OFF-PUMP CORONARY ARTERY BYPASS GRAFT VS. ON-PUMP CORONARY ARTERY BYPASS GRAFT SURGERY: WHAT MATTERS – PROCEDURE VOLUME OR SPECIFICITY/SPECIALIZATION?

by

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ABSTRACT

M. MAKA TSULUKIDZE. Off-pump coronary artery bypass graft vs. on-pump coronary artery bypass graft surgery: What matters – procedure volume or specificity/specialization? (Under the direction of DR. JAMES STUDNICKI)

Context: Existing research has associated higher provider volume with a lower rate of adverse patient outcomes after coronary artery bypass graft (CABG). However, the relationship between surgical procedural volume and specialization and clinical outcomes has been understudied. *Research Objectives:* This research examined the effect of surgical procedural volume and specialization on patient outcomes for 119,559 patients undergoing CABG in Florida short-term acute hospitals from 2000-2006. *Methods:* Florida Hospital Discharge Data were linked with Practitioner Profile Database available from Florida Department of Health by using unique surgeon identifiers. Surgeon on-pump and off-pump CABG volume was assessed in quartiles. In-hospital complications were measured by using Patient Safety Indicators developed by the Agency for Healthcare Research and Quality (AHRQ). Analyses included chi-square, t-test, logistic regression and multilevel regression to adjust for nested surgeon and hospital effects. *Results:* In adjusted analyses stratified by on- and off-pump CABG, patients operated by surgeons with lower volume of a specific CABG type were more likely to have in-hospital mortality: for off-pump CABG quartile 1 OR=3.05, 95% CI: 1.68-5.53, quartile 2 OR=1.57, 95% CI: 1.10-2.26 and quartile 3 OR=1.35, 95% CI: 1.01-1.81, and for on-pump CABG quartile 2 OR=1.82, 95% CI: 1.34-2.47 and quartile 3 OR=1.51, 95% CI: 1.21-1.90. Surgeries performed by physicians in lower on-pump CABG quartiles were also significantly associated with increased odds of complications (quartile 1 OR=1.97, 95% CI: 1.19-3.26, quartile 2 OR=1.43, 95% CI: 1.14-1.80 and quartile 3 OR=1.33, 95% CI: 1.14-1.57). For off-pump CABG only quartile 2 physicians retained significance (OR=1.80, 95% CI: 1.29-2.51) for complications. *Discussion:* The volume/outcome relationship for CABG surgery is specific to the type of procedure, but not total (all procedures) volume. This finding may suggest the need of specialized and focused training of cardiac surgeons as well as development of specific CABG outcome reporting protocols to enable sufficient differentiation in outcomes of two different types of CABG.

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CHAPTER 1: BACKGROUND AND LITERATURE REVIEW

Introduction

Over the last three decades an extensive body of literature has examined the relationship between provider (hospital and surgeon) volume with the outcomes of complex surgical procedures including Coronary Artery Bypass Graft surgery (CABG). The vast majority of these studies have documented that higher volume is associated with better outcomes and there are no studies suggesting the relationship in the opposite direction.[2] Very few studies have examined the relationship between the volume of a specific type of CABG as determined by the use of cardiopulmonary bypass (on-pump vs. off-pump CABG). Considerable debate involving these two types of CABG mainly evolves around their efficacy, cost-effectiveness, graft patency and other clinical outcomes.[3-12]

CABG is an exception among complex surgical procedures due to its frequency of performance. Yet, volume-based policies have often targeted CABG for regionalization to further concentrate the surgeries in high-volume centers and by doing so improve patient outcomes. However, mixed results of studies examining this volume-based policy option have precluded any consensus. For example, based on the body of evidence Dr. Shahian[13] in his editorial argued that the absolute mortality spread for CABG surgery between high- and low-volume centers is small (approximately 1%-2%, compared with

10%-15% for esophagectomy and pancreatectomy), and that many lower-volume programs that outperform state and national averages.

Perhaps more important in this debate is a recognition of the inadequacy of provider volume as a measure of quality of care. While easily accessible and affordable, this indicator does not provide any information on fundamental factors underlying differences in patient outcomes - selection of patients, preoperative preparation, anesthesia, the composition of the surgical team, the techniques used, surgical judgment and skill, and postoperative care.[14] The present study addressed the gap by examining some of these factors including patient characteristics, specific CABG techniques used (on-pump and/or off-pump), surgical skill and specialization and hospital characteristics.

Cardiovascular Disease in the United States

Cardiovascular disease (CVD) death rates declined nationwide during 1995 and 2005. However, it still accounts for 26% of U.S. annual mortality.[15] Nearly 80 million American adults, or one in three people, have at least one form of cardiovascular disease.[16]

Coronary artery disease (CAD), also known as coronary heart disease (CHD), is responsible for more than half of all CVD-related deaths and represents the most common type of heart disease in the US. It affects about 17 million adults aged 20 years and older and kills more than 445,000 Americans a year.[17] Up to 610,000 new cases of heart attack and 325,000 recurrent heart attacks occur in the United States yearly.[18]

As the leading cause of death in the United States, CVD imposes an enormous economic burden on the nation.[15] The estimated total burden of absenteeism, presenteeism (a situation where workers remain on the job but have reduced productivity due to illness, stress, or other types of distraction), caregiver burden, and premature mortality attributable to heart disease ranges up to $122 billion anually.[15]

Coronary Artery Bypass Graft Surgery (CABG) Procedures in the United States: Description of the Procedure and Trends

Description of the Procedure

CABG has been widely introduced as a standard of care for patients with coronary artery disease.[19] This highly complex revascularization procedure and advances in coronary surgery (e.g., innovations in surgical technique, anesthesia, quality improvement initiatives, enhanced myocardial preservation, use of arterial conduits, and improved perioperative and postoperative care) have reduced morbidity, mortality, and rates of graft occlusion.[20] More than 600,000 patients undergo coronary artery bypass graft (CABG) procedures annually in the United States.[19]

The first coronary artery bypass graft was performed on the beating heart in humans in the 1960s.[5] However, after the advent of the heart-lung machine or cardiopulmonary bypass (CPB), off-pump bypass grafting (OPCABG) operations were virtually abandoned to be replaced by what we now refer to as conventional coronary artery bypass graft (CCABG).[5] OPCABG was reintroduced in the 1980s, with reclaimed popularity achieved by the 1990s. Recent technical improvements have made OPCABG grafting operations a routine procedure with roughly 20% to 25% of CABG procedures performed off-pump in the United States currently.[21]

Conventional Coronary Artery Bypass Graft Surgery (CCABG): CPB has been acknowledged to allow the establishment of CABG as a safe and highly effective treatment for CAD. It provides an artificial circulation during the procedure, so that surgery can be performed while the heart is stopped (cardioplegic arrest). This provides a motionless and bloodless operating field for a surgeon, while largely protecting the heart from the effects of ischemia.[21] However, many studies have suggested that CBP may be responsible for CABG related complications and mortality.[4, 9, 10]

Some of the most serious clinical concerns related CPB are: (1) postperfusion syndrome caused by contact of blood components with the artificial surfaces of the bypass circuit, aortic cross-clamping, and reperfusion injury;[5] (2) neurologic and neuropsychologic complications which can increase, on average 5 to 10 times, the in-hospital charge for rehabilitation and outpatient support;[5] (3) higher incidence of postoperative chest infection;[5] (4) intra- and postoperative blood loss, blood product utilization and total surgical time.[22]

Off-pump Coronary Artery Bypass Graft Surgery (OPCABG): OPCABG has been suggested to be a technique with the potential of reducing overall operative mortality and morbidity. It is thought to be a particularly valuable technique to benefit patients at high risk for pump-related complications.[23] It is suggested that OPCABG provides better myocardial protection, lower perioperative and postoperative complication rates, mortality and morbidity, reduced blood loss and transfusion requirements, and alleviate neurological deficits caused through hypoperfusion during CPB and embolic events from the CPB pump and cross-clamping of the aorta.[6] Conducting the surgery on the beating heart also offers the possibility to maintain the functional integrity of major organ systems and reduce mortality and morbidity rates.[5]

As a result, patients undergoing OPCABG have experienced reduced lengths of hospital stay, and reduced costs.[24] However, definitive data establishing the superiority of off-pump CABG over on-pump CABG are lacking and conflicting information regarding efficacy of off-pump CABG from prior studies has led to inconsistent adoption of off-pump CABG as an alternative to on-pump CABG in the United States.[23]

A meta-analysis performed by Reston et al shows that rates of perioperative myocardial infarction, stroke, reoperation for bleeding, renal failure, and mortality were lower after OPCABG than after CABG.[25] Reductions in length of hospital stay, atrial fibrillation, and wound infection were also associated with OPCABG. Thus, the study concludes that off-pump coronary artery bypass grafting appears to reduce length of hospital stay, operative morbidity, and operative mortality relative to on-pump CABG while a trend was noticed toward lower reintervention rates with CCABG.

CABG trends

CABG is a unique procedure among high-complexity surgeries with regard to its frequency – it is 10 times as common as abdominal aortic aneurysm resection in the United States, 150 times as common as esophagectomy, and 2.5 times as common as carotid endarterectomy.[13]

However, time trends of CABG procedures show interesting patterns. Over the last decade there was a substantial decrease in CABG rates with approximately one-third fewer CABG surgeries being performed in 2008 compared with 2001.[26] Specifically, the annual CABG surgery rate decreased steadily from 1742 (95% CI, 1663-1825) CABG surgeries per million adults per year in 2001-2002 to 1081 (95% CI, 1032-1133) surgeries per million adults per year in 2007-2008 (P<.001) according to a recent study published in the Journal of the American Medical Association (JAMA).[26] Subsequently, the median

CABG surgery caseload per hospital decreased by 28% (median [interquartile range], 253 [161-458] in 2001 compared to 183 [98-292] in 2008; $P<.001$).[26]

At the same time, many studies have showed that the number of hospitals performing CABG procedure increased steadily.[26, 27] The number of hospitals in the Nationwide Inpatient Sample providing CABG surgery increased by 12 percent between 2001 and 2008.[26]

Interestingly, while decrease in CABG rate was dramatic, the fall in the total rate of coronary revascularization procedures in the US between 2001 and 2008 was modest.[26] This trend arguably reflects a sizeable shift from complex surgical procedures towards percutaneous, catheter-based interventions and subsequently the changes in the cardiovascular clinical practice patterns.[26]

Factors influencing the CABG outcomes

CABG studies identify several major factors as indicators for quality of care and contributors to surgical outcomes. These factors can be categorized into three groups: 1) provider (hospital, surgeon) volume, 2) provider (hospital, surgeon) specialization, and 3) ‘organizational skills’, i.e. hospital characteristics. All these factors are described in detail below.

Provider Volume

During early 1980s Luft and Flood pioneered research on volume-outcome relationship in their seminal studies.[28-30] Examining 12 surgical procedures including CABG Luft demonstrated the positive association between provider volume and surgical outcomes and explored potential causal factors underlying the volume-outcome relationship. As a result, he postulated a hypothesis that this relationship could be due to experience described as “practice makes perfect “ suggesting that physicians and hospitals develop more effective skills with increased volume of patients and/or selective referral suggesting that physicians and hospitals with demonstrated superior outcomes receive more referrals and thus accrue larger volumes.[2] The study by Luft et al sugested that at least part of the volume-outcome relationship was explaiend by physician referral or patient self-referral.[31]

Since 1980s an extensive body of literature has evolved on the relationship between volume and outcome. Almost 5,000 articles, many of which have been published in top journals including Journal of the American Medical Association (JAMA), New England Journal of Medicine (NEJM), Medical Care, Archives of Internal Medicine have examined the relationship for specific procedures and populations including cancer, transplant, intensive care, trauma, acute myocardial infarction, carotid endarterectomies, abdominal aortic aneurysms, CABG, percutaneous transluminal coronary angioplasty (PTCA), etc.[32]

Two comprehensive reviews of literature on the volume-outcome relationship included CABG as one of the frequently performed complex procedures. Halm et al reviewed 88 studies covering literature from 1980 to 1999 and examining the volume-outcome relationship for eight procedures including CABG.[2] Although the authors noted that the methodological rigor of many studies included in the review was modest, all studies considered to be of the highest quality found statistically significant relationships between volume and outcome. Of all studies reviewed, 77% found statistically significant relationships, and no study found a significant relationship in the opposite direction.

Another review of the volume-outcome literature published in JAMA in 2000 included 72 articles addressing 40 procedures and diagnoses, including CABG.[33] For CABG Dudley et al reviewed eleven studies, nine of which demonstrated a statistically significant differences in mortality between high and low volume centers, and two showing a trend.[34]

Definition of Volume

Volume is unanimously considered as a proxy measure of quality of care and its inadequacy is widely recognized by many studies. Some studies have also argued that volume is a weak predictor of outcomes.[23, 35, 36] However, mostly due to lack of information on the fundamental factors and specific processes of care determining the volume – outcome effects it remains to be one of the quality measures largely used by researchers, policy analysts and policy makers.

The Agency for Healthcare Research and Quality (AHRQ) has included the hospital volume of several surgical procedures in their Inpatient Quality Indicators. These quality indicators have subsequently been used by health insurers (e.g., Blue Cross Blue Shield in New York State) and state health organizations (e.g., Texas Inpatient Hospital Association) for public reporting of volume.[37]

The Leapfrog Group, a consortium of more than 100 large employers, purchasing coalitions, and states that collectively provide health insurance to more than 33 million people, recommends health care purchasers consider hospital volume when contracting for CABG.[36, 38] The group has set CABG volume threshold at 500 per year and estimated that 1486 deaths may be averted by referring CABG patients to hospitals that perform ≥500 procedures annually.[38]

However, despite the attention and consideration given to provider volume as a measure of quality of care, important methodological challenges remain with regard to clear definition of what constitutes high volume; there is a wide variation in the definition of low vs. high volume.[2] In their systematic review of literature on volume-outcome relationship Halm et al noted that "for almost every condition or procedure for which at least three studies were identified, the thresholds used to define high and low volume overlapped substantially, that is, the definition of high volume in one study was the number used to indicate low volume in another".[2]

Recent studies have also questioned the justification of the 500 annual volume threshold for hospitals. Rathore et al conducted a retrospective analysis of the National Inpatient Sample database for patients who underwent CABG in 1998–2000.[36] The study intended to evaluate whether Leapfrog's standard of ≥500 annual CABG procedures and its suggested association with the reduced mortality applies to current practice. A national cohort of patients were categorized into three groups: those who underwent CABG at low (12-249 cases/year), medium (250-499 cases/year), and high (>or=500 cases/year) CABG volume hospitals. The study found that in adjusted analyses patients at low-volume hospitals remained at increased risk of mortality compared with patients at high-volume hospitals (odds ratio 1.26, 95% CI 1.15-1.39). The mortality risk for patients at medium-volume hospitals was of borderline significance (odds ratio 1.11, 95% CI 1.01-1.21). However, the authors noted that 85% of low-volume and 89% of medium-volume hospital-years had risk-standardized mortality rates that were statistically lower or comparable to those expected. In contrast, only 6% of high-volume hospital-years had outcomes that were statistically better than expected. Basing their judgment on the small size of the volume-associated mortality difference and the heterogeneity in outcomes within all CABG volume groups. Rathore et al suggested that individual hospital CABG volume is not a reliable marker of hospital CABG quality.[36]

Other studies also suggest that the most important threshold may occur at a lower volume than Leapfrog's standard and that future studies are needed for the identification of optimal volume.[35, 39-41]

Hospital volume

A large body of research has found that patients who undergo CABG at higher-volume hospitals have better outcomes than patients treated at lower-volume hospitals.[42-49] Using Medicare data, Birkmeyer et al showed that the overall mortality after CABG was 40% higher for hospitals in the lowest volume quintile compared with hospitals in the highest quintile.[42] Hannan et al used data for 12 448 patients undergoing CABG surgery in New York State in 1989 and found that there was a significant inverse relationship between CABG procedural volume and risk-adjusted mortality for both surgeons and hospitals.[44]

In this light, recent trends in increased number of hospitals providing CABG surgeries raise concerns among some researchers. Epstein et al. found that the number of CABG surgery hospitals providing fewer than 100 CABG surgeries per year increased from 23 (11%) in 2001 to 62 (26%) in 2008 (P<.001). Another study examining the U.S. trends in CABG hospital volume and the effect of adding cardiac surgery programs speculates that the increasing proportion of CABG procedures performed at low-volume hospitals and the declining proportion in high-volume hospitals might increase mortality.[50]

Surgeon volume

Considerable body of research has explored the associations between surgeon volume (the number of procedures performed by the surgeon) and mortality for some procedures.[51-54] However, only few studies examine hospital and physician volume simultaneously[2] and relatively few studies account for hospital volume and other potential confounding characteristics of the hospital.[54]

Using Medicare claims data for 1998-1999 and adjusting for patient and provider characteristics Birkmeyer et al[54] found that surgeon volume was inversely related to operative mortality for all eight procedures considered ($P=0.003$ for lung resection, $P<0.001$ for CABG, endarterectomy, aortic-valve replacement, elective repair of an abdominal aortic aneurysm, pancreatic resection, esophagectomy, and cystectomy). The study suggested that surgeon volume accounted for a large proportion of the apparent effect of the hospital volume with a varying degree for each procedure: it accounted for 100 percent of the effect for aortic-valve replacement, 57 percent for elective repair of an abdominal aortic aneurysm, 55 percent for pancreatic resection, 49 percent for coronary-artery bypass grafting, 46 percent for esophagectomy, 39 percent for cystectomy, and 24 percent for lung resection. Furthermore, for most procedures, the mortality rate was higher among patients of low-volume surgeons compared to those of high-volume surgeons, regardless of the surgical volume of the hospital in which they practiced. The findings led the authors to suggest that patients can often substantially improve their chances of survival, even at high-volume hospitals, by selecting high-volume surgeons. In addition, they concluded that for CABG, elective repair of an abdominal aortic aneurysm, and esophagectomy high-volume hospitals (volumes ≥ the Leapfrog cutoffs) had lower overall operative mortality rates than low-volume hospitals, largely because patients at high-volume hospitals were much more likely to be treated by high-volume surgeons than by low-volume surgeons.

In a systematic review by Halm et[2] al 69% of studies of physician volume reported statistically significant associations between higher volume and better outcomes. Interestingly, the same study suggested that surgeon volume seemed to be a more important determinant of outcomes than hospital volume in the case of CABG.[2] A study conducted in Taiwan suggested that referring physicians are more inclined to direct their patients toward surgeons with better patient outcomes, as opposed to those hospitals with superior reputations[55].

A study by Peterson et al[45] also finds that surgeon volume is more important than hopistal volume. Examining 267089 CABG procedures performed at 439 US sites between January 2000 and December 2001 the study found that 82% of STS programs performed fewer than 500 CABG procedures per year, with median CABG procedural volume of 253 cases. Surprisingly, however, after adjusting for patient risk and clustering effects, mortality decreased only by 0.07% with increasing hospital volume for every additional 100 cases and volume was a poor discriminator of better or worse outcomes. The volume-outcome relationship was not significant for patients younger than 65 years or for low-risk patients with expected mortality rates of less than 1.5% and many low-volume hospitals had better than average risk-adjusted mortality.

Provider Specialization

A body of literature has been growing on what exactly is hospital specialization, and what implications does it have for quality and efficiency in medicine.[46] Much like volume, unfortunately, there is no easily applicable definition for what constitutes hospital specialization.[56] Despite this hospital specialization seems quite appealing and has been advocated by champions drawn from industry and corporate strategy.[20] Recent and on-going proliferation of service lines in hospitals focused on specific conditions, procedures, or populations orginized as heart institutes, cancer centers, orthopedic hospitals, women's and children's hospitals is reflectve of this trend.[20]

Yet, compared to hospital volume, which has been widely embraced as a proxy measure for hospital quality, hospital specialization, potentially alternative quality measure, has recieved little attention.[20]

Hospital Specialization

Hospital specialization may be conceptualized as “the degree to which a given hospital focuses its resources on specific diagnoses (e.g., orthopedic diseases) or procedures (e.g., CABG) and may be quantified as the proportion of a hospital's total admissions falling within a single disease category or undergoing a specific procedure.”[20] Accordingly, hospital cardiac specialization can be defined as the degree to which a hospital concentrates its resources in treating patients with cardiovascular diseases and it also follows that a hospital may be low-volume but highly specialized if it concentrates resources in select areas, in this case cardiovascular diseases.[20]

Studies on the relationship of hospital specialization and patient outcomes suggest a complex picture with mixed findings.[57-59] Some suggest that hospital specialization may be associated with improved patient outcomes while others report little or no association. For example, as one study showed lower risk standardized 30-day mortality at cardiac specialty hospitals for AMI (15.0% versus 16.2%, $P<0.001$) and congestive heart failure

(10.7% versus 11.3%, $P<0.001$)[59] another study found that risk and volume-adjusted outcomes after PCI and CABG were similar at specialty cardiac hospitals.[57] However, findings regarding the association of hospital specialization and orthopedic surgeries have been quite consistent demonstrating improved patient outcomes at orthopedic specialty hospitals compared to general hospitals.[60, 61] One common limitation for all citied studies was their focus on physician-owned specialty hospitals, which is considered to be the most extreme example of hospital specialization.[20]

Relatively few studies have examined specialization in the context of acute-care hospitals, again with mixed findings. Nallamothu et al[62] examined hospital specialization with primary PCI and found that greater hospital specialization was associated with shorter door-to-balloon times and lower mortality among patients with ST-elevation–myocardial infarction. However, using the 5% inpatient Medicare sample 2001 to 2003, Hwang et al[63] found no difference in outcomes after CABG surgery for the CABG-performing hospitals categorized as least specialized (<40%), moderately specialized (40% to 60%), and cardiac specialty hospitals (>60%).

