious infarctions, which is consistent with the fact that our hospital mortality was 24.7%, a figure that is roughly twice previously reported rates. Mortality remained essentially unchanged between 2003 and 2010. The high rate of mortality in the matched controls was probably a byproduct of the propensity-matching procedure, which sought to identify comparably sick controls for each patient who experienced PMI. Even if 6% of the “control” group actually had uncoded MIs, it would have no meaningful effect on our primary conclusion that the cost of perioperative infarctions decreased over time.

In summary, charges for patients with PMIs were approximately $100,000 (2012 dollars) greater than those for patients without infarctions. However, mortality remained nearly unchanged from 2003 and 2010, and incremental costs decreased slightly. Reduced incremental cost (in real dollars) and unchanged mortality likely reflect limited improvements in the treatment of perioperative infarctions. Transfers to skilled nursing facilities increased significantly over time. Transfers were not associated with improved outcomes for patients with perioperative infarctions, suggesting that transfers may reduce hospital readmissions. It remains unclear whether transfers may reduce hospital readmissions. It remains unclear whether this trend simply represents a transfer of cost and risk or whether it improves patient care.

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Competing Interests
The authors declare no competing interests.

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