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Evaluation of Complication Rates after Coronary Artery Bypass Surgery using Administrative Data

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Abstract: Our objectives were (1) to determine if studying hospital complication rates after coronary artery bypass graft (CABG) surgery provides information not available when only mortality is studied, and (2) to reexplore the utility of ICD-9-CM administrative data for CABG outcomes assessment. Using data from Massachusetts, we identified CABG cohorts from 1990 and 1992 to respectively develop and validate multivariate risk adjustment models predicting in-hospital mortality and complications. The resulting models had good discrimination and calibration. In 1992, adjusted hospital complication rates ranged widely from 13.0% to 57.6%, while mortality rates ranged from 1.4% to 6.1%. Hospitals with high complication rates tended to have high mortality ($r = 0.74$, $p = 0.006$), but 2 of the 12 hospitals studied ranked quite differently when judged by complications rather than mortality. We conclude that (1) complications after CABG occur frequently and may provide information about hospital quality beyond that obtained from hospital mortality rates, and that (2) administrative data continue to be a promising resource for outcomes research.

Keywords: Coronary Bypass, Complications, Mortality, ICD-9-CM, Risk Adjustment

1. Introduction

Coronary artery bypass grafting (CABG) is a frequently performed surgical procedure which carries significant risk for morbidity and mortality [1]. This has led to a number of CABG outcome studies [2-17] evaluating factors associated with poor outcomes and quality of care in individual hospitals. Most of these studies [4-7, 13-17] have focused on post-operative mortality as an outcome. Non-fatal adverse events such as hemorrhage, infection, and respiratory problems have been less well-studied, but may also prove to be valuable indicators of quality of care. Such complications may be more sensitive quality measures than mortality because they (1) occur more frequently, and (2) may be more strongly linked to poor quality care [10].

Initial studies evaluating hospital outcomes after CABG used ICD-9-CM administrative data to adjust outcome rates for differences in patients' severity of illness across hospitals [2]. However, this early work caused concern about the relative lack of clinical detail in administrative data regarding patients' severity of illness [11, 18-22]. As a result, more recent CABG outcome studies have used detailed clinical data sources (i.e., prospective data collection or detailed record abstraction) to evaluate mortality and complication rates after CABG [9-17]. Unfortunately, the cost and time required to develop such detailed clinical data is considerable. In contrast, the wide availability and relatively low cost of ICD-9-CM administrative data [18] make it important to continue searching for ways to use such data for outcome evaluation, particularly in states or regions where prospective data collection systems do not exist. Most of the significant predictors of post-CABG adverse events identified by Geraci et al. [10] using clinical data are potentially identifiable in administrative data, because they are diagnosis-based (e.g., history of chronic lung disease, acute myocardial infarction) and accordingly can be identified by their corresponding ICD-9-CM codes. In addition, work by the Health Care Financing Administration suggests that

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post-CABG complications can also be detected with administrative data using ICD-9-CM codes which explicitly identify post-CABG non-fatal complications such as infection, hemorrhage, and respiratory problems [1].

In this study, our two general goals were: (1) to reexplore the potential utility of ICD-9-CM administrative data in CABG outcome evaluation, and (2) to examine both non-fatal complications and mortality together, to determine if evaluating non-fatal complications provides information that is not available when mortality is the only outcome studied. Our specific objectives were: (a) to develop and validate two risk adjustment models – one to predict mortality and the other, complications – from baseline clinical variables; and (b) to use these models to determine and compare risk-adjusted hospital mortality and complication rates in Massachusetts.

2. Methods

2.1 Data Source

We used Massachusetts Health Data Consortium (MHDC) hospital discharge abstracts to derive two surgical cohorts (1990 and 1992) for analysis. The MHDC files contain one record for each hospital admission in Massachusetts [23]. Each inpatient record contains up to 15 ICD-9-CM coded diagnoses and 15 procedures, as well as information on patient age, sex, race, payor (e.g., Medicaid, Medicare, HMO), length of stay, admission type (elective, urgent, emergent), and Diagnosis Related Group (DRG) [24].

We identified all CABG cases in each year by screening for ICD-9-CM procedure codes representing CABG surgery (36.10 through 36.19) [25]. This approach to case selection captured all patients who had a simple CABG procedure or a combined valve and CABG procedure. Cases with a DRG outside of 104 through 108 were excluded because CABG surgery was not necessarily the only surgical procedure performed during hospitalization [24]. These excluded cases (n = 33 in 1990 and n = 41 in 1992) were complex and clinically dissimilar from the included cases. All cases from a Veterans Affairs (VA) hospital were also excluded because the data were not comparable.