A study by Girotra et al[20] using a large sample of 705,084 Medicare patients undergoing CABG in 1130 hospitals during 2001 to 2005 showed a modest association between increased specialization and improved CABG outcomes (lower mortality or length of stay) after adjusting for patient comorbidity and hospital volume. Additional sensitivity analysis excluding physician-owned specialty hospitals or using alternative study outcomes did not change the study results. However, there are several important caveats related to the adjusted analyses and hospital stratification by hospital specialization in cardiovascular diseases. The researchers defined hospital specialization by stratifying hospitals into 5 quintiles based on their discharges related to major diagnostic category: ≤25.8%, 25.8% to 28.6%, 28.6% to 31.1%, 31.1% to 35.4%, and ≥35.4% in quintiles 1 through 5, respectively. In unadjusted analyses, overall mortality was similar across quintiles 1 to 4 (4.7% to 4.9%), with a modest but significantly lower overall 30-day mortality in quintile 5, i.e. hospitals with greater specialization. This difference remained the same after accounting for patient characteristics. However, the result was no longer significant after adjustment for both patient characteristics and hospital volume.

First important limitation with the quintile method of defining hospital cardiac specialization was a lack of variability between quintiles 2 through 4, with mean degrees of specialization varying by <6%, which is likely to be masking differences in outcomes due to a small percentage.[56] Secondly, the authors have noted themselves that because volume is endogenous to specialization to some extent, they were unable to fully disentangle its effect from the relationship between specialization and outcomes. This seems to be a critically important consideration as it may suggest biasing the results towards the null due to over adjustment bias.

Surgeon Specialization

One of the main aspects characterizing a physician's specialization is specialty board certification, on which information is publicly available and easily accessible. Specialty board certification is, however, voluntary and does not appear to provide physicians with additional legal privileges in the practice of medicine.[64]

The American Board of Medical Specialties (ABMS) is the umbrella organization for 24 approved medical specialty boards.[65] Six out of these 24 boards are purely surgical

(Colon and Rectal Surgery, Neurological Surgery, Orthopaedic Surgery, Plastic Surgery, General Surgery, Thoracic Surgery) while other four implicitly include surgical sub-specialization (Obstetrics and Gynecology, Ophthalmology, Otolaryngology, Urology). Dr. Richard Corlin, president-elect of the American Medical Association, has been cited to emphasize that "[thoracic] board certification is not legally required to practice . . . but it is considered a general mark of a physician's preparation, learning, knowledge and experience."[66] The certification process, then, reflects the level of knowledge and practical skills held by surgeons.[66] In 2002, more than 85% of licensed thoracic physicians held a valid certificate.[65]

A number of studies have supported the validity of board certification as an indicator of specialization and superior performance. Successfully passing board certification examinations has been positively associated with clinical performance ratings,[67, 68] National Board of Medical Examiners examination scores,[69] and in-training examination scores.[70]

A systematic review by Sharp et al[71] examined the link between physician certification and clinical outcomes and showed that of the 33 studies, 16 demonstrated a significant positive association between certification status and positive clinical outcomes, three revealed worse outcomes for certified physicians, and 14 showed no association. However, as the researchers note, three negative findings and one finding of no association were identified in two papers with insufficient case-mix adjustments in the analyses.

A study examining inpatient complications, mortality, and hospital length of stay following colon resection using an Illinois sample found that increasing years following board certification was associated with reduced morbidity and mortality after adjusting for patient and hospital characteristics.[72] In a review of the effect of surgeon experience and specialization on cancer surgery outcomes, Bilimoria et al[73] found that specialized surgeons had better outcomes and that time since American Board of Surgery (ABS) certification was a significant predictor of patient outcomes.

Another study investigating the association between board certification and physicians' demographics and their performances during medical school and residency demonstrated an overall positive relationship between physicians' board certification status and their academic performances.[74]

A recent article published in JAMA 'the Role of Physician Specialty Board Certification Status in the Quality Movement" offers an interesting insight regarding the subject.[75] The authors argue that certification has received minimal, and therefore inadequate notice within the new quality movement. Specifically, they point out to the lack of attention to renewing or maintaining certification largely overlooked by policy regulators, health plans, and others involved in the quality movement. The study concludes that a physician's current certification status should be among the evidence-based measures used within the context of health care quality movement.

A different approach to account for physician specialization has been offered by a recent study published in the Archives of Surgery.[76] Examining career phase, overall surgical workload and specialization of board-certified general surgeons the study found that the workload composition (i.e. number of specific surgeries characterized based on CCS) changed as general surgeons' career advanced from early (<10 years since board certification) to early mid (10-19 years since board certification), late mid (20-29 years since board certification) or late (≥30 years since board certification) career phase. Specifically, the percent of cardiovascular surgeries among late career surgeons was higher, and the percent of digestive surgeries lower, than for any of the three other career phase cohorts. Subsequently, this variation in surgical composition, which can also be described as a narrow specialization within the practice of general surgery, has affected the surgical outcomes in several important ways. Compared to late career surgeons, the rate of complications from cardiovascular surgeries was higher for surgeons in early career phase (Rate Ratio, RR 1.23, 95% Confidence Interval, CI 1.06 – 1.44) and late mid-career phase (RR 1.18, CI 1.02 – 1.37). The mortality rate for cardiovascular procedures was also higher for early career surgeons (RR 1.23, CI 1.04 – 1.46). For digestive surgeries, early career surgeons had lower complication rates than late career surgeons (RR 0.86, CI 0.75 – 0.99).

A systematic review by Chowdhury et al[77] included 163 studies examining 42 different surgical procedures and covering 13 surgical specialties. Twenty two studies reported surgeon specialization and in 91 per cent of studies specialist surgeons had significantly better outcomes than general surgeons. The review also noted a varying magnitude of the benefit of high surgeon volume and specialization across the specialties. The study concluded that high surgeon volume and specialization are independently positively associated with patient outcomes. Interestingly, the study also noted that high hospital volume is of limited benefit.

Organizational/Hospital Factors

Organizational/hospital factors that may influence the patient outcomes are largely understudied. As Elizabeth Moxey and David B. Nash[32] note in their summary of the literature on volume-outcome in CABG and PTCA more than 30 years after Luft and Flood authored seminal studies on volume-outcome research "many of the questions posed by Luft and Flood remain unanswered: [..] How do other members of the team (nursing staff, anesthesiologist, OR staff, etc.) influence the relationship? Do high volume hospitals have standards and protocols that account for their better performance?"

In a systematic review of the volume-outcome literature, intended to support a May 2000 Institute of Medicine workshop, Halm et al[2] provided a clear conceptual model outlining potential explanatory factors underlying the volume-outcome relationship, which later was included in the Committee on Quality of Health Care in America and the National Cancer Policy Board Workshop Summary[78] (Figure 1). This model along with patient and physician characteristics identifies hospital or organizational "skills" as one of the important contributors to patient outcomes.

A number of studies have speculated that high volume hospitals may enhance the performance of low-volume physicians.[13] The explanation most frequently offered by the studies showing this important synergy between the two provider levels is the processes of care,[13, 78]specialized and more differentiated departments and subunits as well as more specialized staff.[30] In addition, studies have found that many low-volume centers have excellent outcomes,[79] which again calls for further investigation and careful scrutiny of underlying mechanisms (processes of care, specific standards and protocols, etc) for high performance. Another important question, also raised by many investigators, relates to the relative contribution of other members of the team (nursing staff, anesthesiologist, OR staff, etc.) – do they influence the volume-outcome relationship?[32]

The role of anesthesiologist deserves special attention particularly for performing OPCABG surgeries. The beating-heart surgery is incredibly challenging for anesthesiologists as they need to address several major factors that influence the surgical outcomes. Namely, during the surgery anesthesiologist has to ensure the maintenance of hemodynamic stability during heart enucleation necessary for accessing each coronary artery, and the management of intraoperative myocardial ischaemia as coronary flow is interrupted during grafting.[24, 80]

Equally important factors may include nursing staff who are more familiar with certain types of procedures and therefore may attain and maintain more proficiency in their performance. In addition, it is also conceivable that higer volume and/or more specilized hopistals may purchase specialized equipment for specific surgeries.

Although the body of literature on volume-outcome relationship is extensive, the research examining all these or some of these organizational factors and hospital ‘skills’ is very limited. A study by Brown et al[24] examined surgical performance of the operating team performing off-pump CABG procedures. The underlying premise was that with the increasing experience of the cardiovascular surgical team performing off-pump CABG procedures clinical decision-making processes and technical skills necessary for treating all CABG patients would improve (regardless of whether or not cardiopulmonary bypass is used). The study found that although high-volume OPCABG facilities achieved better outcomes, mortality rates were only marginally lower compared to low-volume OPCABG facilities and the difference was not statistically significant. However, higher volumes of OPCABG were associated with lower patient and facility complication rates for major outcomes (shock/hemorrhage, neurologic, renal, and cardiac) with statistically significant results for all four complications. Similarly, six out of seven minor complication rates were lower for high-volume OPCABG facilities.

Summary

Two seminal reports of the Institute of Medicine (IOM)[81, 82] documented that U.S. health system performs far below obtainable levels of patient safety[83] and estimated that 44,000 to 98,000 Americans die each year as a result of medical errors. Thus, the call for achieving excellence in quality and quality improvement remains open.

It is within this context that the effect of hospital and surgeon volume and provider specialization has received special attention. These major structural characteristics are largely used in health services research and policy analysis to inform quality improvement initiatives. However, even with the extensive body of evidence on the positive association of volume with improved outcomes the underpinnings of the volume-outcome relationship remain poorly understood, and the policy implications of this relationship are widely disputed and unclear.[32]

It is important to seek the answers to the question related to this important debate: precisely what is the advantage of higher-volume providers - doing things more often or doing things differently. Some studies have attempted to investigate whether surgical procedures performed in high volumes or using similar technique (e.g. on-pump vs. off-pump CABG) make the difference.

To date, there is a paucity of literature examining the relationship between procedure volumes and underlying mechanisms accounting for differences in off-pump and on-pump CABG operation outcomes.

A study by Konety et al[23] showed that the proportion of CABG procedures performed off-pump may be more important than the actual volume of off-pump CABG operations performed at a hospital. The authors speculated that some hospitals that may ‘‘specialize’’ in off-pump procedures attain certain level of surgical skill, and therefore achieve better outcomes. However, Konety and colleagues did not account for physician volume or technical expertise, an important factor which is likely to be related to the procedural outcomes and is the main focus of the present study.

Another study, conducted by Brown et al,[24] also analyzed the patient and hospital characteristics at high- and low-volume OPCABG sites to examine their association with clinical outcomes. However, selecting the operating team performing OPCABG procedures as the unit of analysis, the study did not account for individual surgeon experience and technical skills.

Few dispute that the individual surgeon’s knowledge and practical abilities play a critical role in the practice of surgery. However, this also is the area of health services research that remains largely understudied and unaddressed. Discussing the role of the individual physicians, their skills and expertise in the overall quality framework Brennan et al[75] suggested that “the minimal attention to the role of the individual physician is a missed opportunity” for achieving better quality of care.

The present study addresses the existing knowledge gap by examining surgeon characteristics, their caseload, and their experience, and the association between those measures and patient outcomes after two different types of CABG with or without cardiopulmonary bypass. Surgeon volume has been suggested by previous studies to be a more important determinant of outcomes than hospital volume in the case of CABG.[2] The addition of surgeon experience and characteristics to the analysis will offer an important insight in the volume-outcome relationship for CABG surgeries.

This study also examines the role of organizational characteristics such as hospital ownership and size, teaching status, overall procedural volume and CABG volume. Previous studies have suggested that high volume hospitals may actually enhance the performance of low-volume physicians.[79] In addition, it could be argued that large hospitals with high overall volumes have specialized facilities and staff, which in turn provides for good teamwork, effective pre- and postoperative care and better management of other processes of care. This focused and specialized management of patients across the continuum of care may be better characterized as economies of scale rather than “practice makes perfect,” as suggested by Luft et al.[31]

The current study contributes to better understanding of the volume-outcome relationship. It may inform policy decisions in several important ways. If findings of the study suggest that performance of a specific type of CABG (CCABGG vs. OPCABG) is associated with better outcomes, specialized and focused training of cardiac surgeons may be warranted. Although mandatory CABG Outcomes Reporting Program has been widely implemented (Appendix A) there is no differentiation in public reporting of two specific types of CABG. If surgeons and hospitals have different patient outcomes depending on a type of CABG performed the reporting protocols should be altered accordingly, as providers performing well for on-pump CABG may not necessarily be the same as those that perform well for off-pump CABG.[23]

Finally, future directions for CABG research should be focused on collecting richer data with more clinical detail to address the concerns about important contributing factors for improved patient outcomes. At the same time, efforts should be made to develop a provider ‘rating’ format that does not rely solely on volume thresholds and can be used for objectively evaluating surgical outcomes based on better measures of quality of care that can be publicly available.

TABLE 1.1: Estimates for the Indirect Costs of Heart Disease

Study	Indirect Costs					
	Absenteeism	Presenteeism	Disability*	Caregiver Burden	Premature Mortality	TOTAL
DeVol R, Bedroussian A., 2007.[84]	$10.7 billion	$38.8 billion	NR	$4.8 billion	NR	$54.3 billion
Druss BG, Marcus SC, Olfson M, et al., 2001.[85]	$65.6 billion	NR	NR	NR	NR	$65.6 billion
American Heart Association. Heart Disease and Stroke Statistics: 2009 Update At-AGlance, 2009.[86]	$24 billion	NR	NR	NR	$97.6 billion	$121.6 billion

* No published data available
NR=not reported

Source: Lissovoy et al. (2009). The burden of disease: the economic case for investment in quality improvement and medical progress. A Literature Review and Synthesis.

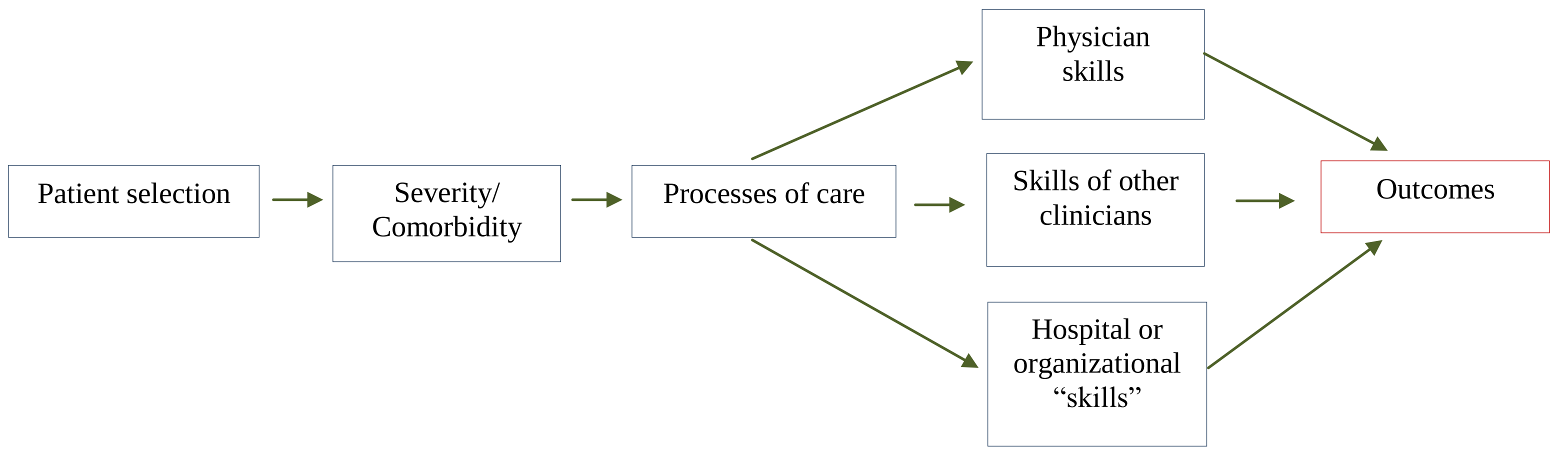

FIGURE 1.1: Conceptual Framework: How Could Volume Affect Quality?

Source: Hewitt, M. (2001). "For the Committee on Quality of Health Care in America and the National Cancer Polocy Board: Interpreting the volume-outcome relationship in the context of cancer care." Washington DC: Institute of Medicine.[1]

CHAPTER 2: OBJECTIVES, HYPOTHESES AND THEORETICAL FRAMEWORK

Main objective of this study is to examine the role of proportional and cumulative surgical volume for two specific types of CABG as well as the contribution of surgical skills and specialization and hospital organizational factors to the patent outcomes after CABG surgery.

The specific objectives and hypotheses are described below.

Objective 1: to explore the relationship between specific CABG procedures, specialty training and selected outcomes

$H_{1.1}$: Higher volume of a given specific type of CABG (OPCABG and/or CCABG) and specialized surgical training (thoracic surgery vs. general surgery) will lead to better outcomes, measured by the occurrence of in-hospital complications or in-hospital mortality.

$H_{1.2}$: The lowest volume of CABG procedures will lead to markedly worse outcomes (in-hospital complications and mortality) compared to other volume categories.

$H_{1.3}$: Cumulative surgical volume will be significant perdictor of improved outcomes (in-hospital complications and mortality).

TABLE 2.1: Variables and Data Sources for Analysis, Objective 1, H1.1 through H1.3

Variable	Data Sources
OPCABG volume per surgeon	Number of off-pump CABG procedures, 2000-2006 Florida Hospital Inpatient Discharge Data
CCABG volume per surgeon	Number of on-pump CABG procedures, 2000-2006 Florida Hospital Inpatient Discharge Data
Total CABG volume	Number of total CABG procedures, 2000-2006 Florida Hospital Inpatient Discharge Data
General Surgery Board Certification	Florida Practitioner Profile Data File
Thoracic Surgery Board Certification	Florida Practitioner Profile Data File
≤ 88 CABG surgeries per seven year study-period	Number of any type of CABG procedures per 7-year, 2000-2006 Florida Hospital Inpatient Discharge Data
Cumulative surgical volume	Number of total CABG procedures (CCABG, OPCABG or both) over 7years, 2000-2006 Florida Hospital Inpatient Discharge Data

Objective 2: to examine the relative contribution of hospital characteristics to the selected outcomes

$H_{2.1}$: Low-volume CABG providers in high-volume hospitals (CABG volume and total discharges) will have better outcomes compared to low-volume CABG providers in low-volume hospitals.

$H_{2.2}$: Hospitals with larger size, more total discharges, and teaching status will have better outcomes for in-hospital complications and in-hospital mortality.

TABLE 2.2: Variables and Data Sources for Analysis, Objective 2, H2.1 and H2.2

Variable	Data Sources
Hospital CABG volume	Number of CABG procedures per hospital, 2000-2006 Florida Hospital Inpatient Discharge Data
Total discharges	Number of total discharges per hospital, American Hospital Association Annual Survey
Hospital characteristics	Hospital teaching status, ownership, American Hospital Association Annual Survey
Bed size	Number of beds per hospital, American Hospital Association Annual Survey

Conceptual Framework

The IOM volume-outcome relationship model[1] developed by Halm et al[2] referenced in the *Background and Literature Review* section of this research has served as foundation for the conceptual framework for the present study. The framework incorporates the following elements: patient characteristics, disease severity/comorbidity, processes of care, hospital characteristics, operating team and operating surgeon characteristics and surgical technique. The last three elements (operating surgeon, operating team and hospital characteristics) have been added to the framework based on the research questions of the current study.

Areas of research that cannot be addressed using the available data are highlighted. These areas include clinical characteristics (e.g. ejection fraction, left ventricular (LV) function, anatomy of Coronary Artery Disease), processes of care (e.g. pharmacologic therapies such as use of heparin, aspirin, or β-blockers, adjunctive procedures such as use of intra-aortic balloon pump or stents, appropriateness of patient selection and surgical technique) and operating team characteristics (e.g. skills of anesthesiologist, clinical perfusionist, nursing staff).

The interactions and interrelationships between these patient and provider characteristics lead to certain outcomes of surgical care, in this case defined as in-hospital mortality or in-hospital complications, the latter being measured as the presence of any of selected PSIs.

Figure 2.2 provides a succinct view of the framework and highlights the areas of research to be examined by the current study, as well as those that need to be addressed, to provide better understanding of the relationship between quality of care and patient outcomes.