Fiscal year 1990 (October 1, 1989 through September 30, 1990) yielded a cohort of 6,326 CABG cases used to develop risk-adjustment models. From fiscal year 1992, a cohort of 6,791 cases was used to validate the risk-adjustment models, and to evaluate adjusted hospital outcome rates. We studied all cases meeting the study criteria from all 12 non-VA hospitals performing CABG in Massachusetts.

2.2 Definition of Baseline Clinical Variables

Baseline variables were organized into three groups – sociodemographic, comorbidity, and disease-specific – and were considered potential preoperative predictors of adverse outcomes after CABG surgery. Care was taken to avoid using factors as "baseline variables" when we judged that the clinical event was likely to arise postoperatively. Thus, codes for variables such as pneumonia and atrial fibrillation were not used because these often occur after surgery. The "baseline variables" which we selected for study were thought to be pre-operative, rather than post-operative, factors.

The sociodemographic variables were sex, race (Caucasian vs. other), age, and socioeconomic status ("low" for free care or Medicaid payor). The comorbidity variables were peripheral vascular disease, cerebrovascular disease, dementia, pulmonary disease, rheumatologic disease, peptic ulcer disease, mild and "moderate-to-severe" liver disease, hemiplegia, chronic renal disease, neoplasia, metastatic disease, and human immunodeficiency virus-related diseases. All comorbidities were identified using an ICD-9-CM coding scheme derived by Deyo et al. [26]. We did not summarize comorbidity using a standard score (such as the Charlson index [27]) because condition and study-specific comorbidity weights are better predictors of adverse outcomes [28].

Disease-specific variables included congestive heart failure, recent myocardial infarction (MI), previous CABG, recent angioplasty, valvular disease, and urgency of admission. Heart failure and MI variables were identified using

Table 1 Demographic characteristics and adverse outcome rates among CABG patients (1990 and 1992).

	1990	1992
Number of cases	6326	6791
Sex (% male)	73	72
Mean age (+/- SD)	65.0 (9.7)	65.7 (9.9)
Race (% Caucasian)	97.5	91.1
Elective (%)	53	45.8
Post-operative mortality (%)	5.7	4.4
Post-operative complications* (%)	34.0	33.3
- cardiac	16.7	15.2
- respiratory	6.3	4.5
- hemorrhagic	5.9	6.9
- graft complications	2.3	3.1
- infection	2.1	2.6

* "Complication" defined as the occurrence of either mortality or at least one non-fatal adverse event.

the ICD-9-CM coding scheme of Deyo et al. [26]; previous CABG, by code V458.1; recent angioplasty, by procedure codes 36.01, 36.03, or 36.09; and valvular disease, by patient assignment to DRG 104 or 105. We also compared elective vs. non-elective ("urgent") CABG admissions.

Four potentially predictive variables – hypertension, old myocardial infarction, angina, and diabetes – were not used because they are known to be selectively undercoded in the discharge abstracts of patients with complicated or fatal hospitalizations [29]. As a result, these medical problems appear, paradoxically, to protect against adverse outcomes. We excluded these variables a priori to improve the face validity of our models.

2.3 Definition of Outcome Variables

We studied two outcomes: (1) in-hospital mortality, and (2) post-operative complications (defined as the occurrence of either a non-fatal adverse event or in-hospital death). We identified adverse events by screening records for the presence of any of 24 ICD-9-CM codes which a Health Care Financing Administration-assembled panel of clinical experts judged to represent complications following CABG [1]. The codes fall within the 990 category of the ICD-9-CM and are only assigned to events and diagnoses which arise post-operatively. The appendix lists the 24 adverse events and corresponding codes.

2.4 Development of Risk Adjustment Models

Using 1990 data, we constructed a logistic regression model to predict mortality and a second model to predict the occurrence of complications. In each case, we used bivariate analyses with chi-square test or Fisher's exact test, as appropriate, to evaluate crude associations between baseline clinical variables and the outcome. Variables appearing at least ten times in the study population, and displaying even weak association ($p \leq 0.15$) with the outcome variable were retained for entry into a forward stepwise logistic regression model. Only variables significant at $p \leq 0.05$ were kept in the final model.

We also examined two-way interaction effects using an additive interaction model [30]. However, such effects were minor (i.e., relative excess risk due to interaction ≤1.0) and were thus not included in our final models.

Model Validation

Using logistic regression, we calibrated the 1990 model predictions to the 1992 data (to account for a drop in the overall state mortality rate between 1990 and 1992), and then computed c and Hosmer-Lemeshow statistics to

Table 2 Bivariate analysis results (1990 data, n = 6,326).

Variable**	N	RR* for mortality (p value)+	RR* for complications (p value)+
Caucasian race	6174	1.4 (.37)	1.3 (.06)
age ≥ 65 (years)	3603	2.6 (<.001)	1.2 (<.001)
urgent admit	2969	1.7 (<.001)	1.3 (<.001)
female	1707	2.0 (<.001)	1.1 (.005)
recent MI	1542	1.7 (<.001)	1.2 (<.001)
heart failure	938	3.6 (<.001)	1.3 (<.001)
valvular dis.	636	2.4 (<.001)	1.3 (<.001)
CEVD	427	1.7 (<.001)	1.3 (<.001)
pulmonary dis.	403	1.4 (.04)	1.0 (.67)
PTCA	280	0.9 (.62)	1.2 (.04)
PVD	258	1.7 (.01)	0.8 (.02)
previous CABG	234	2.0 (<.001)	1.5 (<.001)
low SES	111	1.1 (.78)	1.0 (.81)
PUD	109	0.6 (.36)	0.8 (.15)
chr. renal dis.	100	2.9 (<.001)	1.1 (.53)
neoplasia	56	0.6 (.77)	0.7 (.09)
rheumatic dis.	33	1.6 (.43)	0.9 (.65)
hemiplegia	31	0 (.42)	1.4 (.09)
mild liver dis.	8	2.2 (.40)	1.1 (1.0)
metastatic dis.	5	--- (1.0)	0.6 (.67)
mod. liver dis.	3	--- (1.0)	--- (1.0)
dementia	2	0.8 (.11)	1.5 (1.0)
HIV	1	--- (1.0)	2.9 (.34)

* RR = relative risk

** Abbreviations: MI=myocardial infarction; CEVD=cerebrovascular disease; PTCA=recent angioplasty; PVD=peripheral vascular disease; SES=socioeconomic status; PUD=peptic ulcer disease; HIV=human immunodeficiency virus disease.

\+ p values calculated using chi-square and Fisher's exact tests

Table 3 Mortality model.+

Variable++	Beta coefficient	Odds ratio	95% CI*
intercept	-6.6555	---	---
previous CABG	1.2913	3.6	(2.0-6.5)
chronic renal dis.	1.0643	2.9	(1.6-5.1)
heart failure	0.9866	2.7	(2.1-3.4)
valvular dis.	0.6616	1.9	(1.4-2.6)
PVD	0.5320	1.7	(1.1-2.7)
female	0.4831	1.6	(1.3-2.0)
age**	0.0440	1.6**	(1.5-1.7)
recent MI	0.4138	1.5	(1.2-1.9)
urgent admission	0.3032	1.4	(1.1-1.7)

* CI=confidence interval

** Age modelled as a continuous variable; odds ratio for age calculated for a 10 year age increment.

\+ Mortality model developed using 1990 Massachusetts CABG data. When validated on 1992 data: c statistic=0.74.

++ Variable abbreviations as defined in Table 2.

evaluate model performance [31]. The c statistic measures model discrimination and equals the area under the receiver operating characteristic (ROC) curve, while the Hosmer-Lemeshow statistic measures goodness of fit and calibration across categories defined by deciles of model-predicted risk [31].

2.6 Assessment of Hospital Performance

We used the validated logistic regression models to calculate risk-adjusted 1992 outcome rates for each of the 12 hospitals studied. This involved three steps: (1) Calculating the expected adverse outcome rate for each hospital by averaging the predicted probabilities among patients in each hospital, (2) computing an observed-to-expected (O/E) ratio for each hospital, and (3) multiplying each hospital's O/E ratio by the state's overall mean outcome rate to yield an adjusted outcome rate. We repeated these steps to separately calculate adjusted mortality rates and adjusted complication rates. Confidence intervals for these rates were generated for each hospital using a bootstrapping procedure with 80 replications [31]. With 80 replications, the third highest and third lowest values define the upper and lower bounds for a 95% confidence interval. The bootstrapping procedure produced 80 point estimates for each hospital's risk-adjusted mortality and complication rates, and one-way analysis of variance was used to see if the 80×12 estimates (for each outcome) differed across hospitals. Tukey's procedure was used for pairwise hospital comparisons. We displayed the relationship between adjusted hospital mortality rates and complication rates in a scatter plot, and measured the association between these outcomes using correlation.