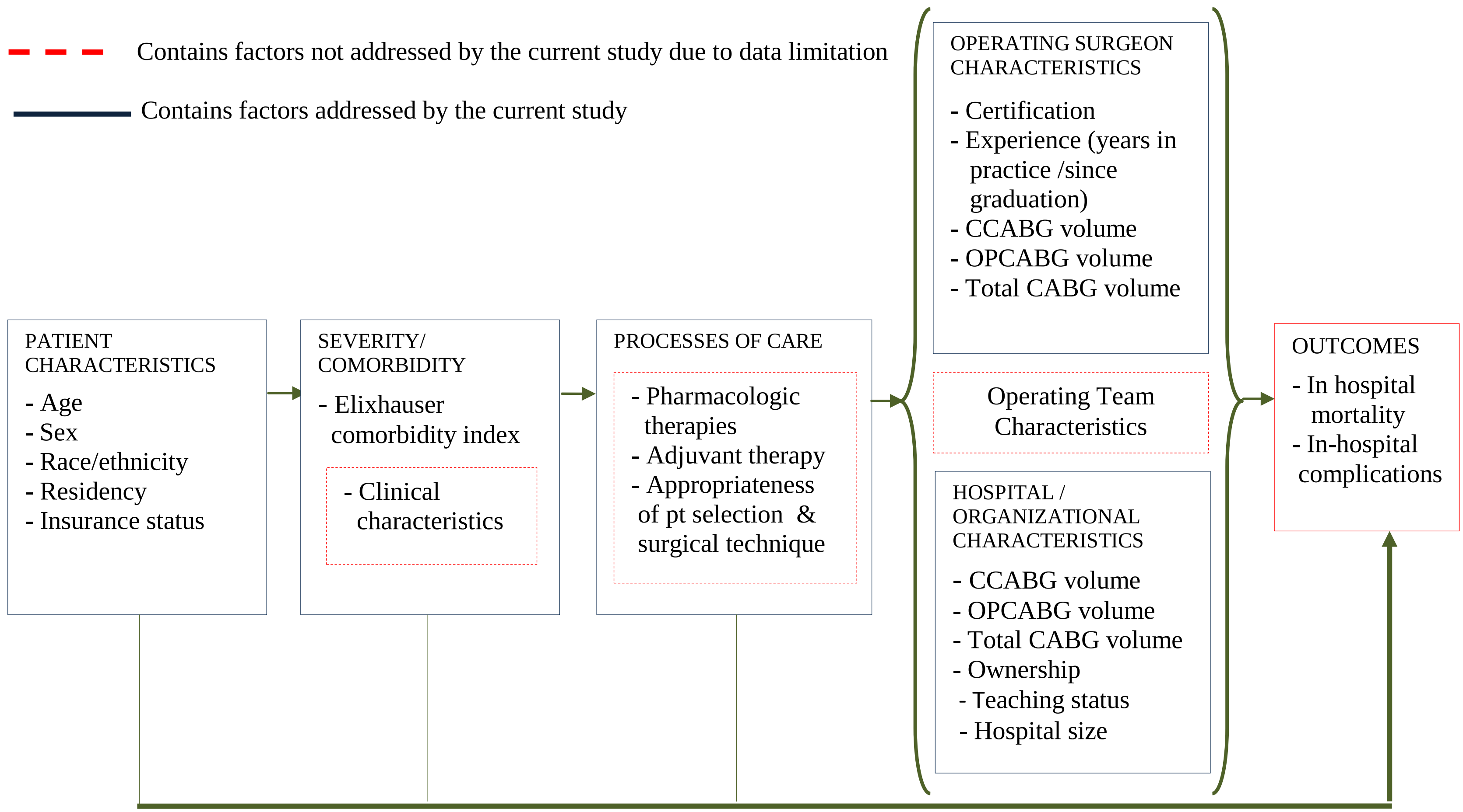

FIGURE 2.1: Conceptual Framework: Volume-Outcome Relationship Incorporating the Procedure Specificity Aspect

Adapted from: Hewitt, M. (2001). "For the Committee on Quality of Health Care in America and the National Cancer Polocy Board: Interpreting the volume-outcome relationship in the context of cancer care." Washington DC: Institute of Medicine.[1]

CHAPTER 3: METHODS

Study Design, Study Population and Data Sources

Data Sources

This pooled cross-sectional study used several sources of retrospective administrative data to examine the research questions.

1. Florida Hospital Inpatient Discharge Data (HIDD) to obtain inpatient discharge data
2. Florida Practitioner Profile Data File (PPDF) to identify board certified thoracic and general surgeons
3. Florida Hospital Characteristics File (HCF) to obtain hospital variables

A common physician and/or hospital identifiers contained in all data files listed above allowed linking the data to incorporate information from the selected data sets and create in-depth analysis. Detailed descriptions of the data files are given below.

Florida Hospital Inpatient Discharge Data (HIDD)

The Florida hospital inpatient discharge data is obtained from Agency for Health Care Administration (AHCA) continuously updated repository of health care data. The AHCA collects inpatient discharge data from 269 acute care, short-term psychiatric, long-term psychiatric and comprehensive rehabilitation facilities and comprehensive rehabilitation hospitals in Florida. The data are updated on a quarterly basis. Each record in the dataset corresponds to an individual inpatient hospital stay. The file has patient-level data and includes information on patient demographics, diagnosis and procedure codes, attending physician, operating or performing physicians, and total gross charges. The Health Data Store created a data dictionary for the file (available at http://www.healthdatastore.com/ahca-florida-hospital-discharge-data.aspx), which describes the data elements and layout.

The CABG discharges were identified using calendar year 2000 through 2006 inpatient discharge records. The de-identified inpatient records in the HIDD included up to 31 diagnosis and procedure codes, demographic characteristics such as patient age, sex, race/ethnicity, zip code, principal payer, admission type and admission source, length of hospital stay (LOS), discharge status, unique attending physician, operating physician and hospital identifiers, reporting year, reporting quarter, charges by 22 revenue centers, total gross charges, diagnosis related group (DRG), day of the week admitted, days to procedure. The diagnosis and procedure codes in the dataset were based on ICD-9-CM coding.

TABLE 3.1: List of variables used in the study, HIDD file

Variable name	Variable description	Code/Values
Age	Patient's age in years at admission	Numeric, continuous
Gender	The gender of the patient at admission	Numeric, nominal 1 Male 2 Female
Race	Race of patient	Numeric, nominal 1-American Indian or Alaska Native 2-Asian or Pacific Islander 3-Black or African American 4-White 5-White Hispanic 6-Black Hispanic 7-Other (Use if not described above) 8-No Response (Patient refuses/fails to disclose)

TABLE 3.1 (continued)

Variable name	Variable description	Code/Values
Discharge Status	Patient disposition at discharge	Numeric, nominal 01 – Discharged to home or self-care 02 – Discharged to a short-term general hospital 03 – Discharged to a skilled nursing facility 04 – Discharged to an intermediate care facility 05 – Discharged to another type of institution 06 – Discharged to home under care of home health care organization 07 – Left this hospital against medical advice (AMA) or discontinued care 08 – Discharged home under care of home IV provider on IV medications (discontinued 2005) 20 – Expired 50 – Discharged to hospice – home 51 – Discharged to hospice – medical facility 62 – Discharged to an inpatient rehabilitation facility including rehabilitation distinct part units of a hospital 63 – Discharged to a Medicare certified long term care hospital 65 – Discharged to a psychiatric hospital including psychiatric distinct part units of a hospital
Pay Source	Principal Payer Code	Character, nominal A – Medicare B – Medicare HMO or Medicare PPO C – Medicaid D – Medicaid HMO E – Commercial Insurance F – Commercial HMO G – Commercial PPO H – Workers’ Compensation I – CHAMPUS/TriCare J – VA K – Other State/Local Government L – Self Pay/Under-insured M – Other N – Charity O – KidCare

TABLE 3.1 (continued)

Variable name	Variable description	Code/Values
Admission Type	Admission Type (A code indicating the priority of this admission)	Numeric, nominal 1- Emergency 2- Urgent 3- Elective 4- Newborn 5- Trauma Center 9- Information not Available
Admission Source	Source of Admission/Point of Origin	Numeric, nominal 01 = Physician Referral 02 = Clinic Referral 03 = HMO Referral 04 = Hospital Transfer (different facility) 05 = Skilled Nursing Home 06 = Transfer- other Facility 07 = Emergency Room 08 = Court/Law Enforcement 09 = Other
Diagnosis Code	A code representing a condition that is related to the services provided during the hospitalization excluding external cause of injury codes. ICD-9-CM or ICD-10-CM code	Alphanumeric
Procedure code	The ICD-9-CM or ICD-10-CM code identifying all significant procedures other than the principal procedure. Report those that are most important for the episode of care and specifically any therapeutic procedures closely related to the principal diagnosis	Alphanumeric

TABLE 3.1 (continued)

Variable name	Variable description	Code/Values
Discharge Year	Year of discharge. The patient’s year of discharge. For example, a patient discharged on July 7, 2004 would have a discharge year of ‘2004.’	Numeric
DRG	Diagnosis Related Group DRG from federal (CMS) Grouper	Numeric
MDC	Major Diagnostic Category MDC from federal (CMS) grouper	Numeric

Florida Practitioner Profile Data File (PPDF)

PPDF was obtained from the Florida Department of Health (DOH) Licensee Data Center. The downloadable data files are available at the following website https://ww2.doh.state.fl.us/downloadnet/Profile.aspx.

PPDF included self-reported information from licensed Medical Physicians, Osteopathic Physicians, Podiatric Physicians, Chiropractic Physicians, and Advanced Registered Nurse Practitioners. The practitioner information contains the following characteristics: certification board, specialty certification area, specialty certificate (if available), education and training, professional and post graduate training, academic appointments, current practice and mailing addresses, staff privileges, faculty appointments and other affiliations, financial responsibility, proceedings and actions including legal litigations, board disciplinary action taken against the practitioner.

As Florida DOH indicates the practitioner profile summarizes data submitted by the practitioner and has not been verified by the Department unless otherwise indicated (http://doh.state.fl.us/mqa/Profiling/pp_about.html).

TABLE 3.2: List of Variables Used in the Study, PPDF file

Variable name	Variable description
MD Operating	Operating or performing physician identification number. The Florida license number of the medical doctor, osteopathic physician, dentist, podiatrist, chiropractor, or advanced registered nurse practitioner who had primary responsibility for theprocedure
MD Attending	Attending physician identification number. The Florida license number of the medical doctor, osteopathic physician, dentist, podiatrist, chiropractor or advanced registered nurse practitioner who had primary responsibility for the patient's medical care and treatment or who certified as to the medical necessity of the services rendered
Specialty Board	Surgeon certifying board
Specialty Certification	Specialty certification name
License ID	System defined numeric used to identify a license through the system
License Number	Current license number. Refers primarily to the number printed on the wall license. Existing wall license numbers are not necessarily unique even within a profession, and they are not identical to the identifier for most boards. This number will only change if the license is revoked and reissued for some reason. For duplicate licenses, the number will not change.
Last name of the Licensee	Last name of a surgeon
First name of the Licensee	First name of a surgeon
Middle Name of the Licensee	Middle name of a surgeon
License Status Description	Active/inactive status of the license

Florida Hospital Characteristics File (HCF)

HCF included hospital identifier, institution name, type, address, county, ownership and teaching status, total discharges, and bed size.

Human Subject Protection

Although the study uses de-identified data approval of the UNCC Institutional Review Board (IRB) has been obtained (Protocol # 10-05-28).

Study population

Surgeons with the American Board of Surgery (ABS) certification in General Surgery (GS) and American Board of Thoracic Surgery (ABTS) certification in Thoracic Surgery (TS) were included in the study. The GS subspecialties of Hand Surgery and Pediatric Surgery and TS subspecialty of Congenital Heart Surgery were excluded. The surgeons were initially categorized based on their performance of CCABG, OPCABG or both types of CABG in the following groups: Group 1- surgeons who performed on-pump CABG only (n=26), Group 2- surgeons who performed off-pump CABG only (n=14), Group 3- surgeons who performed both types of CABG. The third group had two subgroups: 3a- surgeons who performed predominantly on-pump CABG (n=190), 3b- surgeons who performed predominantly off-pump CABG (n=32). The categorization of surgeons in predominantly CCABG or OPCABG subgroups was based on simple majority of CABG type performed by these surgeons. Figure 1 shows the surgeon group categorization.

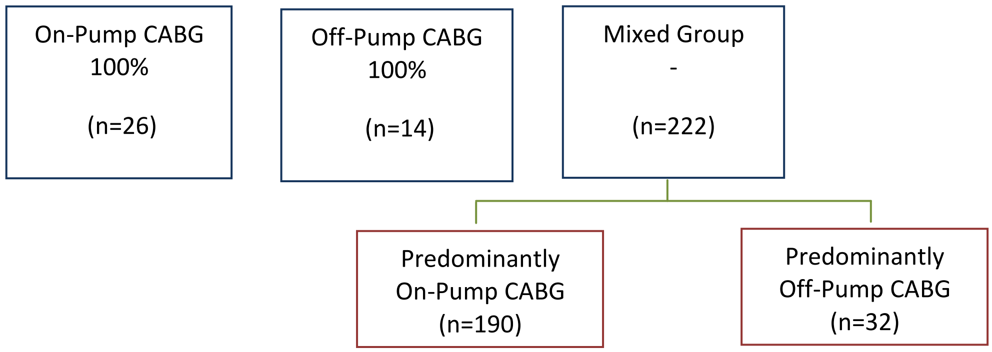

FIGURE 3.1: Surgical Caseload Groups

As CABG procedure is typically performed by thoracic or general surgeons, this study considered only those patients on whom CABG was performed by board certified thoracic or general surgeons only. Operating surgeon for CABG procedure was identified using the unique physician identification number contained in the "MD_operating" field of the HIDD. Previous research has indicated the reliability of this approach in identifying operating surgeons.[87, 88] Next, the unique operating surgeon identifier contained in the HIDD file was linked to Florida practitioners profile data to obtain the board certification information for each surgeon. A surgeon was determined to be a thoracic or general surgeon if the practitioner profile database indicated that he/she was certified by the American Board of Thoracic Surgery (ABTS) or American Board of Surgery (ABS) or "thoracic surgery" or "general surgery" was identified as a specialty program area. When operating physician reported multiple certifications only those including thoracic or general surgery certification were retained. Next, certification information for 264 surgeons remaining in the study was verified through American Board of Medical Specialties ABMS online database for final accuracy and data validation. The ABMS is a not-for-profit organization assisting 24 approved medical specialty boards in the development and use of standards for physician evaluation and certification (http://www.abms.org/).

To identify patient-discharges (n= 119,658) undergoing CABG as a principal procedure performed by the surgeons included in the study population, ICD-9-CM principal procedure codes 36.10–36.19 were used. Although no prior studies have examined the reliability of the coding for the use of a pump for CABG surgery in administrative data, Konety et al have successfully used the presence of ICD-9-CM procedural code for intracorporeal pump (39.61) or cardioplegia (39.63) to distinguish between patients undergoing on-pump CABG or off-pump CABG.[23]

Dependent Variables/Outcome Measures

Patient Safety Indicators

Patient Safety Indicators (PSIs) were chosen as an outcome variable to measure postoperative in-hospital complications. PSIs were developed by the Agency for Healthcare Research and Quality (AHRQ) and revised by the University of California-Stanford University Evidence-based Practice Center (UCSF-Stanford EPC). The PSIs are a set of indicators to provide information on potentially preventable in-hospital complications and adverse events. PSI software (http://www.qualtiyindicators.ahrq.gov/psidownload.htm) is designed for use with administrative data and is commonly being utilized in research. PSIs have been found to be reliable measures, with good construct validity and stability over time[89-92] and have been described in detail in numerous articles.[93-96]

PSIs selected for this study from the set of 20 provider level indicators based on clinical relevance to CABG surgery included: failure to rescue (PSI 4), foreign body left in during procedure (PSI 5), iatrogenic pneumothorax (PSI 6), selected infections due to medical care (PSI 7), postoperative hemorrhage or hematoma (PSI 9), postoperative physiologic and metabolic derangements (PSI 10), postoperative respiratory failure (PSI 11), postoperative pulmonary embolism or deep vein thrombosis (PSI 12), postoperative sepsis (PSI 13), accidental puncture and laceration (PSI 15). Patients were identified as having a complication if any of the 10 PSIs were present on the discharge record.

Although concern has been expressed regarding using PSIs without "present on admission" (POA) indicator due to limited ability of such approach to distinguish between complications and pre-existing comorbid conditions eight PSIs used in the current study (PSI 5, PSI 6, PSI 7, PSI 9, PSI 10, PSI 11, PSI 13, and PSI 15) have been found to remain potential patient safety problems after eliminating conditions reported as POA.[97, 98] The only patient safety indicator with less likelihood to be still considered a potential patient safety problem after eliminating conditions reported as POA was PSI 12, postoperative pulmonary embolism or deep vein thrombosis.[97]

Rationale for selecting the above listed PSIs as the outcome measures is described below.

Failure to rescue (PSI 4)

The failure-to-rescue indicator is considered to be a clinically meaningful and well validated quality measure.[99] This PSI was originally proposed by Silber et al.[100] After conducting extensive empirical analyses on PSI 4the project team developing the AHRQ PSI concluded that it generally performs well on several different dimensions, including reliability, bias, relatedness of indicators, and persistence over time.[101] One major advantage emphasized by the AHRQ panelists was that this PSI is fundamentally different than other AHRQ PSIs, as it reflects effectiveness in rescuing a patient from a complication versus preventing a complication.[101]

A study using Veteran Affairs (VA) administrative data examining the construct validity of the PSIs found that out of total 11,411 PSI events 46% occurred in surgical hospitalisation and 54% in medical hospitalisation.[90] Failure to rescue had the highest rate observed among all AHRQ PSIs, 155.55 per 1000 discharges and was significantly associated with the AHRQ PSIs for death in low-mortality DRGs, postoperative pulmonary embolism or deep vein thrombosis, and decubitus ulcer.[101]

Foreign body left in during procedure (PSI 5)

Surgeons and operating room teams typically rely on the practice of countin surgical instruments as a means of eliminating foreign bodies left in during procedure. However, practices are not standardised and occurrence of such adverse event may signal a serious system failure that should be addressed.[101] Thus, foreign body left during procedure is a suitable measure of patient safety.

Iatrogenic pneumothorax (PSI 6)

Iatrogenic pneumothorax may occur following intrathoracic surgery or during any procedure which involves entry into the pleural cavity, such as thoracentesis or placement of a chest drain. The leading causes of iatrogenic pneumothorax were transthoracic needle aspiration (128), subclavicular needle stick (119), thoracentesis (106), transbronchial biopsy (54), pleural biopsy (45) and positive pressure ventilation (38).[102]

Study by Çelik et al[103]showed that 56.7 % of the invasive procedures, which caused iatrogenic pneumothorax, were performed under emergency conditions and 43.3 % were performed under elective conditions. In 69 patients (42 %) the procedures were performed due to underlying lung diseases and in 95 patients (58 %) for diseases other than lung diseases. The most frequent procedure type causing iatrogenic pneumothorax was central venous catheterization, with 72 patients (43.8%). The other frequent causes were thoracentesis with 33 patients (20.1%) and barotrauma due to mechanical ventilation with 15 patients (9.1%).[103]

While being frequent in occurrence iatrogenic pneumothorax also is a preventable complication. Thus, it is a suitable measure of patient safety.

Selected infections due to medical care (PSI 7)

This PSI is intended to flag cases of infection due to medical care, primarily those related to intravenous (IV) lines and catheters. This PSI is defined on a provider level by including cases based on secondary diagnosis associated with the same hospitalisation. Patients with potential immuno-compromised states (e.g., AIDS, cancer, and transplant) are excluded, as they may be more susceptible to such infections.[101]

Postoperative hemorrhage or hematoma (PSI 9)

Postoperative haemorrhage or haematoma is a harmful and potentially life-threatening complication in surgical care. Thus, it is a suitable measure of patient safety.[101]

Postoperative physiologic and metabolic derangements (PSI 10)

Postoperative physiologic metabolic derangements is a potentially life-threatening complication in surgical care. This PSI encompasses codes for ketoacidosis, hyperosmolarity, or other coma, diabetes, acute renal failure, acute myocardial infarction, cardiac arrhythmia, cardiac arrest, shock, hemorrhage, or gastrointestinal hemorrhage.[104] The project team developing the AHRQ PSIs conducted extensive empirical analyses on this PSI. The team concluded that this PSI generally performs well on several different dimensions, including reliability, bias, relatedness of indicators, and persistence over time.[101] AHRQ panellists had a concern about the definition of acute renal failure: what one doctor may call acute renal failure, another may not. To ensure that the only renal failure cases that are accounted for are those that are clinically severe, the panel suggested that acute renal failure be included only when it is paired with a procedure code for dialysis.[101] Panellists also noted that coding of relatively transient metabolic and physiologic complications may be lacking, e.g. cases of diabetic ketoacidosis. Conversely, some physicians may capture non-clinically significant events in this indicator.[101]

Postoperative respiratory failure (PSI 11)

A study on multifactorial risk index for predicting postoperative respiratory failure in men after major noncardiac surgery found that 5% to 10% of all surgical patients and 9% to 40% of those undergoing abdominal surgery experience postoperative pulmonary complications.[105] Postoperative respiratory failure was defined as mechanical ventilation for more than 48 hours after surgery or reintubation and mechanical ventilation after postoperative extubation, which is the most common definition for this adverse event.

Prior studies have suggested that the risk factors for postoperative respiratory failure include those that are patient-specific and those that are operation-specific.

Patients with increased chance of developing postoperative respiratory failure include those who have the following risk factors: impaired general health status (*e.g.*, older age, poor functional status, diabetes mellitus, cancer, alcohol use), pulmonary (*e.g.*, smoking, chronic obstructive pulmonary disease [COPD], increased body mass index), neurologic (*e.g.*, impaired sensorium), and cardiac disorders (*e.g.*, myocardial infarction), and renal and fluid status (*e.g.*, renal failure, blood transfusion). The operation-specific risk factors include the location of the incision in relation to the diaphragm, emergent operation, and the type of anesthesia used (*e.g.*, general vs. spinal).[105]

Johnson et al[106] found that 28 variables were found to be independently associated with postoperative respiratory failure. Patients with a higher American Society of Anesthesiologists classification, emergency operations, more complex operation as measured by work relative value units, preoperative sepsis, and elevated creatinine were more likely to experience Postoperative respiratory failure. Older patients, male patients, smokers, and those with a history of congestive heart failure or COPD, or both, were also predisposed.[106]

Postoperative pulmonary embolism or deep vein thrombosis (PSI 12)

The occurrence of postoperative pulmonary embolism (PE) or deep vein thrombosis (DVT) can range from mild symptoms to fatal clinical consequences including pain, respiratory distress, and death. PE/DVT can be prevented through the appropriate use of anticoagulants and other preventive measures. The identification and stratification of patients at risk for venous thromboembolism is critical. Despite numerous studies demonstrating the efficacy and safety of prophylaxis, it is still underused and most patients who die from pulmonary embolism do so within 30 minutes of the acute event, which is far from sufficient time for anticoagulation to be effective.[107] Thus, PE or DVT is a suitable measure of patient safety.

Postoperative sepsis (PSI 13)

Sepsis is a severe complication of surgical procedures with a mortality rate of up to 30%.[101] Typically, many cases of postoperative sepsis can be prevented through the appropriate use of antibiotics, good preoperative preparation, careful and sterile surgical techniques and good post-operative care.[101] Thus, PSI 13 is a suitable measure of patient safety.