3. Results

Table 1 shows the characteristics of the CABG cohorts studied in 1990 and 1992. In each year, the mean age was approximately 65 years and most patients were Caucasian and male. Mortality after CABG in Massachusetts was 5.7% in 1990, and 4.4% in 1992; complications were much more common (34.0% in 1990 and 33.3% in 1992). In each year, the most common complications were cardiac and respiratory complications, hemorrhage/hematoma, mechanical graft complications, and postoperative infection (Table 1).

3.1 Bivariate Results

Table 2 presents bivariate associations (from 1990 data) between baseline variables and the two study outcomes. Age, urgent admission, female sex, recent MI, heart failure, valvular disease, cerebrovascular disease, peripheral vascular disease, and previous CABG were significantly associated with complications and mortality and were thus entered into both models. Pulmonary disease and chronic renal disease were also used in the model to predict mortality, while the variables race, angioplasty, peptic ulcer disease, neoplasia, and hemiplegia were entered into the model predicting complications.

3.2 Multivariate Results

Tables 3 and 4 display the logistic regression models predicting mortality and complications, respectively. Previous CABG was the strongest predictor in both models (odds ratios 3.6 and 2.4, respectively); valvular disease, heart failure, urgent admission, recent MI, and increasing age were also predictors of both mortality and complications. Recent angioplasty and cerebrovascular disease were significantly associated only with complications, while chronic renal failure and female sex were significantly associated only with mortality.

The c statistic for the mortality model was 0.75; for the complications model, it was 0.60. When applied to the 1992 validation data, the validated c statistics were 0.74 and 0.60, respectively. Our better ability to model mortality suggests that the available baseline clinical variables were more strongly associated with mortality than they were with complications.

Table 5 shows the goodness of fit of both models across deciles of increasing

predicted risk. Observed and predicted deaths (and complications) are similar within deciles. This indicates that the models predict accurately across all levels of severity. Neither model was rejected for poor fit using the Hosmer-Lemeshow test. Meanwhile, the ratios of predicted risk for the highest to lowest risk deciles indicate that the models can distinguish high vs. low risk cases. This is particularly true for the mortality model which identifies a high-risk decile of CABG patients with a 17-fold greater risk of dying than cases in the lowest-risk decile.

3.3 Risk-Adjusted Hospital Outcome Rates

Table 6 shows 1992 risk-adjusted mortality and complication rates in the 12 Massachusetts hospitals studied. The number of procedures performed per hospital ranged from 310 to 947 cases (mean = 566). Hospital mortality rates varied considerably from a low of 1.4% (hospital A) to a high of 6.1% (hospital L). Meanwhile, adjusted complication rates also ranged widely from a low of 13.0% (hospital A) to a high of 57.6% (hospital L). Hospitals differed both in their adjusted mortality and complication rates (ANOVA, each $p < 0.0001$); Tukey's test identified pairs of hospitals which differed significantly ($p < 0.05$) for each outcome (see Table 6).

Figure 1 plots adjusted hospital complication rates against adjusted mortality rates for the 12 hospitals studied. Complications and mortality were highly correlated ($r = 0.74$, $p = 0.006$), and 10 of the hospitals had their paired rates fall on or very close to the regression line. However, two hospitals (E and K) had discrepant mortality and complication rates: In hospital K, mortality was high relative to complications, whereas the reverse was true in hospital E. Correlation was also strong ($r = 0.70$, $p = 0.01$) when death was not included in the definition of post-operative complication.

Adjusted hospital mortality and complication rates were also calculated for fiscal year 1990, and a similar correlation between mortality and complications was seen ($r = 0.73$, $p = 0.007$). One of the "discrepant" hospitals from 1992 (hospital E), was similarly discrepant in 1990 (i.e., complication rate high relative to mortality). Furthermore, there was significant correlation between hospitals' performances in 1990 and 1992 for the two outcome measures ($r = 0.68$, $p = 0.02$ for mortality; $r = 0.67$, $p = 0.02$ for complications). The 1990 data are not shown.