Accidental puncture and laceration (PSI 15)

Accidental puncture or laceration is an important and potentially life-threatening complication in surgical care.[101] Thus, it is a suitable measure of patient safety.

In-hospital Mortality

In-hospital mortality has been used as a common measure for evaluating the quality of surgical procedures.[27, 108-118] Improvements in CABG technique have resulted in a steady decline in the risks of the procedure and, subsequently in around 2% mortality rates nationwide with steady decline since the 1990s.[27, 119] In the present study, in-hospital mortality has been identified in the HIDD as ‘expired’ (coded 20) under the discharge status. Crude in-hospital mortality rate for CABG was 2.59% (n=3,096 out of 119,664 patients originally included in the study).

A summary of the clinical relevance of the selected PSIs to CABG and the rationale for measuring surgical outcomes by these indicators is provided in Exhibit 3.1.

Exhibit 3.1: Clinical Relevance of the Selected PSIs to CABG Surgery

Patient Safety Indicators (PSI)	1	2	3	4	5
PSI 4 Failure to rescue				√	√
PSI 5 Foreign body left in during procedure		√	√		√
PSI 6 Iatrogenic pneumothorax	√	√			
PSI 7 Selected infections due to medical care			√		√
PSI 9 Postoperative hemorrhage or hematoma		√	√		
PSI 10 Postoperative physiologic and metabolic derangement		√	√		
PSI 11 Postoperative respiratory failure			√	√	√
PSI 12 Postoperative PE/ DVT		√	√	√	
PSI 13 Postoperative sepsis		√	√	√	
PSI 15 Accidental puncture or laceration		√	√		

1=clinical relevance to chest surgery
2=technical proficiency/skills of the operating surgeon
3= technical proficiency/skills of the operating team
4=postoperative care
5=hospital/organizational factors

TABLE 3.3: Patient Safety Indicators (AHRQ)

Variable name	Variable description	Codes/Values	n(%)
PSI 4	Failure to rescue	1= Yes, 0= No	528(0.44)
PSI 5	Foreign body left in during procedure	1= Yes, 0= No	31(0.03)
PSI 6	Iatrogenic pneumothorax	1= Yes, 0= No	28(0.02)
PSI 7	Selected infections due to medical care	1= Yes, 0= No	480(0.40)
PSI 9	Postoperative hemorrhage or hematoma	1= Yes, 0= No	524(0.44)
PSI 10	Postoperative physiologic and metabolic derangement	1= Yes, 0= No	202(0.17)
PSI 11	Postoperative respiratory failure	1= Yes, 0= No	71(0.06)
PSI 12	Postoperative Pulmonary Embolism or Deep Vein Thrombosis	1= Yes, 0= No	1017(0.85)
PSI 13	Postoperative Sepsis	1= Yes, 0= No	418(0.35)
PSI 15	Accidental Puncture or Laceration	1= Yes, 0= No	1003(0.84)

Independent/Predictor Variables

Patient Characteristics

Demographic factors: age (continuous), sex (binary), race/ethnicity (categorical), pay source, type of admission and binary indicators for 30 comorbidities.

All above listed variables were included in the HIDD except comorbidities. To generate comorbodities the comorbidity software, version 3.0, was obtained from the Agency for Healthcare Research and Quality (http://www.hcupus.ahrq.gov/toolssoftware/comorbidity/comorbidity.jsp#download). The comorbidity measure used by the software was developed by Elixhauser and colleagues to predict length of hospital stay, total charges and in-hospital mortality.[120] Extensive body of literature has examined the adequacy of administrative data for measurement of comorbidity and risk adjustment.[121] Main concerns are the inherent limitations with regard to distinguishing in-hospital complications from comorbid conditions, accuracy and variations in coding of diagnoses across hospitals.

Only several of the 30 comorbidities were included in the analysis based on their clinical relevance. These comorbidities were congestive heart failure (CHF), chronic pulmonary disease, diabetes with chronic complications, hypertension, pulmonary circulation disease, valvular disease and liver disease. All of these conditions were selected based on the chronicity of their nature and evidence for increased risk for surgery.

It is well-documented that history of CHF is associated with increased risk of perioperative cardiac and extracardiac complications, morbidity and mortality.[122-125] In addition, patients with CHF may require prolonged postoperative mechanical ventilation[126] or conversion of off-pump to on-pump CABG.[127]

Similarly, valvular heart disease can be associated with increased perioperative cardiac risk.[128] Specifically, patients with aortic stenosis are at greatest risk – severe aortic stenosis leads to a 14-fold increase in sudden death due to the potential for severe decrease in cardiac output.[122] Other valvular diseases such as aortic insufficiency, mitral stenosis, mitral regurgitation as well as prosthetic valves also carry the risk of increased perioperative complications including left ventricular failure, severe pulmonary congestion, endocarditis and thromboembolic phenomena.[122, 128] Severe hypertension (diastolic BP >110 mm/Hg) may be associated with some increased postoperative risk.[122]

Studies have found that patients with diabetes mellitus have increased rates of cardiovascular morbidity and mortality.[129, 130] In addition, diabetic patients with identified complications, such as nephropathy and peripheral arteriosclerosis, have the highest mortality after heart surgery.[131] In general, there is a twofold increase in both early and late mortality among diabetic patients compared to those who do not have diabetes.[122]

Chronic pulmonary disease includes several conditions affecting the blood circulation in the lungs such as chronic thromboembolic disease, pulmonary arterial hypertension, pulmonary veno-occlusive disease, arteriovenous malformations and pulmonary edema. Patients with pulmonary hypertension are at increased risk of perioeperative complications including hypoxia, right ventricular failure, and ischemia.[132] These risks are especially high for cardiac surgery[133] increasing mortality rates up to 25%.[132] Chronic thromboembolic pulmonary disease is one of the leading causes of severe pulmonary hypertension and progressive right heart failure.[134]

Studies have found that patients with chronic liver disease are at higher risk of mortality and complications during surgery.[135, 136] Specifically, risk factors for perioperative death for patients with liver disease included a low hematocrit (< 30%), an elevated serum bilirubin (>11 mg/dL), and a malignant cause of biliary obstruction. The mortality rate was 60% when all three were present vs. only 5% when none were present.[136]

Four comorbidities that are highly relevant to CABG surgery were not entered in the models due to their potential of being a post-surgical complication rather than a pre-existing condition. These comorbidities were: (1) other neurological disorders – numerous studies find that neurologic complications are second only to heart failure as a cause of morbidity and mortality following cardiac surgery.[137-139] The chance of neurological dysfunction as a surgical complication is particularly high when CPB is involved despite the recent advances in cardiopulmonary bypass technology, surgical techniques and anaesthetic management;[140] (2) renal failure – the risk of renal failure after cardiopulmonary bypass ranges from 3% to 31%, depending on the classification used;[141] (3) coagulopthy – major changes may occur in the coagulation system during cardiopulmonary bypass[142] and studies have documented a wide variety of derangements in laboratory measurements of blood coagulation during cardiopulmonary bypass;[143] (4) fluid and electrolyte disorders –CPB can cause multiple electrolyte disturbances.[144] Cardioplegic solutions and induced hypothermia impose alterations in potassium metabolism and pH, dilution of the circulating blood volume from pump perfusate and volume resuscitation with crystalloid and colloid solutions produce fluid, electrolyte, and hemostatic disorders.[144]

TABLE 3.4: Patient Comorbidities (Elixhauser Comorbidities Based on ICD-9-CM codes)

Variable description	Codes/Values
Acquired immune deficiency syndrome	1= Yes, 0= No
Alcohol abuse	1= Yes, 0= No
Deficiency Anemias	1= Yes, 0= No
Rheumatoid Arthritis	1= Yes, 0= No
Chronic blood loss anemia	1= Yes, 0= No
Congestive Heart Failure	1= Yes, 0= No
Chronic Pulmonary Disease	1= Yes, 0= No
Depression	1= Yes, 0= No
Diabetes mellitus without chronic complications	1= Yes, 0= No
Diabetes mellitus with chronic complications	1= Yes, 0= No
Drug abuse	1= Yes, 0= No
Hypertension	1= Yes, 0= No
Hypothyroidism	1= Yes, 0= No
Liver disease	1= Yes, 0= No
Lymphoma	1= Yes, 0= No
Metastatic cancer	1= Yes, 0= No
Obesity	1= Yes, 0= No
Paralysis	1= Yes, 0= No
Peripheral vascular disease	1= Yes, 0= No
Psychoses	1= Yes, 0= No
Pulmonary circulation disease	1= Yes, 0= No
Solid tumor w/out metastasis	1= Yes, 0= No
Valvular disease	1= Yes, 0= No
Weight loss	1= Yes, 0= No

All patient characteristic variables were coded as categorical variables. The referent group was the group with the most observations or/and the least risk associated with the outcomes of interest. As listed in Table 3.5, age was categorized into the following groups: 30-39, 40-49, 50-59, 60-69, 70-79 (referent), 80 and over. Elective admission was the referent group for admission type, whites were the referent group for race, men for gender.

Surgeon Characteristics

The analysis initially included 264 surgeons with verified board certification either in general surgery or thoracic surgery. Two surgeons with exact same number of CABG surgeries were excluded to allow creation of four categories (surgeons who performed 100% on- or off-pump CABG and those who performed mostly on- or off-pump CABG). However, one of these categories (100% off-pump CABG) was eliminated entirely due to subsequent exclusion of surgeons who performed only one procedure over the entire study period (n=32).

The definition and coding of all variables characterizing 230 surgeons remaining in the analytic sample are presented in Table 3.5. Medical education and practice information was obtained from PPDF. Location of surgeon was determined based on Rural-Urban Commuting Area Codes (RUCAs) obtained from the 2000 US Census.

Total procedure volume was measured as total number of CABG cases performed by each board certified thoracic or general surgeon over 7-year study period, which was also defined as cumulative volume.

Further, surgeon volume was assessed by ranking all surgeons into quartiles based on their CABG, CCABG and OPCABG operations. Surgeon case volumes in the off-pump models were based only on procedures performed off-pump, and surgeon case volumes in the on-pump models were based only on procedures performed on-pump.

Hospital volume was based on the total number of off-pump and on-pump CABG procedures performed at a particular hospital.

Models were developed with patient volume quartiles as categorical variables for each of the volume measures, with the highestvolume quartile used as the reference category (for both surgeons and hospitals). Model coefficients for the other three volume quartiles were used to estimate the risk-adjusted mortality for those quartiles relative to the highest-volume quartile. Next, lowest volume surgeons were identified by obtaining univariate distribution of the CABG volume. There was a break at 1% of surgeons who did 88 procedures, which was considered to be the lowest volume.

Hospital Characteristics

Hospital variables included hospital CABG volume expressed as volume quartiles, hospital teaching and ownership status (public, not-for-profit, investor-owned), total discharges, location (urban vs. rural) and bed size (Table 3.5). For all variables a category with the most observations was referent in both anadjsuted and adjusted analyses. For hospital CABG volume a referent category was quartile 4, for teaching status – non-teaching hopistals, for ownership not-for-profit hospitals, for total discharges hospitals with 29,292 – 52,006 dischargres, for bed size – 500 and more beds, for location – urban hospitals.

TABLE 3.5: Definition of Variables and Coding

Variable	Definition
Patient age	30-39
	40-49
	50-59
	60-69
	70-79
	80+
Patient gender	Man
	Woman
Patient race/ethnicity	Black, non-Hispanic
	White, non-Hispanic
	Hispanic
	Other

TABLE 3.5 (continued)

Variable	Definition
Primary payer	Medicare Medicaid Commercial insurance Self-pay/Charity Other
Admission type	Elective Emergency Urgent Other
Patient comorbidities	Comorbid conditions identified by applying Elixhauser Comorbidity Algorithm based on ICD-9-CM codes Individual 24 comorbidities and number of comorbidities 0 1 2 3 or more
Surgeon board certification	ABS (American Board of Surgery) ABTS and ABTS (dual certification obtained from American Board of Surgery and American Board of Thoracic Surgery) ABTS (American Board of Thoracic Surgery)
Years since medical school graduation	0-10 11-20 21-30 31+ Unknown Mean(SD)
Years practicing	0-10 11-20 21-30 31+ Unknown Mean(SD)

TABLE 3.5 (continued)

Variable	Definition
Medical school location	US
	Foreign
	Unknown
County physician located	Metropolitan
	Non-metropolitan
	Out of state
Surgeon total CABG volume	All CABG procedures per surgeon
	Quartile 1
	Quartile 2
	Quartile 3
	Quartile 4
Surgeon CCABG volume	All on-pump CABG procedures performed by a surgeon
	Quartile 1
	Quartile 2
	Quartile 3
	Quartile 4
Surgeon OPCABG volume	All off-pump CABG procedures performed by a surgeon
	Quartile 1
	Quartile 2
	Quartile 3
	Quartile 4
Hospital total CABG volume	All CABG procedures per hospital
	Quartile 1
	Quartile 2
	Quartile 3
	Quartile 4
Hospital teaching status	Non-teaching
	Teaching
Hospital Ownership status	Investor-owned
	Not-for-profit
	Public

TABLE 3.5 (continued)

Variable	Definition
Hospital Bed size	Less than 200
	200-299
	300-399
	400-499
	500+
Total hospital discharges	582-13,209
	13,210-29,291
	29,292-52,006
Hospital Location	Urban
	Rural

CCABG=Conventional Coronary Artery Bypass Graft, OPCABG=Off-pump Coronary Artery Bypass Graft

Data Analysis

Univariate analysis included frequencies (n, %) for categorical variables and means and standard deviations for continuous variables. Bivariate analysis used Chi square test to examine differences between patient and surgeon characteristics.

The data structure was hierarchical as it contained nesting of patients within surgeons and nesting of surgeons within hospitals. To address this issue of non-independence multilevel modeling of hierarchical data was used for the present study. The method was selected as it enables to model variability at each level of the hierarchy. The response is measured at the individual level, and includes both the effect of that individual and the effect of the context. Consequently, the regression coefficient is an estimate of how the outcome changes as a function of predictors conditional on the random effects.[145] The GLIMMIX procedure used for the analysis incorporates random effects in the model thus allowing for subject-specific (conditional) and populationaveraged (marginal) inference.[146] Predictor variables for the three levels of hierarchical data included: level 1 predictors – patient age, race, residence, gender, insurance type, admission type, number of comorbidities; level 2 predictors – surgeon specialty certification, years in practice, CABG volume (total, CCABG and OPCABG) expressed in quartiles; level 3 predictors – hospital ownership (public, private), teaching status, total discharges, total CABG volume (expressed in quartiles), bed size, location (urban vs. rural).

All statistical analyses were conducted using SAS release 9.2 (SAS Institute Inc., Cary, NC) with $P<.05$ considered statistically significant.

Hypothesis 1.1

Four separate models were fit to assess the effect of procedure-specific CABG volume on each outcome measure (Table 3.6, models 1.1a – 1.1d). The sample was grouped by off-pump and on-pump CABG, and models were fit to assess each outcome for off-pump CABG and on-pump CABG patients separately. Eight surgeons performing exclusively CCABG were not included in the analysis (surgeons n=222, discharges n=119,403, CCABG cases n=94,808, OPACABG cases n=24,595).

Hypothesis 1.2

A dummy variable was created for surgeons with total CABG volume of ≤88 procedures over 7 years. The cut point of ≤88 procedures was obtained from univariate distribution of the CABG volume. There was a gap from 2 procedures to 88 procedures perfomed by 1% of surgeons. Thus, ≤88 procedures over the 7-year study period was considered be the lowest volume (Table 3.6, models 1.2a and 1.2b). The analysis did not adjust for any other surgeon volume covariates including on-pump or off-pump volume quartiles.

Hypothesis 1.3

Similar to the analysis conducted to test Hypothesis 1.1, four separate models were fit to assess the effect of total 7-year CABG volume (cumulative volume) and proportional (off-pump vs. on-pump CABG) CABG volume (Table 3.6, models 1.3a and 1.3b).

Hypothesis 2.1

If surgeon was in the lowest total CABG quartile and hospital was in the total CABG quartile 3 or 4 and had highest number of total discharges then the ‘low volume MD in high volume hospital’ variable was created. If surgeon was in the lowest total CABG quartile and hospital was in the total CABG quartile 1 or 2 and had the lowest number of total discharges then the ‘low volume MD in low volume hospital’ variable was created and both variables were entered in the multilevel models. The analyses were adjusted for patient characteristics, surgeon board certification and experience and hospital ownership and teaching status (Table 3.6, models 2.1a and 2.1b).

Hypothesis 2.2

Analyses were adjusted for patient risk factors and hospital characteristics including bed size, total discharges, total CABG volume (expressed in quartiles) and ownership and teaching status (Table 3.6, models 2.2a and 2.2b).

TABLE 3.6: Description of Models

Hypothesis	Model Type	Model No
$H_{1.1}$	Mortality ~ patient age, race/ethnicity/sex, admission type, comorbidities, + surgeon volume (all CABG cases, and *on-pump CABG cases*) + surgeon certification + surgeon practice+ hospital CABG volume, teaching status , ownership, location, bed size, total discharges	1.1a
	Complications ~ patient age, race/ethnicity/sex, admission type, comorbidities, + surgeon volume (all CABG cases, and *on-pump CABG cases*) + surgeon certification + surgeon practice+ hospital CABG volume, teaching status , ownership, location, bed size, total discharges	1.1b
	Mortality ~ patient age, race/ethnicity/sex, admission type, comorbidities, + surgeon volume (all CABG cases, and *off-pump CABG cases*) + surgeon certification + surgeon practice+ hospital CABG volume, teaching status , ownership, location, bed size, total discharges	1.1c
	Complications ~ patient age, race/ethnicity/sex, admission type, comorbidities, + surgeon volume (all CABG cases, and *off-pump CABG cases*) + surgeon certification + surgeon practice+ hospital CABG volume, teaching status , ownership, location, bed size, total discharges	1.1d
$H_{1.2}$	Mortality ~ patient age, race/ethnicity/sex, admission type, comorbidities, + surgeon volume (≤88 CABG cases) + surgeon certification + surgeon practice+ hospital CABG volume, teaching status , ownership, location, bed size, total discharges	1.2a
	Complications ~ patient age, race/ethnicity/sex, admission type, comorbidities, + surgeon volume (≤88 CABG cases) + surgeon certification + surgeon practice+ hospital CABG volume, teaching status , ownership, location, bed size, total discharges	1.2b

TABLE 3.6 (continued)

Hypothesis	Model Type	Model No
$H_{1.3}$	Mortality ~ patient age, race/ethnicity/sex, admission type, comorbidities, + cumulative surgeon volume (all CABG cases, 2000-2006) + surgeon certification + surgeon practice+ hospital CABG volume, teaching status , ownership, location, bed size	1.3a
	Complications ~ patient age, race/ethnicity/sex, admission type, comorbidities, + cumulative surgeon volume (all CABG cases, 2000-2006) + surgeon certification + surgeon practice+ hospital CABG volume, teaching status , ownership, location, bed size	1.3b
$H_{2.1}$	Mortality ~ patient age, race/ethnicity/sex, admission type, comorbidities, + LVMD/HVH + LVMD/LVH + surgeon certification + surgeon practice + teaching status + ownership + location + bed size	2.1a
	Complications ~ patient age, race/ethnicity/sex, admission type, comorbidities, + LVMD/HVH + LVMD/LVH + surgeon certification + surgeon practice + teaching status + ownership + location + bed size	2.1b
$H_{2.2}$	Mortality ~ patient age, race/ethnicity/sex, admission type, comorbidities, + hospital CABG volume, teaching status , ownership, location, bed size, total discharges	2.2a
	Complications ~ patient age, race/ethnicity/sex, admission type, comorbidities, + hospital CABG volume, teaching status , ownership, location, bed size, total discharges	2.2b

CHAPTER 4: RESULTS

Descriptive Statistics

The study population included 119,559 patients undergoing isolated CABG surgery in Florida who were discharged from the hospital between 2000 and 2006. The sample was restricted to patients ages 30-80 and over. These patients were treated by 230 surgeons (meeting the study inclusion criteria) working at 80 hospitals. Overall, 94,964 (79.43%) of the CABG procedures were performed on-pump and 24,595 (20.57%) off-pump. Of the 230 surgeons in the study cohort, 222 performed ≥2 on- or off-pump CABG procedures over the 7-year period, and eight performed exclusively on-pump CABG.

Patient Characteristics

Patients demographic characteristics – age, sex, race/ethnicity, insurance status and type of admission included in the analyses are described below (Table 4.1). Overall, the patients operated on by board certified general and thoracic surgeons had a mean age of 66 (10.68) years. Largest proportion of patients were 70–79 years of age (33.65%) followed by those in 60 -69 age category (30.08%). In addition, 72.13% were male (n=86237) white (82.49 %), had Medicare insurance (59.52 %) and were admitted electively (40.79%).

Further, as displayed in Table 4.1 larger proportion of patients undergoing both types of CABG - CCABG and OPCABG were white (83.21% and 79.69% respectively, p<0.0001), male (72.88% and 69.22% respectively, p<0.0001), ages of 70-79 (34.04% and 32.15% respectively, p<0.0001), Medicare beneficiaries (59.72% and 58.76% respectively, p<0.0001) and admitted electively (40.51% and 41.87% respectively, p<0.00).

Table 4.2 shows patient characteristics by total CABG volume quartiles. Quartile 1 (low volume) surgeons operated on higher proportion of non-Hispanic black and Hispanic patients (8.16% and 18.06%) and Medicaid (7.36%) and uninsured or underinsured patients (9.78%) compared to surgeons in other three CABG volume quartiles. Higher proportion of white patients was seen by quartile 3 and 4 surgeons (85.16% and 82.17% respectively) as well as Medicare and commercially insured patients compared to other CABG volume categories. The distribution of patients across all CABG volume quartiles was similar with regard to sex, age, and number of comorbid conditions.