Table 4 Complications model.+

Variable++	Beta coefficient	Odds ratio	95% CI*
intercept	-1.9231	---	---
previous CABG	0.8674	2.4	(1.6-3.5)
valvular dis.	0.3574	1.4	(1.2-1.7)
CEVD	0.2910	1.3	(1.1-1.6)
heart failure	0.2754	1.3	(1.1-1.5)
PTCA	0.2805	1.3	(1.0-1.7)
urgent admission	0.2602	1.3	(1.2-1.5)
recent MI	0.1486	1.2	(1.0-1.3)
age**	0.0150	1.2**	(1.1-1.2)
PVD	-0.3648	0.7	(0.5-0.9)

* CI=confidence interval

** Age modelled as a continuous variable; odds ratio for age calculated for a 10 year age increment.

\+ Complications model developed using 1990 Massachusetts CABG data. When validated on 1992 data: c statistic=0.60.

++ Variable abbreviations as defined in Table 2.

4. Discussion

In this study, we have used ICD-9-CM administrative data to study both mortality and complication rates after CABG. The simultaneous assessment of mortality and complications provides information about hospitals that would not be available if only mortality were

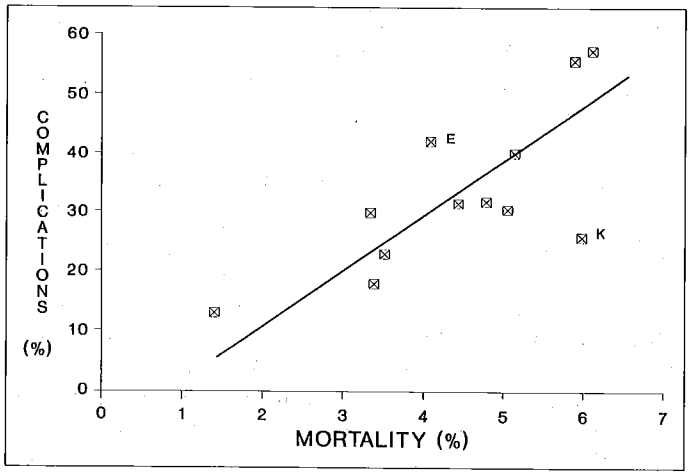

Fig. 1 Plot of 1992 risk-adjusted complication rates vs. risk-adjusted mortality rates for the 12 Massachusetts hospitals.

Table 5 Decile-of-risk table for the mortality and complication models (1992 data).

Decile+	Mortality Model*		Complications Model**	
	Predicted deaths	Observed deaths	Predicted compl.	Observed compl.
1	6	4	153	148
2	9	8	175	160
3	12	9	187	196
4	15	11	200	199
5	18	22	213	223
6	22	30	226	242
7	27	21	239	222
8	36	34	257	265
9	52	59	282	288
10	102	100	329	317
Ratio of predicted risk (10th/1st decile)		17.0		2.2

* The Hosmer-Lemeshow test of goodness-of-fit across deciles of risk does not reject the mortality model (chi-square=9.69).

** The Hosmer-Lemeshow test also does not reject the complications model (chi-square=8.26).

\+ The deciles of risk are defined by groupings of increasing predicted risk for mortality and complications as calculated by the models for 1992 data.

studied. We identified a high rate (over 30%) of post-operative complications in both 1990 and 1992. The high frequency of complications in certain hospitals (e.g., 57.6% in hospital L), and wide variation across facilities raise concerns about quality of care.

Studying complication and mortality rates together as shown in Fig. 1 may contribute more than looking at either outcome alone. On one hand, the general agreement and strong correlation between mortality and complication rates strengthen our concerns about some hospitals. For example, hospitals J and L have higher-than-expected rates for both outcomes, and should probably be directly evaluated to look for process of care problems which may be affecting outcomes. On the other hand, there are two hospitals – E and K – where apparent performance depends on the outcome considered. When evaluated by mortality rates only, hospital E appears to be doing very well, while complication rates suggest otherwise. For these two hospitals, a closer look is needed to understand the discrepancy between complication and mortality rates, and to search for potential quality shortfalls. It may be that hospital E has specific quality problems that lead to non-fatal complications, but not mortality (e.g., poor sterile technique causing treatable infections). In hospital K, the complications which do occur may be relatively serious and more often fatal, thus making the total number of complications low relative to mortality. Alternatively, hospital K may simply be underreporting its complications. Audits (e.g., using medical record review or prospective data collection) in these "discrepant" hospitals may be especially helpful in furthering our understanding of factors which affect post-operative outcomes.

Some of the observed variation in hospital complication rates may be due to variations in coding practices. Our methodology only detects a non-fatal complication when a hospital's ICD-9-CM coders use codes which explicitly indicate that a post-operative event was a complication of surgery (i.e., 990 codes). For such an approach to outcome evaluation to be broadly applied in the evaluation of hospitals, explicit and auditable protocols will be needed to reduce variation in coding. Despite the concern about coding differences, hospital complication rates in this study correlated with mortality rates, suggesting that there may in fact be some consistency in the use of 990 codes across hospitals.

We found the same positive correlation between mortality and complication rates for 12 Massachusetts hospitals in two separate surgical cohorts ($r = 0.73$ in 1990 and $r = 0.74$ in 1992). These findings contrast with those of Silber et al. [12] who report lack of correlation ($r = 0.07$, $p = 0.58$) between these outcomes among 57 Pennsylvania hospitals in a single year. At least three factors may explain some of the discrepancy between these two studies. First, Silber et al. [12] defined a complication as any finding not present at admission, but arising on or after the second day of hospitalization. This could result in the identification of complications of pre-operative care. In contrast, the ICD-9-CM 990 codes which we used to define complications are explicitly-designated indicators of post-operative events. A second consideration is that some of the complications identified by detailed chart abstraction in the Silber study may be less severe than those which result in 990 codes being recorded in the administrative discharge abstract. For example, electrocardiographic (ECG) changes such as left ventricular strain pattern and bradycardia were counted as complications in Silber's study [12]. These relatively "benign" ECG changes would usually not be recorded with 990 codes as post-operative complications on hospital discharge abstracts. (Note:

Silber et al. recalculated their correlation coefficient excluding "less severe" complications such as ECG changes and found a higher correlation coefficient of 0.13.) Finally, it is possible that the reporting of complications was less consistent across the 56 facilities studied by Silber et al. than it was in the 12 facilities evaluated in this study. Silber et al. conclude that complication rates should not be used to judge hospital quality, whereas our findings suggest a different conclusion. Further research evaluating mortality and complications together is needed to clarify the relationship between these outcomes and quality of care.

We developed logistic regression models to adjust outcome rates for differences in average baseline severity of illness across hospitals. Despite this, both mortality and complication rates varied greatly for the 12 Massachusetts hospitals performing CABG. Similar differences in adjusted mortality rates across hospitals have been observed in New York State [13, 14] and Northern New England [17]. We believe that some of this variation is related to unmeasured differences in baseline severity of illness across hospitals; even risk adjustment models with more clinical detail than ours may not fully capture differences between hospitals in patient severity before surgery [32-35]. For this reason, adjusted outcome rates should be interpreted cautiously, and be complemented by studies evaluating appropriateness of surgery [36] and process of care [37-40]. In Northern New England, for example, the reporting of hospital mortality rates has stimulated hospital-level research evaluating process of care (pre-, intra-, and post-operative) to identify factors associated with poor outcomes [37].

Recent studies comparing administrative and clinical databases have raised concern about the validity of conclusions based on administrative data [11, 19-22]. In this study, however, we use administrative data because we have observed that the predictive variables in clinical data-derived CABG risk-adjustment models [9, 10, 13-17] are predominantly diagnoses (as opposed to laboratory values or physiological parameters). Furthermore, we used a high quality administrative database [23] which has very few missing data elements and which contains 15 diagnosis and 15 procedure fields for each patient. Many other administrative databases used in similar work have only 5 diagnosis fields and 5 or fewer procedure fields [2, 11, 19]. Romano et al. [41] have demonstrated increased sensitivity for detecting diagnoses and procedures when there are at least 9 fields. We thus believe that we had higher sensitivity for detecting diagnoses with Massachusetts data than did researchers evaluating CABG outcomes using different administrative databases [1, 2, 11, 19].

We also note that our logistic regression models predicting mortality (Table 3) and complications (Table 4) have face validity. The variables in each model are plausibly associated with poor outcomes. Furthermore, we see remarkable similarity (in constituent variables and odds ratios) between our two models and published models derived from clinical data sources [9, 10, 13-17].