The comorbid conditions (selected from original 30 comorbidities included in the algorithm developed by Elixhauser et al[120]) for the patients included in the study and stratified by CABG technique are reported in Table 4.3. Overall, 9.33% of patients had no comorbidities, 26.94% had at least one comorbidity, and over 30% had two comorbidities or more. The major comorbidities for CABG patients were hypertension (65.48%), diabetes mellitus without chronic complications (26.7%), chronic pulmonary disease (22.73%), congestive heart failure (18.95%), valvular disease (11.65%), deficiency anemias (11.53%) and peripheral vascular disease (11.24%).

Surgeon Characteristics

Table 4.4 presents surgeon characteristics for 262 surgeons by original surgeon categories (100% on- or off-pump CABG and mostly on- or off-pump CABG). Largest proportion of surgeons performed both types of CABG with those providing mostly CCABG being the biggest category with 190 surgeons (92.5%). Only 32 (12.2%) surgeons provided OPCABG more frequently than CCABG; 26 (9.9%) and 14 (5.3%) surgeons provided exclusively CCABG and OPCABG operations. The distribution of surgeons with respect to years since graduation from medical school, years in practice and practice and medical school location was quite similar across all categories.

As shown in Table 4.5, exclusively OPCABG surgeons had very few number of cases during the study period (n=14, 0.01%). Their patients were predominantly white (78.6%), male (85.7%), 60-69 years of age and Medicare beneficiaries (64.3%). Distribution was similar for all other groups with several exceptions: larger proportion of patients of exclusively CCABG, predominantly CCABG and OPCABG surgeons were 70-79 years of age (33.5%, 34.3%, and 31.8% respectively). In addition, majority of operations (87.88%) were performed by surgeons who did mostly CCABG. Overall, largest proportion of CABG was performed by surgeons that were providing both types of CABG – on-pump and off pump. Surgeons with the preference of performing OPCABG operated on 11.96% of patients and only 0.16% and 0.01% of patients were operated on by surgeons who provided exclusively on-pump or off-pump surgery respectively.

After excluding 32 surgeons due to extremely small number of procedures over 7-year study period OPCABG category was eliminated as all 14 surgeons in this category were excluded. As reported in Table 4.6 out of remaining 230 surgeons 16 (6.96%) were board certified by American Board of Surgery (ABS), 90 surgeons (39.13%) had obtained dual certification by ABS and American Board of Thoracic Surgery (ABTS) while majority of them 124 (53.91%) were ABTS certified surgeons. In addition, higher proportion of surgeons were in practice for 11-20 years (29.57%), US graduates (96.52%) and had graduated from medical school 11-20 years ago (36.65%). After stratifying surgeons based on their performance of CCABG or OPCABG this distribution remained similar, except certification status. Larger proportion of surgeons performing OPCABG was dually certified (47.17%) compared to ABTS certified surgeons (45.28%).

In addition, highest proportion of surgeons included in the study practiced at one hospital 79 (34.35%), 58 surgeons (25.22%) practiced at two hospitals and 41 (17.83%) at three hospitals, 52 surgeons (22.60%) at 4 and more hospitals (Table 4.7).

Table 4.9 shows surgeon workload and their patient demographics by four surgeon volume quartiles. Surgeons in quartile 1 performed 2,729 CABG procedures; quartile 2, 3 and 4 surgeons performed 15,278, 37,145 and 64,417 procedures respectively. Average total CABG, CCABG and OPCABG volume was largest among surgeons in quartile 4 volume category 164.47(34.37), 130.11(49.01) and 34.36(36.85) respectively with their OPCABG volume being markedly smaller compared to total and CCABG volume ($p<0.0001$).

ABS and dually certified (ABS and ABTS) surgeons with the largest patient workload were in quartile 2 (8.06% and 44.23% respectively, $p<0.0001$) while ABTS certified surgeons in quartile 4 operated on the largest proportion of patients (67.08%).

Overall, ABTS certified surgeons had larger patient workload in all volume quartiles compared to physicians with other certification status (ABS or dual certification).

Surgeons with fewer years in practice (0-10 and 11-20) with higher patient workload were in lower volume quartiles (1 and 2), (17.03% and 39.50% respectively) while with the increasing experience (31 and more years in practice) their patient workload decreased with the volume increase, in a linear fashion: 14.01%, 11.34%, 8.33% and 7.57% for quartile 1, 2, 3 and 4 respectively ($p<0.0001$).

With respect to years since graduation surgeons' patient workload increased markedly for the higher volume quartiles (3 and 4) for those with 11-20 and 21-30 years since graduation while it decreased for those with 0-10 and 31 and more years since graduation for the same volume quartiles ($p<0.0001$). In addition, surgeons with highest patient workload in all four quartiles were US graduates.

Hospital characteristics

The hospital characteristics including hospital CABG volume, ownership and teaching status, location (urban vs. rural), bed size and total discharges for the population used in the analyses are described below (Table 4.8). Largest proportion of patients were operated on at not-for-profit (56.52%, $p<0.0001$) non-teaching (76.96%, $p<0.0022$), urban (88.06%, $p<0.0001$) hospitals with over 500 beds (44.21%, $p<0.0001$) and total hospital discharges ranging between 13,210 and 29,291 (49.43%, $p<0.0001$).

Table 4.10 displays patient and hospital characteristics as a function of hospital volume. Compared with higher-volume centers, lowest-volume hospitals (quartile 1 and 2) were more likely to operate on older patients (11.70%, $p<0.0001$) who were non-Hispanic Black (4.60% for quartile 1 and 7.24% for quartile 2 vs. 5.60% and 3.79% for quartiles 3 and 4 respectively, p<0.0001) or Hispanic (5.32% - quartile 1 and 18.18% - quartile 2 vs. 8.14% and 5.13% for quartiles 3 and 4 respectively, p<0.0001), had 3 or more comorbid conditions (36.18% - quartile 1, vs. 34.05% and 30.99% in quartiles 3 and 4 respectively, p<0.0001) and unscheduled (emergency) surgery (30.24% - quartile 1, 35.10% - quartile 2 vs. 28.43% and 22.23% for quartiles 3 and 4 respectively, p<0.000).

Outcomes

Overall, in-hospital mortality and complications for CABG patients operated by general surgeons and thoracic surgeons was 2.59 % and 3.29% respectively.

Complications (any PSI)

As shown in Table 4.11, greater proportion of patients having a complication was male (67.57%, p<0.0001), ages of 70-79 (37.97%, p<0.0001), had Medicare (67.24%, p<0.0001), and had one or two of the selected Elixhauser comorbidities (31.33% and 31.13%, respectively p<0.0001).

In addition, as reported in table 4.12, compared to patients with no complications, those having any PSI were operated by low volume (total CABG quartile 1 and 2) surgeons (2.80% vs. 2.26% and 13.72% vs. 12.75% respectively, p=0.0208), while for surgeons in quartile 3 and 4 the rate of complications were almost same and lower (31.28% vs. 31.06% and 52.20% vs. 53.93% respectively, p=0.0208). With regard to specific CABG volume, patients who were operated by CCABG volume quartile 1, 2 and 3 surgeons had higher rates of complications (3.56 vs. 2.88, 17.00 vs. 16.28 and 32.25 vs. 29.42 respectively, p<0.0001). Only CCABG quartile 4 surgeons achieved lower rates of complications (47.19 vs. 51.41, p<0.0001). For patients operated by surgeons categorized in OPCABG volume quartiles, there was no obvious trend or any significant differences between the patients with and without complications in any volume quartiles (p=0.0697). Furthermore, the patients operated by ABS certified general surgeons had higher rates of complications (2.42% vs. 1.89%, p=0.0277) while patients of those surgeons that had obtained ABTS certification (either in addition to ABS certification or alone) had similar or lower complication rates (36.93% vs. 36.18% and 60.65% vs. 61.93%, p=0.0009). The differences were also observed between patients with and without complications based on surgical training. Patients of surgeons who had graduated from medical school 11-20 years ago had lower rate of complications (37.72% vs. 40.59%, p=0.0050) while patients of surgeons at two extremes of medical school graduation (i.e. 0-10 and 31 and more years) had higher rates of complications (16.03% vs. 15.48% and 12.83% vs. 11.59% respectively, p=0.0050). Similarly, patients of surgeons practicing for 11-20 years had lower rates of complications (29.12% vs. 30.24%, p=0.0002).

The differences in complication rates based on hospital characteristics where patients were operated were significantly different based on ownership status: patients operated in not-for-profit and investor-owned hospitals had lower rates (55.92% vs. 56.54% and 27.87% vs. 28.74% respectively, p=0.0296) while public hospitals had higher complication rates (16.21% vs. 14.72%, p=0.0296)

Mortality

Patient distribution with regard to mortality was quite similar to that of complications (Tables 4.11 – 4.12): patients in the age group of 70-79 (43.39%, p<0.0001) males (62.15%, p<0.0001), and Medicare beneficiaries had higher rates of mortality. Furthermore, patients operated by lower total CABG volume surgeons (quartile 1 and 2) had higher mortality rates (2.55% vs. 2.27% and 14.35% vs. 12.27%

respectively, p=0.0362). The trend was, however, reversed for patients seen by the quartile 3 and 4 surgeons (30.14% vs. 31.09% and 52.97% and 53.90% respectively, p=0.0362). Similar pattern was observed for patients seen by surgeons CCABG quartile 1, 2 and 4. However, those seen by CCABG quartile 3 surgeons still had higher rates of mortality (32.53% vs. 29.43%, p<0.0001). There was no clear trend in mortality for patients operated on by surgeons in OPCABG quartiles and the differences did not reach the level of significance.

Interesting pattern was observed among the patient mortality outcomes with regard to surgeon certification. Those operated by ABS certified surgeons had higher mortality rates (2.80% vs. 1.88%); similar rates were noted for patients of dually certified surgeons (36.40% vs. 36.20%) and lower rate of ABTS certified surgeons (60.80% vs. 61.92%), p= 0.0009. In addition, patients seen by surgeons with highest number of years since graduation and years practicing (31 and more) had higher proportion of mortality (14.89% vs.11.53%, p<0.0001and 10.28% vs. 8.39%, p<0.0001).

No significant differences were observed in mortality rates for patients with respect to hospital teaching and ownership status and total CABG volume.

Unadjusted Results for the Independent Variables and Each Outcome

Tables 4.13 – 4.14 report unadjusted results for the independent variables and the outcomes of interest.

Unadjusted Results for Patient Characteristics

Patients in all age groups except 80 years of age and over had lower odds of complications and mortality compared to those in the 70-79 age category. Out of these groups only odds of complication for 30-39 year-olds was not significant (p=0.0728).

Females had 60% higher odds of mortality (OR=1.60, 95% CI: 1.49-1.72) and 25% higher odds of complications (OR=1.25, 95% CI: 1.17-1.34) compared to males. Although whites represented about 80% of the study sample, all minority groups had higher unadjusted odds of mortality although it did not reach the level of significance.

Unadjusted Results for Provider Characteristics

As Table 4.14 shows, patients operated by surgeons in lower total CABG quartiles (1 and 2) had significantly higher odds of complications (OR=1.28, 95% CI: 1.05-1.55 and OR=1.11, 95% CI: 1.01-1.23 respectively) compared to highest CABG volume surgeons (quartile 4). Patients seen by quartile 2 surgeons also had significantly higher odds of mortality (OR=1.15, 95% CI: 1.03-1.28) compared to quartile 4 surgeons. The volume effect was even more pronounced for patients operated by CCABG quartile 1, 2 and 3 surgeons: they had higher odds of complications (OR=1.47, 95% CI: 1.34-1.62, OR=1.34, 95% CI: 1.22-1.48 and OR=1.38, 95% CI: 1.25-1.52 respectively) and mortality (OR=1.30, 95% CI: 1.18-1.44, OR=1.23, 95% CI: 1.10-1.36 and OR=1.12, 95% CI: 1.01-1.25 respectively) compared to the patients of the highest CCABG volume surgeons. No clear association was found among patients across OPCABG surgeon quartiles except the only significant association between lower odds of complications (OR=0.90, 95% CI: 0.83-0.97) for quartile 3 compared to quartile 4.

Furthermore, patients operated by ABS certified surgeons had significantly higher odds of complications (OR=1.31, 95% CI: 1.06-1.61) and mortality (OR=1.52, 95% CI: 1.22-1.89) compared to patients of ABTS certified surgeons while there was no difference for the outcomes of dually certified physicians.

Consistent trends in outcomes emerged based on practice patterns of operating physicians. Patients seen by surgeons on either extreme of experience expressed as years in practice and years since graduation had significantly higher odds of complications and mortality. Specifically, patients operated by surgeons with 0-10 years since graduation had higher odds of complications (OR=1.11, 95% CI: 1.01-1.22) as well as those treated by 31 years and over since graduation (OR=1.19, 95% CI: 1.07-1.32) who also had higher odds of mortality (OR=1.35, 95% CI: 1.21-1.50) compared to those seen by surgeons with 11-20 years since graduation. Similarly, unadjusted odds of complications and mortality were higher for patients operated by surgeons with 30 and more years in practice (OR=1.24, 95% CI: 1.11-1.39 and OR=1.29, 95% CI: 1.14-1.46 respectively).

No clear association was found between the outcomes of interest and hospital CABG volume. Patients operated at teaching and public hospitals had higher odds of complications (OR=1.08, 95% CI: 1.01-1.17 and OR=1.11, 95% CI: 1.02-1.22 respectively).

Adjusted Analyses

Hypothesis 1.1

Four separate models were fit to examine risk-adjusted mortality and complications for on-pump and off-pump CABG. These analyses included only 222 surgeons performing both types of CABG. The analyses were adjusted for patient characteristics, surgeon and hospital characteristics. On-pump, off-pump and total CABG volume was expressed as quartiles with the referent category of quartile 4.

The tables 4-15 and 4-16 present adjusted results for off-pump mortality, off-pump complications and on-pump mortality and on-pump complications. As Table 4.15

demonstrates older age (70-79 referent, and 80 and over OR=1.42, 95% CI: 1.17-1.73), emergency admission (OR=1.63, 95% CI: 1.34-1.97), Medicare insurance (OR=1.37, 95% CI: 1.05-1.78) and OPCABG operation performed by lower volume surgeon (quartile 1 OR=3.05, 95% CI: 1.68-5.53, quartile 2 OR=1.57, 95% CI: 1.10-2.26 and quartile 3 OR=1.35, 95% CI: 1.01-1.81) at public (OR=1.51, 95% CI: 1.08-2.11) hospitals were significantly associated with higher in-hospital mortality for patients undergoing OPCABG. In addition, patients with CHF (OR=2.62, 95% CI: 2.23-3.09), pulmonary circulation disease (OR=1.71, 95% CI: 1.16-2.51), valvular disease (OR=1.37, 95% CI: 1.13-1.66) and cardiogenic shock (OR=2.14, 95% CI: 1.46-3.13) had higher odds of mortality. For complications the following patient risk factors emerged as significantly associated with surgical complications: Medicare, Medicaid and other type of insurance (OR=1.39, 95% CI: 1.12-1.72, OR=1.83, 95% CI: 1.27-2.63, OR=1.82, 95% CI: 1.17-2.85 respectively), CHF (OR=1.69, 95% CI: 1.45-1.98) and pulmonary circulation disease (OR=5.65, 95% CI: 4.32-7.39). In addition, OPCABG surgery performed by only quartile 2 physicians retained significance (OR=1.80, 95% CI: 1.29-2.51) for complications. Other quartiles were not statistically different from the highest-volume quartile.

According to Table 4.16 older age (70-79 referent, and 80 and over OR=1.62, 95% CI: 1.45-1.81), female sex (OR=1.43, 95% CI: 1.31-1.57) emergency or urgent admission (OR=1.58, 95% CI: 1.42-1.77 and OR=1.13, 95% CI: 1.01-1.27 respectively), Medicare, Medicaid and other type of insurance (OR=1.47, 95% CI: 1.27-1.71, OR=1.71, 95% CI: 1.31-2.22 and OR=1.49, 95% CI: 1.04-2.13 respectively) were significantly associated with higher in-hospital mortality for patients undergoing CCABG surgery.

CHF, pulmonary circulation disease, Valvular disease, liver disease and cardiogenic shock (OR=2.12, 95% CI: 1.93-2.32, OR=1.67, 95% CI: 1.33-2.08, OR=2.23, 95% CI: 1.48-3.36 and OR=1.82, 95% CI: 1.44-2.29 respectively) were also risk factors for increased mortality. With respect to surgeon-level predictors CCABG operation performed by lower volume surgeons (quartile 2 OR=1.82, 95% CI: 1.34-2.47 and quartile 3 OR=1.51, 95% CI: 1.21-1.90) were significantly associated with higher in-hospital mortality for patients undergoing CCABG surgery. Operations performed by quartile 1 surgeons were marginally significant (OR=1.79, 95% CI: 0.99-3.25).

For CCABG complications, in addition to female sex (OR=1.23, 95% CI: 1.13-1.33), Medicare insurance (OR=1.24, 95% CI: 1.10-1.39), CHF (OR=1.66, 95% CI: 1.53-1.81), pulmonary circulation disease (OR=6.17, 95% CI: 5.36-7.10), liver disease (OR=1.76, 95% CI: 1.21-2.56) and cardiogenic shock (OR=1.58, 95% CI: 1.27-1.97) Hispanic ethnicity (OR=1.41, 95% CI: 1.21-1.65) and Black race (OR=1.20, 95% CI: 1.01-1.44) also emerged as significant patient level-risk factors.

Surgeries performed by physicians in lower CCABG quartiles were also significantly associated with increased odds of complications (quartile 1 OR=1.97, 95% CI: 1.19-3.26, quartile 2 OR=1.43, 95% CI: 1.14-1.80 and quartile 3 OR=1.33, 95% CI: 1.14-1.57).

Hypothesis 1.2

Adjusted results presented in Table 4.17 suggest that there was no significant association between the lowest surgical total CABG volume ($\leq$ 88 procedures) and outcomes measures with OR=1.13, 95% CI: 0.82-1.56 for complications and OR=0.94, 95% CI: 0.63-1.43 for in-hospital mortality. Only patient risk factors achieved statistical significance for both complications and mortality. Specifically, female sex (OR=1.21, 95% CI: 1.13-1.30 for complications and OR=1.34, 95% CI: 1.24-1.44 for mortality), Medicare (OR=1.27, 95% CI: 1.15-1.40 for complications and OR=1.44, 95% CI: 1.26-1.63 for mortality) and Medicaid (OR=1.30, 95% CI: 1.08-1.58 for complications and OR=1.66, 95% CI: 1.32-2.08 for mortality) insurance, CHF (OR=1.68, 95% CI: 1.56-1.81 for complications and OR=2.23, 95% CI: 2.06-2.42 for mortality) pulmonary circulation disease (OR=6.02, 95% CI: 5.32-6.82 for complications and OR=1.68, 95% CI: 1.39-2.04 for mortality) and cardiogenic shock (OR=1.44, 95% CI: 1.18-1.75 for complications and OR=1.90, 95% CI: 1.56-2.31 for mortality) were significantly associated with the increased risk for both outcome measures. In addition, mortality-specific significant risk factors were emergency (OR=1.60, 95% CI: 1.46-1.76) and urgent (OR=1.16, 95% CI: 1.05-1.29) admission, while Black race (OR=1.17, 95% CI: 1.00-1.36) and Hispanic ethnicity (OR=1.20, 95% CI: 1.04-1.38) were significantly associated with increased odds of complications.

Hypothesis 1.3

As table 4.16 presents, cumulative CABG volume was not significantly associated with surgical outcomes.

Hypothesis 2.1

The analyses adjusted for patient characteristics, surgeon board certification and experience and hospital ownership and teaching status showed that low surgical volume in either high volume or low volume hospitals was not significantly associated with in-hospital complications and mortality (Table 4.18).

Hypothesis 2.2

As Table 4.19 displays, analyses adjusted for patient risk factors and hospital characteristics including bed size, total discharges, total CABG volume (expressed in quartiles) and ownership and teaching status did not show any significant association between hospital characteristics and adverse outcomes. Only patient-level risk factors noted in all other analyses had significant association with the outcomes of interest.

TABLE 4.1: Characteristics of Patients Undergoing Any CABG Procedure, Florida Hospital Inpatient Discharge Data 2000 – 2006

			CCABG		OPCABG		
	N	% [a]	n	%	n	%	p-value
Patient Race/Ethnicity							
Black, non-Hispanic	5,752	4.81	4,399	4.63	1,353	5.50	
White, non-	98,623	82.49	79,024	83.21	19,599	79.69	
Hispanic	9,399	7.86	6,898	7.26	2,501	10.17	
Other	3,519	2.94	2,901	3.05	618	2.51	<.0001
Patient Sex							
Male	86,237	72.13	69,213	72.88	17,024	69.22	
Female	33,322	27.87	25,751	27.12	7,571	30.78	<.0001
Patient Age							
30-39	834	0.70	634	0.67	200	0.81	
40-49	7,264	6.08	5,629	5.93	1,635	6.65	
50-59	22,245	18.61	17,647	18.58	4,598	18.69	
60-69	35,966	30.08	28,874	30.41	7,092	28.84	
70-79	40,232	33.65	32,325	34.04	7,907	32.15	
80+	13,018	10.89	9,855	10.38	3,163	12.86	<.0001

TABLE 4.1 (**c**ontinued)

			CCABG		OPCABG		
	N	% [a]	n	%	n	%	p- value
Primary Payer							
Medicare	71,166	59.52	56,715	59.72	14,451	58.76	
Medicaid	3,747	3.13	2,869	3.02	878	3.57	
Commercial insurance	36,510	30.54	29,071	30.61	7,439	30.25	
Self-pay/Charity	5,686	4.76	4,350	4.58	1,336	5.43	
Other	2,450	2.05	1,959	2.06	491	2.00	<.0001
Admission type							
Elective	48,765	40.79	38,468	40.51	10,297	41.87	
Emergency	31,177	26.08	24,142	25.42	7,035	28.60	
Urgent	39,589	33.11	32,329	34.04	7,260	29.52	
Other	28	0.02	25	0.03	3	0.01	<.0001

CCABG=Conventional Coronary Artery Bypass Graft, OPCABG=Off-pump Coronary Artery Bypass Graft, [a]Percentages may not total 100 due to missing values, N=total number of patients, n=on- or off-pump CABG patients

TABLE 4.2: Patient Characteristics by Surgeon Volume

	Surgeon total CABG Volume				
	Quartile 1 (2,729 procs per 7-year study period) (n=57)	Quartile 2 (15,278 procs per 7-year study period) (n=58)	Quartile 3 (37,145 procs per 7-year study period) (n=58)	Quartile 4 (64,417 procs per 7-year study period) (n=57)	p-value
Patient Characteristics					
Age, years, n (%)					
30-39	25(0.92)	116(0.76)	265(0.71)	428(0.66)	
40-49	202(7.43)	981(6.42)	2,275(6.12)	3,806(5.91)	
50-59	575(21.15)	2,932(19.19)	6,945(18.70)	11,793(18.31)	
60-69	849(31.22)	4,554(29.81)	11,010(29.64)	19,553(30.35)	
70-79	801(29.46)	4,997(32.71)	12,416(33.43)	22,018(34.18)	
80+	268(9.82)	1,698(11.11)	4,234(11.40)	6,819(10.59)	<.0001
Sex, n (%)					
Male	1,926(70.83)	10,864(71.11)	26,785(72.11)	46,662(72.44)	
Female	797(29.17)	4,414(28.89)	10,360(27.89)	17,755(27.56)	0.0042
Race/Ethnicity, n (%)					
Black, non-Hispanic	222(8.16)	1,106(7.24)	1,730(4.66)	2,694(4.18)	
White, non-Hispanic	1,871(68.81)	12,190(79.79)	31,632(85.16)	52,930(82.17)	
Hispanic	491(18.06)	1,250(8.18)	2,037(5.48)	5,621(8.73)	
Other	83(3.05)	514(3.36)	1,050(2.83)	1,872(2.91)	
No Response	52(1.91)	218(1.43)	696(1.87)	1,300(2.02)	<.0001

TABLE 4.2 (continued)

	Surgeon total CABG Volume				
	Quartile 1 (2,729 procs per 7-year study period) (n=57)	Quartile 2 (15,278 procs per 7-year study period) (n=58)	Quartile 3 (37,145 procs per 7-year study period) (n=58)	Quartile 4 (64,417 procs per 7-year study period) (n=57)	p-value
Primary Payer, n (%)					
Medicare	1,399(51.45)	8,940(58.52)	22,157(59.65)	38,670(60.03)	
Medicaid	200(7.36)	570(3.73)	1,105(2.97)	1,872(2.91)	
Commercial insurance	758(27.88)	4,462(29.21)	11,131(29.97)	20,159(31.29)	
Self-pay/Charity	266(9.78)	820(5.37)	1,858(5.00)	2,742(4.26)	
Other	96(3.53)	486(3.18)	894(2.41)	974(1.51)	<.0001
Elixhauser Comorbidities, n (%)					
0	236(8.68)	1,377(9.01)	3,399(9.15)	6,148(9.54)	
1	714(26.26)	4,016(26.29)	9,835(26.48)	17,647(27.39)	
2	841(30.82)	4,847(31.73)	11,555(31.11)	20,206(31.37)	
3 or more	935(34.24)	5,038(32.98)	12,356(33.26)	20,416(31.69)	<.0001

Surgeons n= 230, patients n= 119,559, hospitals n=80

TABLE 4.3: Patient Comorbidities, (Elixhauser Comorbidities Based on ICD-9-CM codes) by CABG type

Comorbid conditions			CCABG		OPCABG	
	N	%	n	%	n	%
Individual Comorbidities						
Acquired immune deficiency syndrome	90	0.1	62	0.07	28	0.11
Alcohol abuse	2,252	1.90	1,751	1.84	501	2.04
Deficiency Anemias	14,236	11.53	11,180	11.77	3,056	12.43
Rheumatoid Arthritis	1,315	1.10	1,022	1.08	293	1.19
Chronic blood loss anemia	1,291	1.11	982	1.03	309	1.26
Congestive Heart Failure	22,683	18.95	17,966	18.92	4,717	19.18
Chronic Pulmonary Disease	26,745	22.73	21,085	22.20	5,660	23.01
Depression	2,912	2.40	2,272	2.39	640	2.60
Diabetes mellitus without chronic complications	31,761	26.72	25,640	27.00	6,121	24.89
Diabetes mellitus with chronic complications	5,122	4.24	4,156	4.38	966	3.93
Drug abuse	495	0.40	373	0.39	122	0.50
Hypertension	78,340	65.48	62,521	65.84	15,819	64.32
Hypothyroidism	6,948	5.72	5,533	5.83	1,415	5.75
Liver disease	742	0.60	556	0.59	186	0.76

TABLE 4.3 (continued)

Comorbid conditions			CCABG		OPCABG	
	N	%	n	%	n	%
Lymphoma	320	0.31	247	0.26	73	0.30
Metastatic cancer	192	0.22	144	0.15	48	0.20
Obesity	11,175	9.24	8,914	9.39	2,261	9.19
Paralysis	864	0.80	694	0.73	170	0.69
Peripheral vascular disease	13,396	11.24	10,463	11.02	2,933	11.93
Psychoses	1,049	0.92	848	0.89	201	0.82
Pulmonary circulation disease	2,201	1.91	1,756	1.85	445	1.81
Solid tumor w/out metastasis	1,260	1.00	962	1.01	298	1.21
Valvular disease	14,058	11.65	11,214	11.81	2,844	11.56
Weight loss	811	0.72	613	0.65	198	0.81
Number of Comorbidities						
0	11,160	9.33	8,766	9.23	2,394	9.73
1	32,212	26.94	25,606	26.96	6,606	26.86
2	37,446	31.32	29,816	31.40	7,630	31.02
3 or more	38,741	32.40	30,776	32.41	7,965	32.38

CCABG=Conventional Coronary Artery Bypass Graft, OPCABG=Off-pump Coronary Artery Bypass Graft

TABLE 4.4: Characteristics of Board Certified Thoracic and General Surgeons by CABG Caseload Group

		CABG Caseload Group			
	All	CCABG	OPCABG	PredCCABG	PredOPCABG
Surgeons, total	262	26 (9.9)	14 (5.3)	190 (72.5)	32 (12.2)
County physician located, n, (%)					
Metropolitan	156 (59.5)	15 (57.7)	9 (64.3)	112(59.0)	20(62.5)
Non-metropolitan	75 (28.6)	10(38.5)	3(21.4)	54(28.4)	8(25.0)
Out of state	27(10.3)	1(3.9)	2(14.3)	22 (11.6)	2(6.3)
Years since medical school graduation, mean(SD)	14.77 (10.0)	16.92(10.6)	19.08 (13.0)	14.44 (9.8)	13.27 (9.4)
Years practicing, mean(SD)	15.14 (8.9)	18.79 (8.3)	15.50(10.7)	14.95 (9.0)	13.26 (8.2)
Medical school location, n, (%)					
US	263 (96.6)	26 (9.9)	13 (5.0)	185 (70.6)	29 (11.1)
Foreign	7(2.7)	-	-	4 (1.5)	3 (1.2)
Unknown	2(0.8)	-	1 (0.4)	1 (0.4)	-

CCABG=Conventional Coronary Artery Bypass Graft, OPCABG=Off-pump Coronary Artery Bypass Graft, PredCCABG= Predominantly Conventional Coronary Artery Bypass Graft, PredOPCABG= Predominantly Off-pump Coronary Artery Bypass Graft, SD= standard deviation, surgeons n=262, hospitals n=82

TABLE 4.5: Patient Characteristics by CABG Caseload Group

		n(%) CABG Caseload Group			
	All	CCABG	OPCABG	PredCCABG	PredOPCABG
Surgical procedures,	119,658	186(0.16)	14(0.01)	105,151(87.88)	14,307(11.96)
Patient					
Black, non-	5,739 (4.8)	16 (8.6)	1 (11.3)	4,953 (4.7)	769 (5.4)
White, non-	98,819	139 (74.7)	11 (78.6)	87,412 (83.1)	11,257 (78.7)
Hispanic	9,364 (7.8)	15 (8.0)	1 (7.1)	7,785 (7.4)	1,563 (10.9)
Other	3,477 (2.9)	12 (6.5)	1 (7.1)	3,103 (3.0)	361 (2.5)
No Response	2,259(1.9)	4(2.2)	-	1,898(1.8)	357(2.5)
Patient Sex					
Male	86,279	125 (67.2)	12 (85.7)	75,857 (72.1)	10,285 (71.9)
Female	33,379	61 (32.8)	2 (14.3)	29,294 (27.9)	4,022 (28.1)
Patient Age					
30-39	836 (0.7)	3 (1.6)	1 (7.1)	714 (0.7)	118 (0.8)
40-49	7,279 (6.1)	15 (8.4)	2 (15.4)	6,295 (6.0)	967 (6.8)
50-59	22,208	43 (24.0)	1 (7.7)	19,226 (18.4)	2,938 (20.7)
60-69	35,913	44 (24.6)	7 (53.8)	31,561 (30.2)	4,301 (30.3)
70-79	40,360	60 (33.5)	3 (21.4)	35,784 (34.3)	4,513 (31.8)
80+	12,998(10.9)	17(9.5)	-	11,521(11.0)	1,460(10.3)
Patient Comorbidities					
0	11,327 (9.5)	15 (8.1)	1 (7.1)	9,893 (9.4)	1,418 (9.9)
1	32402 (27.1)	62 (33.3)	5 (35.7)	28496 (27.1)	3839 (26.8)
2	37,464	56 (30.1)	6 (42.9)	32,953 (31.3)	4,449 (31.1)
3 or more	38,465	53 (28.5)	2 (17.3)	33,809 (32.1)	4,601 (32.2)

TABLE 4.5 (continued)

	n(%) CABG Caseload Group				
	All	CCABG	OPCABG	PredCCABG	PredOPCABG
Primary Payer					
Medicare	71,294	102 (54.8)	9 (64.3)	63,199 (60.1)	7,984 (55.9)
Medicaid	3,771 (3.2)	11 (5.9)	1 (7.1)	3,125 (3.0)	634 (4.4)
Commercial	36,525	52 (28.0)	1 (7.1)	31,976 (30.4)	4,496 (31.4)
Self-pay/Charity	5,661 (4.7)	12 (6.5)	2 (14.3)	4,737 (4.5)	910 (6.4)
Other	2,407 (2.0)	9 (4.8)	1 (7.1)	2,114 (2.0)	283 (2.0)

Surgeons n= 262, patients n= 119,658, hospitals n=80

TABLE 4.6: Surgeon Characteristics by CABG Type

			CCABG		OPCABG	
	N	%	n	%	n	%
Surgeon board certification						
ABS	16	6.96	12	6.78	4	7.55
ABTS and ATS	90	39.13	65	36.72	25	47.17
ABTS	124	53.91	100	56.50	24	45.28
Years since medical school graduation						
0-10	49	21.30	35	19.77	14	26.42
11-20	82	35.65	64	36.16	18	33.96
21-30	60	26.09	47	26.55	13	24.53
31+	35	15.22	28	15.82	7	13.21
Unknown	4	1.74	3	1.69	1	1.89
Years practicing						
0-10	28	12.17	19	10.73	9	16.98
11-20	68	29.57	54	30.51	14	26.42
21-30	63	27.39	48	27.12	15	28.30
31+	26	11.30	20	11.30	6	11.32
Unknown	45	19.57	36	20.34	9	16.98
Medical school location						
US	222	96.52	172	97.18	50	94.34
Foreign	7	3.04	4	2.26	3	5.66
Unknown	1	0.43	1	0.56	-	-

CCABG=Conventional Coronary Artery Bypass Graft, OPCABG=Off-pump Coronary Artery Bypass Graft,surgeons n=230, hospitals n=80

TABLE 4.7**:** Number of Hospitals Where Surgeons Practiced

	Surgeons	
Number of Hospitals	n	%
1	79	34.35
2	58	25.22
3	41	17.83
4	26	11.30
5	15	6.52
6	6	2.61
7	4	1.74
8	1	0.43

Surgeons n=230, hospitals n=80

TABLE 4.8: Hospital Characteristics by CABG Type

			CCABG (n=94,964)		OPCABG (n=24,595)		
	N	%	n	%	n	%	P-value
Hospital total CABG volume							
Quartile 1	4,477	3.74	3,734	83.40	743	16.60	
Quartile 2	17,656	14.77	14,191	80.37	3,465	19.63	
Quartile 3	31,679	26.50	22,797	71.96	8,882	28.04	
Quartile 4	65,740	54.99	54,236	82.50	11,504	17.50	<.0001
Teaching status							
Non-teaching	92,016	76.96	72,891	79.22	19,125	20.78	
Teaching	27,541	23.04	22,072	80.14	5,469	19.86	0.0022
Ownership							
Investor-owned	34,334	28.72	28,017	81.60	6,317	18.40	
Not-for-profit	67,571	56.52	51,731	76.56	15,840	23.44	
Public	17,654	14.77	15,216	86.19	2,438	13.81	<.0001
Bed size							
Less than 200	8,183	6.84	6,041	73.82	2,142	26.18	
200-299	15,650	13.09	12,459	79.61	3,191	20.39	
300-399	21,577	18.05	19,623	90.94	1,954	9.06	
400-499	21,297	17.81	14,471	67.95	6,826	32.05	
500+	52,852	44.21	42,370	80.17	10,482	19.83	<.0001

TABLE 4.8 (continued)

Total discharges							
582-13,209	30,619	25.61	24,360	79.56	6,259	20.44	
13,210-29,291	59,098	49.43	47,912	81.07	11,186	18.93	
29,292-52,006	29,842	24.96	22,692	76.04	7,150	23.96	<.0001
Location							
Urban	10,5289	88.06	84,108	79.88	21,181	20.12	
Rural	14,270	11.94	10,856	76.08	3,414	23.92	<.0001

CCABG=Conventional Coronary Artery Bypass Graft, OPCABG=Off-pump Coronary Artery Bypass Graft, hospitals n=80, patients n=119,559

TABLE 4.9: Patient-Level Surgeon Characteristics by Surgeon Volume

	Surgeon Total CABG Volume				
	Quartile 1 (2,729 procs per 7-year study period) (n=57)	Quartile 2 (15,278 procs per 7-year study period) (n=58)	Quartile 3 (37,145 procs per 7-year study period) (n=58)	Quartile 4 (64,417 procs per 7-year study period) (n=57)	p-value
Surgeon Characteristics					
Average surgeon CABG volume, Mean (SD)	11.95(6.92)	44.21(15.20)	93.64(13.11)	164.47(34.37)	<.0001
Average surgeon CCABG volume, Mean, (SD)	7.79(6.21)	37.82(16.25)	74.76(24.65)	130.11(49.01)	<.0001
Average surgeon OPCABG volume, Mean (SD)	4.16(4.65)	6.39(5.52)	18.88(23.49)	34.36(36.85)	<.0001
Patient Workload, n (%)					
Surgeon board certification					
ABS	105(3.86)	1,231(8.06)	-	943(1.46)	
ABS and ABTS	1,150(41.93)	6,758(44.23)	15,126(40.72)	20,260(31.45)	
ATS	1,474(54.21)	7,289(47.71)	22,019(59.28)	43,214(67.08)	<.0001
Years practicing					
0-10	333(12.25)	2,602(17.03)	3,976(10.70)	6,219(9.65)	
11-20	1,074(39.50)	3,290(21.53)	12,727(34.26)	19,018(29.52)	
21-30	232(8.53)	5,283(34.58)	10,319(27.78)	20,622(32.01)	
31+	381(14.01)	1,733(11.34)	3,096(8.33)	4,875(7.57)	
Unknown	699(25.71)	2,370(15.51)	7,027(18.92)	13,683(21.24)	<.0001

TABLE 4.9 (continued)

	Surgeon Total CABG Volume				
	Quartile 1 (2,729 procs per 7-year study period) (n=57)	Quartile 2 (15,278 procs per 7-year study period) (n=58)	Quartile 3 (37,145 procs per 7-year study period) (n=58)	Quartile 4 (64,417 procs per 7-year study period) (n=57)	p-value
Years since medical school graduation					
0-10	1,138(41.85)	4,859(31.80)	5,489(14.78)	7,038(10.93)	
11-20	693(25.49)	3,392(22.20)	17,165(46.21)	27,165(42.17)	
21-30	333(12.25)	4,469(29.25)	10,331(27.81)	22,181(34.43)	
31+	394(14.49)	2,558(16.74)	2,908(7.83)	8,033(12.47)	
Unknown	161(5.92)	-	1,252(3.37)	-	<.0001
Medical school location					
US	2,684(98.34)	14,591(95.50)	35,397(95.29)	63,519(98.61)	
Foreign	45(1.66)	687(4.50)	1,199(3.23)	898(1.39)	
Unknown	-	-	549(1.48)	-	<.0001

CCABG=Conventional Coronary Artery Bypass Graft, OPCABG=Off-pump Coronary Artery Bypass Graft, CABG= total CABG, ABS=American Board of Surgery, ABTS=American Board of Thoracic Surgery, SD= standard deviation, surgeons n=230, patients n=119,559

TABLE 4.10: Patient Characteristics by Hospital Volume

	Hospital Total CABG Volume				
	Quartile 1	Quartile 2	Quartile 3	Quartile 4	p-value
Patient Characteristics					
Age, years, n (%)					
30-39	34 (0.76)	141 (0.80)	232 (0.73)	427 (0.65)	
40-49	234 (5.23)	1314 (7.44)	2059 (6.50)	3656 (5.56)	
50-59	778(17.38)	3652(20.68)	6256(19.75)	11559(17.58)	
60-69	1369(30.58)	5545(31.41)	9685(30.57)	19367(29.46)	
70-79	1538(34.35)	5438(30.80)	10173(32.11)	23080(35.11)	
80+	524(11. 70)	1566(8.87)	3274(10.33)	7651(11.64)	<.0001
Sex, n (%)					
Male	3204(71.57)	12563(71.15)	22934(72.39)	47531(72.30)	
Female	1273(28.43)	5093(28.85)	8745(27.61)	18209(27.70)	0.0110
Race/Ethnicity, n (%)					
Black, non-Hispanic	206(4.60)	1278(7.24)	1774(5.60)	2494(3.79)	
White, non-Hispanic	3885(86.78)	12450(70.51)	25707(81.15)	56575(86.06)	
Hispanic	238(5.32)	3210(18.18)	2580(8.14)	3371(5.13)	
Other	118(2.64)	389(2.20)	943(2.98)	2069(3.15)	
No Response	30(0.67)	329(1.86)	675(2.13)	1231(1.87)	<.0001
Primary Payer, n (%)					
Medicare	2762(61.69)	9686(54.86)	18153(57.30)	40559(61.70)	
Medicaid	128(2.86)	881(4.99)	988(3.12)	1750(2.66)	
Commercial insurance	1321(29.51)	5314(30.10)	10090(31.85)	19784(30.09)	
Self-pay/Charity	140(3.13)	1230(6.97)	1781(5.62)	2535(3.86)	
Other	126(2.81)	545(3.09)	667(2.11)	1112(1.69)	<.0001

TABLE 4.10 (continued)

	Hospital Total CABG Volume				
	Quartile 1	Quartile 2	Quartile 3	Quartile 4	p-value
Elixhauser Comorbidities, n (%)					
0	317(7.08)	1562(8.85)	2696 (8.51)	6585(10.02)	
1	1180 (26.36)	4647(26.32)	8097(25.56)	18287(27.82)	
2	1360(30.38)	5487(31.08)	10100(31.88)	20497(31.18)	
3 or more	1620(36.18)	5960(33.76)	10786(34.05)	20371(30.99)	<.0001
Admission type					
Elective	1985(44.34)	8414(47.66)	12413(39.18)	25952(39.48)	
Eemrgency	1354(30.24)	6198(35.10)	9006(28.43)	14615(22.23)	
Urgent	1138(25.42)	3042(17.23)	10256(32.37)	25151(38.26)	<.0001

Patients n= 119,559, surgeons n=230, hospitals n=80

TABLE 4.11: Patient Characteristics by Surgical Outcomes

	Complications			Mortality		
	Yes (n=3,989)	No (n=11,5580)	p-value	Yes (n=3,103)	No (n=11,6466)	p-value
Patient Characteristics						
Age, years, n (%)						
30-39	21(0.53)	813(0.70)		7(0.23)	827(0.71)	
40-49	175(4.45)	7,089(6.13)		80(2.58)	7,185(6.17)	
50-59	586(14.91)	21,659(18.73)		260(8.38)	21,987(18.88)	
60-69	1,117 (28.43)	34,849(30.14)		643(20.73)	35,323(30.33)	
70-79	1,492 (37.97)	38,740 (33.50)		13,46(43.39)	38,886(33.39)	
80+	538(13.69)	12,480(10.79)	<.0001	766(24.69)	12,252(10.52)	<.0001
Sex, n (%)						
Male	2,655 (67.57)	83,588(72.28)		1,928(62.15)	84,315(72.39)	
Female	1,274 (32.43)	32,052(27.72)	<.0001	1,175(37.85)	32,151(27.61)	<.0001
Race/Ethnicity, n (%)						
Black, non-Hispanic	192(4.89)	5,560(4.81)		158(5.09)	5,594(4.80)	
White, non-Hispanic	3,241 (82.49)	95,382(82.48)		2,509(80.88)	96,114(82.53)	
Hispanic	323 (8.22)	9,076(7.85)		265(8.54)	9,134(7.84)	
Other	107(2.72)	3,412(2.95)		97(3.13)	3,422(2.94)	
No Response	66(1.68)	2,200(1.90)	0.6703	73(2.35)	2,193(1.88)	0.1211