The validated c statistic for our complications model was only 0.60, versus 0.75 for the mortality model. These c statistic values are similar to the c statistics for the clinical data models published in the literature [9-17]. The low c statistic for complications relative to mortality may reflect a weak association between baseline severity of illness (as measured by the model) and the occurrence of non-fatal complications. Such complications may be more strongly influenced by hospital- or physician-related quality of care factors

Table 6 Risk-adjusted hospital outcome rates – 1992.+

Hospital	Mortality (%) (95% CI)++	Tukey group*	Complications (%) (95% CI)++	Tukey group*
A	1.4 (0.3-2.7)	1	13.0 (9.5-15.9)	1
B	3.3 (2.2-4.5)	2	30.0 (27.4-33.2)	5
C	3.4 (2.0-4.3)	2	18.0 (15.3-20.6)	2
D	3.5 (2.4-5.2)	2,3	23.0 (18.8-26.0)	3
E**	4.1 (2.3-5.6)	3,4	42.3 (37.8-47.6)	9
F	4.4 (2.5-6.5)	4,5	31.6 (28.1-35.1)	6,7
G	4.8 (3.6-6.0)	5,6	32.0 (28.6-35.0)	7
H	5.1 (3.5-6.6)	6,7	30.6 (26.1-34.3)	5,6
I	5.1 (3.9-6.4)	6	40.3 (37.4-43.0)	8
J	5.9 (3.7-7.7)	8	55.9 (51.8-59.7)	10
K**	6.0 (2.1-9.2)	7,8	26.0 (21.1-30.1)	4
L	6.1 (4.0-8.2)	8	57.6 (53.0-61.5)	11

+ Complication and mortality rates are adjusted for baseline severity of illness using the models in Tables 3 and 4.

++ 95% confidence intervals were generated by a bootstrap procedure with 80 replications (see methods).

* Hospitals which do not share Tukey groupings have outcome rates which differ significantly ($p \leq 0.05$).

** Hospitals E and K rank very differently when assessed by complication rates rather than mortality rates.

which are not captured by the risk-adjustment model [10]. If so, we would expect complications to be more sensitive indicators of quality than is mortality.

An important limitation of this study is our inability to incorporate left ventricular ejection fraction into our models because this information cannot be conveyed with ICD-9-CM codes. While ejection fraction has been shown to be strongly associated with mortality in studies using clinical data [13-17], our variable for congestive heart failure should capture some of the severity of illness associated with low ejection fraction. Some of the observed variation in hospital outcome rates may be related to differences in mean ejection fraction across hospitals. In this regard, clinical data sources would be better able to characterize pre-operative patient risk. However, the decile-of-risk tables shown in Table 5 clearly indicate that our models derived from administrative data do very well in distinguishing high risk cases from lower risk cases, especially when predicting mortality.

Our analyses were limited to only one state's administrative data. Work is needed to explore the applicability of these methods to other administrative databases. These data sources represent a potentially valuable resource for health care researchers, particularly considering their availability and relatively low cost [18]. Learning how to use these data effectively should be a priority in the field of health services.

In summary, we conclude that research with administrative data continues to show promise in outcomes assessment. In this study, we have used administrative data to develop clinical risk-adjustment models which predict mortality and complications after CABG. Our results suggest that studying complications and mortality together provides information that would not be available if mortality were the only outcome studied.

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Appendix

Complications with corresponding ICD-9-CM codes, as selected by a Health Care Financing Administration expert panel [1].

Code	Adverse Event
996.03	Mechanical complication of graft
996.6	Infection or inflammatory reaction due to internal prosthetic device or graft
996.7	Other (embolism, pain, hemorrhage, graft stenosis)
997.0	Central nervous system (cerebral hypoxia)
997.1	Cardiac (insufficiency, arrest)
997.2	Peripheral vascular complications
997.3	Respiratory (aspiration pneumonia)
997.4	Gastrointestinal complications
997.5	Urinary (acute renal failure)
998.0	Post-operative shock
998.1	Hemorrhage/hematoma
998.2	Accidental puncture/laceration during procedure
998.3	Disruption of operation wound
998.4	Foreign body accidentally left during procedure
998.5	Post-operative infection
998.7	Acute reaction secondary to foreign body left during procedure
998.8	Other (emphysema, subcutaneous)
998.9	Unspecified complication of procedure not elsewhere classified
999.1	Air embolism
999.2	Other vascular complications
999.3	Other infection
999.6	ABO incompatability reaction
999.7	Rh incompatability reaction
999.8	Other transfusion reaction