TABLE 4.11 (continued)

	Complications			Mortality		
	Yes (n=3989)	No (n=115580)	p-value	Yes (n=3103)	No (n=116466)	p-value
Primary Payer, n (%)						
Medicare	2,642(67.24)	68,524(59.26)		2,410(77.69)	68,756(59.04)	
Medicaid	141(3.59)	3,606(3.12)		108(3.48)	3,639(3.12)	
Commercial insurance	928(23.62)	35,582(30.77)		453(14.60)	36,057(30.96)	
Self-pay/Charity	137(3.49)	5,549(4.80)		86(2.77)	5,600(4.81)	
Other	81(2.06)	2,369(2.05)	<.0001	45(1.45)	2,405(2.07)	<.0001
Elixhauser Comorbidities, n (%)						
0	508(12.93)	10,652(9.21)		382(12.31)	10,778(9.25)	
1	1,231(31.33)	30,981(26.79)		921(29.69)	31,291(26.87)	
2	1,223(31.13)	36,223(31.33)		950(30.63)	36,496(31.34)	
3 or more	967(24.61)	37,774(32.67)	<.0001	849(27.37)	37,892(32.54)	<.0001

Patients n=119,559, surgeons n=230

TABLE 4.12: Provider Characteristics by Surgical Outcomes

	Complications			Mortality		
	Yes (n=3,929)	No (n=115,630)	p-value	Yes (n=3,103)	No (n=116,466)	p-value
Surgeon Characteristics						
Surgeon CABG volume, n (%)						
Quartile 1	110(2.80)	2,609(2.26)		79(2.55)	2,640(2.27)	
Quartile 2	539(13.72)	14,739(12.75)		445(14.35)	14,833(12.74)	
Quartile 3	1,229(31.28)	35,916(31.06)		935(30.14)	36,210(31.09)	
Quartile 4	2,051(52.20)	62,366(53.93)	0.0208	1,643(52.97)	62,774(53.90)	0.0362
Surgeon CCABG volume, n (%)						
Quartile 1	140 (3.56)	3,335(2.88)		105(3.38)	3,370(2.89)	
Quartile 2	668 (17.00)	18,822(16.28)		539(17.38)	18,951(16.27)	
Quartile 3	1,267 (32.25)	34,017(29.42)		1,009 (32.53)	34,275(29.43)	
Quartile 4	1,854 (47.19)	59,456(51.41)	<.0001	1,449 (46.71)	59,861(51.40)	<.0001
Surgeon OPCABG volume, n (%)						
Quartile 1	264 (6.72)	7,767(6.73)		225 (7.25)	7,806(6.70)	
Quartile 2	986 (25.10)	28,537(24.68)		732 (23.60)	28,791(24.72)	
Quartile 3	911 (23.19)	28,922(25.01)		751 (24.21)	29,082(24.97)	
Quartile 4	1,768 (45.00)	50,404(43.59)	0.0697	1,394 (44.94)	50,778(43.60)	0.1830

TABLE 4.12 (continued)

	Complications			Mortality		
	Yes (n=3929)	No (n=115630)	p-value	Yes (n=3103)	No (n=116466)	p-value
Surgeon board certification, n (%)						
ABS	95(2.42)	2,184(1.89)		87(2.80)	2,192(1.88)	
ABS and ATS	1,451(36.93)	41,833(36.18)		1,129(36.40)	42,155(36.20)	
ATS	2,383(60.65)	71,613(61.93)	0.0277	1,886(60.80)	72,110(61.92)	0.0009
Years since medical school graduation, n (%)						
0-10	630(16.03)	17,894(15.48)		486(15.67)	18,038(15.49)	
11-20	1,482 (37.72)	46,933(40.59)		1,211(39.04)	47,204(40.53)	
21-30	1,265 (32.20)	36,049(31.17)		909(29.30)	36,405(31.26)	
31+	504 (12.83)	13,389(11.59)		462(14.89)	13,431(11.53)	
Unknown	48(1.22)	1,365(1.18)	0.0050	34(1.10)	1,379(1.18)	<.0001
Years practicing, mean(SD)						
0-10	401(10.21)	12,729(11.01)		330(10.64)	12,800(10.99)	
11-20	1,144 (29.12)	34,965(30.24)		963(31.04)	35,146(30.18)	
21-30	1,210 (30.80)	35,246(30.48)		834(26.89)	35,622(30.59)	
31+	408 (10.38)	9,677(8.38)		319(10.28)	9,766(8.39)	
Unknown	766 (19.50)	23,013(19.90)	0.0002	656(21.15)	23,123(19.86)	<.0001
Medical school location, n (%)						
US	3,824(97.33)	11,2367(97.17)		2,993(96.49)	11,3188 (97.19)	
Foreign	87(2.21)	2,742(2.37)		90(2.90)	2,739(2.35)	
Unknown	18(0.46)	531(0.46)	0.8167	19(0.61)	530(0.46)	0.0596

TABLE 4.12 (continued)

	Complications			Mortality		
	Yes (n=3929)	No (n=115630)	p-value	Yes (n=3103)	No (n=116466)	p-value
Hospital Characteristics						
Hospital CABG volume, n (%)						
Quartile 1	152(3.87)	4,325(3.74)		126(4.06)	4351(3.74)	
Quartile 2	516(13.13)	17,150(14.83)		457(14.73)	17,199(14.77)	
Quartile 3	1067(27.16)	30,612(26.47)		806(25.98)	30,873(26.51)	
Quartile 4	2,194 (55.84)	63,546(54.95)	0.0602	1,713(55.22)	64,027(54.98)	0.8451
Teaching hospital, n (%)						
Teaching	960(24.43)	26,581(22.99)		725(23.37)	26,816(23.03)	
Non-teaching	2,969 (75.57)	89,057(77.01)	0.1024	2,377(76.63)	89,639(76.97)	0.8797
Ownership, n (%)						
Non-profit	2,197 (55.92)	65,384(56.54)		1,770(57.06)	65,801(56.50)	
Investor-owned	1,095 (27.87)	33,239(28.74)		878(28.30)	33,456(28.73)	
Public	637(16.21)	17,017(14.72)	0.0296	454(14.64)	17,200(14.77)	0. 8221

CCABG=Conventional Coronary Artery Bypass Graft, OPCABG=Off-pump Coronary Artery Bypass Graft, CABG= total CABG, ABS=American Board of Surgery, ABTS=American Board of Thoracic Surgery, SD= standard deviation, surgeons n=230, patients n=119,559, hospitals n=80.

TABLE 4.13: Unadjusted Associations between Independent Patient Variables and Patient Outcomes

	Complications		Mortality	
	OR	95% CI, p-value	OR	95% CI, p-value
Patient Characteristics				
Age				
30-39	0.67	0.43-1.04, 0.0728	0.25	0.12-0.52, 0.0002
40-49	0.64	0.55-0.75, <.0001	0.32	0.26-0.40, <.0001
50-59	0.70	0.64-0.77, <.0001	0.34	0.30-0.39, <.0001
60-69	0.83	0.77-0.90, <.0001	0.53	0.48-0.58, <.0001
70-79	1		1	
80+	1.12	1.01-1.24, 0.0281	1.81	1.65-1.98, <.0001
Sex				
Male	1		1	
Female	1.25	1.17-1.34, <.0001	1.60	1.49-1.72, <.0001
Race/Ethnicity				
Black, non-Hispanic	1.02	0.88-1.18, 0.8304	1.08	0.92-1.27, 0.3432
Hispanic	1.05	0.93-1.18, 0.4431	1.12	0.98-1.27, 0.0963
Other	0.92	0.76-1.12, 0.4217	1.09	0.88-1.33, 0.4322
White	1		1	
Primary Payer				
Medicare	1		1	
Medicaid	1.01	0.85-1.21, 0.8726	0.85	0.70-1.03, 0.0948
Commercial insurance	0.68	0.63-0.73, <.0001	0.36	0.32-0.40, <.0001
Self-pay/Charity	0.64	0.54-0.76, <.0001	0.44	0.35-0.54, <.0001
Other	0.89	0.71-1.11, 0.2953	0.53	0.400.72, <.0001

TABLE 4.13 (continued)

	Complications		Mortality	
	OR	95% CI, p-value	OR	95% CI, p-value
Elixhauser Comorbidities				
0	1.86	1.67-2.08, <.0001	1.58	1.40-1.79, <.0001
1	1.55	1.43-1.69, <.0001	1.32	1.20-1.45, <.0001
2	1.32	1.21-1.44, <.0001	1.16	1.06-1.28,0.0017
3 and more	1		1	

Patients n=119,559, surgeons n=230

TABLE 4.14: Unadjusted Associations between Independent Provider Variables and Patient Outcomes

	Complications		Mortality	
	Odds Ratio	95% CI, p-value	Odds Ratio	95% CI, p-value
Surgeon Characteristics				
Surgeon CABG volume				
Quartile 1	1.28	1.05-1.55, 0.0142	1.15	0.92-1.45, 0.218
Quartile 2	1.11	1.01-1.23, 0.0312	1.15	1.03-1.28, 0.0118
Quartile 3	1.04	0.97-1.12, 0.2789	0.99	0.91-1.07, 0.7444
Quartile 4	1		1	
Surgeon CCABG volume				
Quartile 1	1.47	1.34-1.62, <.0001	1.30	1.18-1.44, <.0001
Quartile 2	1.34	1.22-1.48, <.0001	1.23	1.10-1.36, 0.0001
Quartile 3	1.38	1.25-1.52, <.0001	1.12	1.01-1.25, 0.0307
Quartile 4	1		1	
Surgeon OPCABG volume				
Quartile 1	0.97	0.85-1.10, 0.6254	1.05	0.91-1.22, 0.4744
Quartile 2	0.99	0.91-1.07, 0.7092	0.93	0.85-1.01, 0.0969
Quartile 3	0.90	0.83-0.97, 0.0094	0.94	0.86-1.03, 0.1821
Quartile 4	1		1	
Surgeon board certification				
ABS	1.31	1.06-1.61, 0.012	1.52	1.22-1.89, 0.0002
ABS and TS	1.04	0.98-1.11, 0.2232	1.03	0.95-1.10, 0.5223
ATS	1		1	
Years since medical school graduation				
0-10	1.11	1.01-1.22, 0.0282	1.05	0.95-1.17, 0.3551
11-20	1		1	
21-30	1.11	1.03-1.20, 0.0081	0.97	0.89-1.06, 0.5565
31+	1.19	1.07-1.32, 0.001	1.35	1.21-1.50, <.0001

TABLE 4.14 (continued)

	Complications		Mortality	
	Odds Ratio	95% CI, p-value	Odds Ratio	95% CI, p-value
Years practicing				
0-10	0.93	0.83-1.04, 0.1844	1.02	0.90-1.15, 0.7911
11-20	0.97	0.90-1.04, 0.3405	1.08	1.00-1.17, 0.0653
21-30	1		1	
31+	1.24	1.11-1.39, <.0001	1.29	1.14-1.46, <.0001
Hospital Characteristics				
Hospital CABG volume				
Quartile 1	1.02	0.86-1.20, 0.8342	1.08	0.90-1.30, 0.397
Quartile 2	0.87	0.79-0.96, 0.0056	1.00	0.90-1.10, 0.9239
Quartile 3	1.01	0.94-1.09, 0.8002	0.98	0.90-1.06, 0.5731
Quartile 4	1		1	
Teaching Status				
Teaching	1.08	1.01-1.17, 0.0341	1.02	0.94-1.11, 0.6558
Non- teaching	1		1	
Ownership				
Investor-owned	0.98	0.91-1.06, 0.5988	0.98	0.90-1.06, 0.5491
Public	1.11	1.02-1.22, 0.0184	0.98	0.88-1.09, 0.7166
Not-for-profit	1		1	

CCABG=Conventional Coronary Artery Bypass Graft, OPCABG=Off-pump Coronary Artery Bypass Graft, CABG= total CABG, ABS=American Board of Surgery, ABTS=American Board of Thoracic Surgery, SD= standard deviation, surgeons n=230, hospitals n=80, patients n=119,559

TABLE 4.15: Predictors of In-Hospital Mortality and Complications Following Off-pump CABG, Multilevel Models

	Complications				Mortality			
Parameters	OR	LB	UB	p-value	OR	LB	UB	p-value
Age								
30-39	0.67	0.29	1.58	0.364	0.65	0.25	1.66	0.370
40-49	0.80	0.56	1.13	0.204	0.31	0.18	0.54	<.0001
50-59	0.84	0.64	1.09	0.188	0.45	0.32	0.64	<.0001
60-69	0.93	0.77	1.12	0.448	0.61	0.49	0.77	<.0001
70-79	1				1			
80+	0.89	0.72	1.10	0.285	1.42	1.17	1.73	<.0001
Race/Ethnicity								
Black, non-Hispanic	1.02	0.75	1.39	0.897	1.33	0.95	1.87	0.100
Hispanic	0.69	0.51	0.92	0.013	1.29	0.96	1.72	0.091
Other	0.84	0.52	1.36	0.478	1.03	0.62	1.73	0.897
White	1				1			
Sex								
Male	1				1			
female	1.12	0.97	1.30	0.125	1.06	0.91	1.25	0.450
Primary Payer								
Medicare	1.39	1.12	1.72	0.003	1.37	1.05	1.78	0.021
Medicaid	1.83	1.27	2.63	0.001	1.48	0.93	2.35	0.095
Commercial insurance	1				1			
Self-pay/Charity	1.16	0.81	1.67	0.411	0.96	0.59	1.56	0.881
Other	1.82	1.17	2.85	0.008	1.31	0.67	2.57	0.433

TABLE 4.15 (continued)

Parameters	Complications				Mortality			
	OR	LB	UB	p-value	OR	LB	UB	p-value
Admission Type								
Elective	1				1			
Emergency	0.76	0.64	0.90	0.002	1.63	1.34	1.97	<.0001
Urgent	0.67	0.56	0.81	<.0001	1.21	0.99	1.49	0.069
Elixhauser Comorbidities								
CHF	1.69	1.45	1.98	<.0001	2.62	2.23	3.09	<.0001
Chronic Pulmonary Disease	0.96	0.81	1.12	0.573	1.02	0.86	1.22	0.806
Diabetes w/ Chronic Complications	0.47	0.39	0.58	<.0001	0.47	0.37	0.60	<.0001
Hypertension	0.37	0.32	0.42	<.0001	0.39	0.33	0.46	<.0001
Pulmonary circulation disease	5.65	4.32	7.39	<.0001	1.71	1.16	2.51	0.007
Valvular disease	0.96	0.79	1.17	0.682	1.37	1.13	1.66	0.002
Liver disease	0.26	0.06	1.05	0.058	1.27	0.55	2.93	0.583
Clinical History								
Cardiogenic Shock	1.05	0.68	1.61	0.839	2.14	1.46	3.13	<.0001
Previous CABG	0.48	0.22	1.02	0.057	0.58	0.25	1.32	0.193
Surgeon Total CABG Volume								
Quartile 1	1.32	0.66	2.65	0.428	0.56	0.25	1.25	0.159
Quartile 2	1.15	0.73	1.80	0.542	0.98	0.60	1.58	0.923
Quartile 3	1.05	0.78	1.42	0.741	0.75	0.54	1.04	0.088
Quartile 4	1				1			

TABLE 4.15 (continued)

Parameters	Complications				Mortality			
	OR	LB	UB	p-value	OR	LB	UB	p-value
Surgeon CCABG Volume								
Quartile 1	1.10	0.62	1.93	0.753	1.05	0.56	1.96	0.874
Quartile 2	0.90	0.65	1.24	0.509	0.70	0.49	1.01	0.058
Quartile 3	1.11	0.82	1.49	0.503	1.04	0.75	1.45	0.813
Quartile 4	1				1			
Surgeon OPCABG Volume								
Quartile 1	1.38	0.73	2.60	0.319	3.05	1.68	5.53	<.0001
Quartile 2	1.73	1.24	2.40	0.001	1.57	1.10	2.26	0.014
Quartile 3	0.85	0.64	1.14	0.277	1.35	1.01	1.81	0.043
Quartile 4	1				1			
Surgeon board certification								
ABS	0.85	0.44	1.63	0.625	1.17	0.61	2.27	0.635
ABS and TS	1.10	0.91	1.34	0.332	1.07	0.86	1.33	0.541
ABTS	1				1			
Years practicing								
0-10	0.90	0.65	1.23	0.506	0.86	0.60	1.22	0.393
11-20	0.92	0.74	1.15	0.463	1.11	0.88	1.40	0.377
21-30	1				1			
31+	1.25	0.86	1.82	0.240	1.20	0.80	1.81	0.375

TABLE 4.15 (continued)

Parameters	Complications				Mortality			
	OR	LB	UB	p-value	OR	LB	UB	p-value
Hospital CABG volume								
Quartile 1	1.19	0.72	1.98	0.489	1.46	0.91	2.36	0.118
Quartile 2	0.91	0.64	1.30	0.609	0.86	0.61	1.21	0.401
Quartile 3	0.85	0.63	1.14	0.284	0.79	0.61	1.03	0.085
Quartile 4	1				1			
Hospital Bed Size								
Less than 200	1.02	0.51	2.05	0.955	0.94	0.48	1.86	0.864
200-299	0.88	0.48	1.61	0.671	1.02	0.56	1.87	0.939
300-399	0.77	0.48	1.26	0.304	0.54	0.33	0.87	0.011
400-499	1.13	0.80	1.61	0.479	0.88	0.64	1.20	0.426
500+	1				1			
Hospital Ownership								
Investor-owned	1.22	0.85	1.75	0.272	0.95	0.68	1.34	0.772
Public	1.30	0.89	1.89	0.170	1.51	1.08	2.11	0.017
Not-for-profit	1				1			
Hospital Teaching Status								
Teaching	1.27	0.92	1.76	0.149	1.16	0.88	1.54	0.290
Non-teaching	1				1			
Total discharges								
582-13,209	0.94	0.53	1.67	0.821	1.16	0.66	2.04	0.611
13,210-29,291	0.88	0.63	1.24	0.472	1.35	1.00	1.81	0.052
29,292-52,006	1				1			

Surgeons n=222, hospitals n=80, patients n= 119,403

TABLE 4.16: Predictors of In-Hospital Mortality and Complications Following On-pump CABG, Multilevel Models

	Complications				Mortality			
Parameters	OR	LB	UB	p-value	OR	LB	UB	p-value
Age								
30-39	0.70	0.41	1.18	0.180	0.05	0.01	0.38	0.003
40-49	0.72	0.58	0.89	0.002	0.42	0.32	0.56	<.0001
50-59	0.85	0.74	0.98	0.030	0.45	0.37	0.55	<.0001
60-69	0.95	0.86	1.05	0.281	0.64	0.57	0.72	<.0001
70-79	1				1			
80+	1.04	0.92	1.18	0.494	1.62	1.45	1.81	<.0001
Race/Ethnicity								
Black, non-Hispanic	1.20	1.01	1.44	0.044	1.22	0.99	1.49	0.057
Hispanic	1.41	1.21	1.65	<.0001	1.06	0.88	1.27	0.567
Other	1.11	0.89	1.39	0.363	1.28	1.01	1.62	0.045
White	1				1			
Sex								
Male	1				1			
female	1.23	1.13	1.33	<.0001	1.43	1.31	1.57	<.0001
Primary Payer								
Medicare	1.24	1.10	1.39	<.0001	1.47	1.27	1.71	<.0001
Medicaid	1.16	0.92	1.45	0.203	1.71	1.31	2.22	<.0001
Commercial insurance	1				1			
Self-pay/Charity	0.80	0.64	1.01	0.056	1.04	0.78	1.38	0.776
Other	1.11	0.83	1.48	0.477	1.49	1.04	2.13	0.030

TABLE 4.16 (continued)

	Complications				Mortality			
Parameters	OR	LB	UB	p-value	OR	LB	UB	p-value
Admission Type								
Elective	1				1			
Emergency	0.96	0.88	1.06	0.465	1.58	1.42	1.77	<.0001
Urgent	0.78	0.71	0.87	<.0001	1.13	1.01	1.27	0.031
Elixhauser Comorbidities								
CHF	1.66	1.53	1.81	<.0001	2.12	1.93	2.32	<.0001
Chronic Pulmonary Disease	0.98	0.89	1.07	0.616	0.97	0.88	1.07	0.523
Diabetes w/ Chronic Complications	0.57	0.51	0.63	<.0001	0.61	0.54	0.68	<.0001
Hypertension	0.39	0.36	0.42	<.0001	0.40	0.37	0.44	<.0001
Pulmonary circulation disease	6.17	5.36	7.10	<.0001	1.67	1.33	2.08	<.0001
Valvular disease	0.88	0.79	0.98	0.020	1.34	1.20	1.49	<.0001
Liver disease	1.76	1.21	2.56	0.003	2.23	1.48	3.36	<.0001
Clinical History								
Cardiogenic Shock	1.58	1.27	1.97	<.0001	1.82	1.44	2.29	<.0001
Previous CABG	0.79	0.56	1.10	0.161	1.05	0.75	1.48	0.759
Surgeon Total CABG Volume								
Quartile 1	0.64	0.38	1.08	0.096	0.69	0.37	1.27	0.227
Quartile 2	0.83	0.64	1.08	0.166	0.67	0.47	0.95	0.026
Quartile 3	0.90	0.76	1.07	0.246	0.85	0.67	1.08	0.176
Quartile 4	1				1			

TABLE 4.16 (continued)

Parameters	Complications				Mortality			
	OR	LB	UB	p-value	OR	LB	UB	p-value
Surgeon CCABG Volume								
Quartile 1	1.97	1.19	3.26	0.008	1.79	0.99	3.25	0.056
Quartile 2	1.43	1.14	1.80	0.002	1.82	1.34	2.47	<.0001
Quartile 3	1.33	1.14	1.57	<.0001	1.51	1.21	1.90	<.0001
Quartile 4	1				1			
Surgeon OPCABG Volume								
Quartile 1	0.97	0.77	1.23	0.805	0.96	0.71	1.30	0.795
Quartile 2	1.00	0.85	1.18	0.952	0.83	0.67	1.03	0.098
Quartile 3	0.88	0.76	1.02	0.082	0.89	0.74	1.09	0.266
Quartile 4	1				1			
Surgeon board certification								
ABS	1.20	0.88	1.64	0.253	1.34	0.87	2.05	0.189
ABS and TS	1.01	0.91	1.13	0.821	0.96	0.82	1.11	0.560
ABTS	1				1			
Years practicing								
0-10	1.01	0.86	1.18	0.951	1.09	0.87	1.36	0.459
11-20	1.03	0.92	1.16	0.595	1.12	0.96	1.32	0.160
21-30	1				1			
31+	1.00	0.83	1.19	0.962	1.20	0.93	1.55	0.158

TABLE 4.16 (continued)

	Complications				Mortality			
Parameters	OR	LB	UB	p-value	OR	LB	UB	p-value
Hospital CABG volume								
Quartile 1	1.04	0.76	1.44	0.795	0.92	0.66	1.30	0.652
Quartile 2	0.77	0.60	1.00	0.054	1.04	0.81	1.33	0.745
Quartile 3	1.01	0.80	1.28	0.919	0.92	0.73	1.14	0.441
Quartile 4	1				1			
Hospital Bed Size								
Less than 200	0.76	0.46	1.26	0.288	1.07	0.66	1.75	0.786
200-299	0.95	0.63	1.44	0.827	0.93	0.62	1.41	0.746
300-399	1.01	0.73	1.39	0.976	0.81	0.59	1.10	0.180
400-499	1.04	0.78	1.39	0.801	1.05	0.80	1.38	0.703
500+	1				1			
Hospital Ownership								
Investor-owned	1.01	0.79	1.29	0.938	0.85	0.67	1.08	0.184
Public	1.16	0.87	1.56	0.312	1.05	0.80	1.39	0.719
Not-for-profit	1				1			
Hospital Teaching Status								
Teaching	1.19	0.91	1.55	0.202	1.00	0.78	1.28	0.998
Non-teaching	1				1			
Total discharges								
582-13,209	1.12	0.74	1.70	0.596	1.23	0.82	1.83	0.315
13,210-29,291	0.96	0.71	1.29	0.793	1.18	0.89	1.55	0.247
29,292-52,006	1				1			

Surgeons n=222, hospitals n=80, patients n= 119,403

TABLE 4.17: Predictors of In-Hospital Mortality and Complications, Lowest Volume Surgeons, Multilevel Models

	Complications				Mortality			
Parameters	OR	LB	UB	p-value	OR	LB	UB	p-value
Age								
30-39	0.68	0.44	1.07	0.097	0.22	0.10	0.50	<.0001
40-49	0.74	0.62	0.89	0.001	0.39	0.30	0.50	<.0001
50-59	0.84	0.74	0.96	0.009	0.45	0.38	0.53	<.0001
60-69	0.94	0.86	1.03	0.161	0.63	0.56	0.70	<.0001
70-79	1				1			
80+	1.01	0.91	1.13	0.804	1.57	1.43	1.73	<.0001
Race/Ethnicity								
Black, non-Hispanic	1.17	1.00	1.36	0.053	1.27	1.07	1.51	0.007
Hispanic	1.20	1.04	1.38	0.012	1.10	0.94	1.29	0.245
Other	1.03	0.85	1.27	0.743	1.23	0.99	1.52	0.063
White	1				1			
Sex								
Male	1				1			
female	1.21	1.13	1.30	<.0001	1.34	1.24	1.44	<.0001
Primary Payer								
Medicare	1.27	1.15	1.40	<.0001	1.44	1.26	1.63	<.0001
Medicaid	1.30	1.08	1.58	0.007	1.66	1.32	2.08	<.0001
Commercial insurance	1				1			
Self-pay/Charity	0.88	0.73	1.06	0.186	1.03	0.81	1.32	0.781
Other	1.26	0.99	1.61	0.058	1.45	1.06	1.99	0.020

TABLE 4.17 (continued)

	Complications				Mortality			
Parameters	OR	LB	UB	p-value	OR	LB	UB	p-value
Admission Type								
Elective	1				1			
Emergency	0.91	0.83	0.98	0.020	1.60	1.46	1.76	<.0001
Urgent	0.76	0.69	0.82	<.0001	1.16	1.05	1.29	0.003
Elixhauser Comorbidities								
CHF	1.68	1.56	1.81	<.0001	2.23	2.06	2.42	<.0001
Chronic Pulmonary Disease	0.97	0.90	1.05	0.461	0.98	0.90	1.07	0.650
Diabetes w/ Chronic Complications	0.54	0.50	0.60	<.0001	0.57	0.52	0.64	<.0001
Hypertension	0.38	0.36	0.41	<.0001	0.39	0.37	0.43	<.0001
Pulmonary circulation disease	6.02	5.32	6.82	<.0001	1.68	1.39	2.04	<.0001
Valvular disease	0.89	0.81	0.98	0.021	1.36	1.24	1.50	<.0001
Liver disease	1.32	0.92	1.89	0.133	1.96	1.36	2.83	<.0001
Clinical History								
Cardiogenic Shock	1.44	1.18	1.75	<.0001	1.90	1.56	2.31	<.0001
Previous CABG	0.72	0.53	0.97	0.033	0.94	0.69	1.29	0.704
Surgeon Total CABG Volume								
≥88 procedures	1				1			
≤ 88 procedures	1.13	0.82	1.56	0.457	0.94	0.63	1.43	0.785

TABLE 4.17 (continued)

	Complications				Mortality			
Parameters	OR	LB	UB	p-value	OR	LB	UB	p-value
Surgeon board certification								
ABS	1.19	0.89	1.58	0.244	1.31	0.91	1.89	0.146
ABS and TS	1.02	0.92	1.12	0.722	1.00	0.87	1.14	0.941
ABTS	1				1			
Years practicing								
0-10	0.96	0.82	1.11	0.560	1.06	0.87	1.29	0.551
11-20	1.00	0.89	1.11	0.964	1.10	0.95	1.27	0.195
21-30	1				1			
31+	1.05	0.89	1.24	0.572	1.14	0.91	1.43	0.247
Hospital CABG volume								
Quartile 1	1.14	0.84	1.55	0.398	1.10	0.81	1.49	0.530
Quartile 2	0.85	0.66	1.10	0.214	1.09	0.87	1.37	0.457
Quartile 3	1.01	0.80	1.28	0.924	0.97	0.79	1.20	0.785
Quartile 4	1				1			
Hospital Bed Size								
Less than 200	0.84	0.51	1.37	0.477	1.08	0.68	1.71	0.748
200-299	0.94	0.63	1.42	0.776	1.00	0.68	1.46	0.982
300-399	0.94	0.68	1.30	0.719	0.78	0.58	1.05	0.098
400-499	1.05	0.79	1.39	0.741	1.01	0.79	1.30	0.931
500+	1				1			

TABLE 4.17 (continued)

Parameters	Complications				Mortality			
	OR	LB	UB	p-value	OR	LB	UB	p-value
Hospital Ownership								
Investor-owned	1.07	0.84	1.36	0.582	0.89	0.71	1.11	0.310
Public	1.18	0.88	1.57	0.269	1.09	0.84	1.42	0.500
Not-for-profit	1				1			
Hospital Teaching Status								
Teaching	1.22	0.94	1.58	0.132	1.08	0.86	1.36	0.526
Non-teaching	1				1			
Total discharges								
582-13,209	1.03	0.69	1.55	0.881	1.15	0.79	1.67	0.478
13,210-29,291	0.89	0.67	1.19	0.432	1.13	0.88	1.46	0.345
29,292-52,006	1				1			

Surgeons n=44, patients n=1,248, CCABG procedures n=946 , OPCABG procedures n= 302, hospitals n=31

TABLE 4.18: Association of Low-volume Surgeon Practice in Low- or High-volume Hospitals and In-hospital Mortality and Complications, Multilevel Models

	Complications				Mortality			
Parameters	OR	LB	UB	p-value	OR	LB	UB	p-value
Age								
30-39	0.68	0.44	1.07	0.098	0.22	0.10	0.50	<.0001
40-49	0.74	0.62	0.89	0.001	0.39	0.30	0.50	<.0001
50-59	0.84	0.74	0.96	0.008	0.45	0.38	0.53	<.0001
60-69	0.94	0.86	1.03	0.158	0.63	0.56	0.70	<.0001
70-79	1				1			
80+	1.01	0.91	1.13	0.801	1.58	1.43	1.73	<.0001
Race/Ethnicity								
Black, non-Hispanic	1.16	0.99	1.36	0.061	1.28	1.07	1.52	0.005
Hispanic	1.19	1.03	1.36	0.014	1.11	0.95	1.30	0.178
Other	1.03	0.84	1.26	0.749	1.23	0.99	1.53	0.058
White	1				1			
Sex								
Male	1				1			
female	1.21	1.13	1.30	<.0001	1.33	1.24	1.44	<.0001
Primary Payer								
Medicare	1.27	1.14	1.40	<.0001	1.43	1.26	1.63	<.0001
Medicaid	1.30	1.07	1.58	0.007	1.66	1.32	2.09	<.0001
Commercial insurance	1				1			
Self-pay/Charity	0.88	0.73	1.06	0.179	1.04	0.81	1.32	0.763
Other	1.26	0.99	1.60	0.058	1.45	1.06	1.99	0.021

TABLE 4.18 (continued)

Parameters	Complications				Mortality			
	OR	LB	UB	p-value	OR	LB	UB	p-value
Admission Type								
Elective	1				1			
Emergency	0.91	0.83	0.99	0.022	1.60	1.46	1.76	<.0001
Urgent	0.76	0.69	0.83	<.0001	1.16	1.05	1.29	0.003
Elixhauser Comorbidities								
CHF	1.68	1.56	1.81	<.0001	2.23	2.06	2.42	<.0001
Chronic Pulmonary Disease	0.97	0.90	1.05	0.470	0.98	0.90	1.07	0.650
Diabetes w/ Chronic Complications	0.54	0.50	0.60	<.0001	0.57	0.52	0.64	<.0001
Hypertension	0.38	0.36	0.41	<.0001	0.39	0.37	0.43	<.0001
Pulmonary circulation disease	6.01	5.31	6.80	<.0001	1.68	1.39	2.04	<.0001
Valvular disease	0.89	0.81	0.98	0.022	1.36	1.24	1.50	<.0001
Liver disease	1.31	0.91	1.88	0.140	1.96	1.36	2.83	<.0001
Clinical History								
Cardiogenic Shock	1.44	1.19	1.75	<.0001	1.90	1.56	2.31	<.0001
Previous CABG	0.72	0.53	0.97	0.033	0.94	0.69	1.29	0.704
Surgeon/Hospital Volume								
LVMD/HVH	1.48	0.85	2.58	0.163	1.69	0.86	3.31	0.125
LVMD/LVH	1.04	0.56	1.95	0.894	0.87	0.38	2.01	0.748

TABLE 4.18 (continued)

Parameters	Complications				Mortality			
	OR	LB	UB	p-value	OR	LB	UB	p-value
Surgeon board certification								
ABS	1.21	0.91	1.61	0.187	1.36	0.95	1.95	0.098
ABS and TS	1.02	0.93	1.13	0.672	1.01	0.89	1.15	0.850
ABTS	1				1			
Years practicing								
0-10	0.95	0.82	1.11	0.523	1.04	0.86	1.27	0.662
11-20	1.00	0.90	1.12	0.974	1.08	0.94	1.25	0.259
21-30	1				1			
31+	1.06	0.90	1.25	0.514	1.10	0.88	1.36	0.414
Hospital Ownership								
Investor-owned	1.03	0.85	1.25	0.728	0.93	0.77	1.12	0.457
Public	1.21	0.94	1.57	0.145	1.03	0.80	1.33	0.820
Not-for-profit	1				1			
Hospital Teaching Status								
Teaching	1.16	0.93	1.46	0.195	1.14	0.91	1.42	0.250
Non-teaching	1				1			

Surgeons n=230, LVMD/HVH= Low Volume MD/High Volume Hospital, LVMD/LVH =Low Volume MD/Low Volume Hospital

TABLE 4.19: Association of Hospital Characteristics and In-Hospital Mortality and Complications, Multilevel Models

	Complications				Mortality			
Parameters	OR	LB	UB	p-value	OR	LB	UB	p-value
Age								
30-39	0.68	0.44	1.07	0.096	0.22	0.10	0.50	<.0001
40-49	0.74	0.62	0.89	0.001	0.39	0.30	0.50	<.0001
50-59	0.84	0.74	0.96	0.008	0.45	0.38	0.53	<.0001
60-69	0.94	0.86	1.03	0.161	0.63	0.56	0.70	<.0001
70-79	1				1			
80+	1.01	0.91	1.13	0.801	1.57	1.43	1.73	<.0001
Race/Ethnicity								
Black, non-Hispanic	1.17	1.00	1.36	0.052	1.27	1.07	1.51	0.007
Hispanic	1.20	1.04	1.38	0.012	1.10	0.94	1.29	0.236
Other	1.03	0.84	1.26	0.754	1.23	0.99	1.52	0.064
White	1				1			
Sex								
Male	1				1			
female	1.21	1.13	1.30	<.0001	1.34	1.24	1.44	<.0001
Primary Payer								
Medicare	1.27	1.15	1.40	<.0001	1.43	1.26	1.63	<.0001
Medicaid	1.30	1.08	1.58	0.007	1.66	1.32	2.08	<.0001
Commercial insurance	1				1			
Self-pay/Charity	0.88	0.73	1.06	0.186	1.03	0.81	1.32	0.792
Other	1.26	0.99	1.61	0.057	1.46	1.06	2.00	0.019

TABLE 4.19 (continued)

Parameters	Complications OR	Complications LB	Complications UB	Complications p-value	Mortality OR	Mortality LB	Mortality UB	Mortality p-value
Admission Type								
Elective	1				1			
Emergency	0.90	0.83	0.98	0.019	1.60	1.46	1.76	<.0001
Urgent	0.75	0.69	0.82	<.0001	1.16	1.05	1.28	0.003
Elixhauser Comorbidities								
CHF	1.68	1.56	1.81	<.0001	2.23	2.06	2.42	<.0001
Chronic Pulmonary Disease	0.97	0.90	1.05	0.471	0.98	0.90	1.07	0.657
Diabetes w/ Chronic Complications	0.54	0.50	0.60	<.0001	0.57	0.52	0.64	<.0001
Hypertension	0.38	0.36	0.41	<.0001	0.39	0.37	0.43	<.0001
Pulmonary circulation disease	6.01	5.31	6.81	<.0001	1.68	1.39	2.04	<.0001
Valvular disease	0.89	0.81	0.98	0.021	1.36	1.24	1.50	<.0001
Liver disease	1.31	0.92	1.88	0.136	1.95	1.36	2.82	<.0001
Clinical History								
Cardiogenic Shock	1.44	1.18	1.75	<.0001	1.90	1.56	2.31	<.0001
Previous CABG	0.72	0.53	0.97	0.033	0.94	0.69	1.29	0.707
Hospital CABG volume								
Quartile 1	1.14	0.84	1.55	0.397	1.11	0.82	1.50	0.502
Quartile 2	0.85	0.66	1.09	0.193	1.07	0.86	1.34	0.543
Quartile 3	1.02	0.80	1.29	0.892	0.97	0.79	1.20	0.798
Quartile 4	1				1			

TABLE 4.19 (continued)

	Complications				Mortality			
Parameters	OR	LB	UB	p-value	OR	LB	UB	p-value
Hospital Bed Size								
Less than 200	0.84	0.51	1.38	0.498	1.04	0.66	1.64	0.871
200-299	0.94	0.63	1.42	0.779	0.99	0.68	1.45	0.976
300-399	0.94	0.68	1.29	0.695	0.78	0.58	1.05	0.098
400-499	1.04	0.78	1.39	0.771	1.01	0.79	1.30	0.941
500+	1				1			
Hospital Ownership								
Investor-owned	1.07	0.84	1.36	0.585	0.90	0.72	1.12	0.343
Public	1.17	0.88	1.57	0.275	1.08	0.84	1.40	0.542
Not-for-profit	1				1			
Hospital Teaching Status								
Teaching	1.24	0.95	1.60	0.108	1.08	0.86	1.36	0.495
Non-teaching	1				1			
Total discharges								
582-13,209	1.03	0.68	1.55	0.882	1.16	0.80	1.68	0.436
13,210-29,291	0.88	0.66	1.18	0.409	1.13	0.88	1.46	0.332
29,292-52,006	1				1			

Surgeons n=230

CHAPTER 5: DISCUSSION

Overall Findings

This retrospective, cross-sectional study investigated the effect of surgeon volume and specialization on patient outcomes after CABG using 2000-2006 Florida hospital discharge data.

Two research objectives and five hypotheses guided this research. First objective was to explore the relationship between specific CABG procedures (on-pump and off-pump), specialty training and in-hospital mortality and complications. Hypothesis $H_{1.1}$ under this objective was that higher volume of OPCABG and/or CCABG and specialized surgical training (thoracic surgery vs. general surgery) would lead to better outcomes. The results supported this hypothesis. For both OPCABG and CCABG lower volume was associated with increased odds of complications and mortality. In unadjusted analysis, patients operated on by ABS certified surgeons had higher odds of complications and mortality. However, this finding did not retain the level of significance after adjusting for patient, surgeon and hospital characteristics. These results support the findings of other studies which suggest that the surgeon's experience and competence with performing a specific CABG technique is a key for successful surgery.[147] This is especially true about off-pump CABG which is technically more challenging. According to Dr. John Puskas, an associate professor of surgery at Emory University School of Medicine in Atlanta, Georgia, "it takes the most experienced cardiac surgeons between

50 and 100 cases before they are very comfortable with the off-pump technique."[147] A study, which examined short- and long-term outcomes for 59,044 patients undergoing on-pump CABG and 9,135 undergoing off-pump CABG between 1997 and 2000 in New York State, also suggested that surgeon experience could be a factor in improved outcomes.[148]

Another study hypothesis related to surgeon volume ($H_{1.2}$) was that the lowest volume of CABG procedures would lead to markedly worse outcomes. This hypothesis, however, was not supported by the study findings. A systematic review of literature by Halm et al[2] suggested that surgeons with the lowest volume had worse results compared with providers in other volume categories. However, the cut-point for this volume threshold was much lower (≤1 per year) compared to the cut-point selected for this study (≤88 procedures per 7 years). The same research also suggested that formal statistical analysis to confirm this finding was often lacking.[2]

Hypothesis stating that cumulative surgical volume would be a better indicator for improved outcomes ($H_{1.3}$) was not supported. However, it is important to note that the nature and design of this study did not allow to fully evaluate the effect of the different measures of volume on outcomes. Total CABG volume (all CABG cases for 7 years of data) was already a snapshot of surgical experience as the study design was cross-sectional. Longitudinal analysis and more detailed information of surgical experience will be needed to conduct a complete analysis and test this hypothesis, particularly with regard to cumulative volume. This gap has been also noted by other studies, which recommend more careful examination whether cumulative surgeon volume occurring over many years is a more appropriate volume measure and whether annual surgeon volume is equally important in determining quality of care for surgeons with many years of experience versus less experienced surgeons.[149]

In general, little is known about mechanisms underlying variation in surgeon performance[150] although the role of hospital-procedure and surgeon-procedure volumes on CABG outcomes have been investigated by numerous studies to better define whether procedure volume effects are surgeon or institutional in origin.[149] In addition, studies have also examined the relationship between surgeon age and adverse surgical outcomes. Although surgeon age was not available for the analysis in the present study, information on surgeon's experience expressed as years in practice may be considered as a proxy for age. As seen in the byvariate analysis in the present study, surgeons at two extremes of experience (0-10 and 31+ years in practice) had higher mortality rates. This finding is supported by Waljee et al who have found that surgeons over 60 years had higher mortality rates with pancreatectomy, coronary artery bypass grafting and carotid endarterectomy.[150] One explanation for these results is that older surgeons may have diminished fine motor skills, visual acuity and other important competencies, including less familiarity with new operative techniques and technologies.[150] It is important to note, however, that in the present study the effect of surgeon experience did not persist after controlling for other surgeon and hospital characteristics. It is possible that older surgeons make some practice modifications to compensate for the above listed disadvantages; for example, they may begin to restrict their practices to less risky patients, thus accruing less volume.

Another important factor related to surgeon experience is the role of specialization. Younger surgeons become much more specialized through fellowship and other training opportunities, which may affect the outcomes. So, there may be an important modification to “practice makes perfect” hypothesis – there is a new argument that not just practice but “perfect practice makes ”.[150] This trend of targeted specialization is particularly noticeable in the field of thoracic surgery, one of the most specialized subsets of surgery.[66] So, for future research it would be useful to evaluate this information as well not to rely heavily on surgical volume because volume is endogenous to specialization to some extent and it is therefore not possible to fully disentangle its effect from the relationship between specialization and outcomes.[20]

Two hypothesized expectations involving hospital volume were not supported by the present study. Hypothesis 2.1 stated that lower volume surgeons in high volume hospitals would have a better outcome. Thus, the expectation was that hospital volume and some unmeasured institutional factors (more specialized staff, availability of advanced technology, etc.) would safeguard low volume surgeons from poor outcomes. However, in the light of other studies, the fact that this hypothesis was not supported is not surprising. Hospital procedure volume has been found to be only modestly associated with CABG outcomes in the study by Peterson et al.[45] A very interesting study was conducted by Zacharias et al[149] where they selected a team of high volume surgeons serving at two very different centers – one high procedure volume, long-established urban hospital meeting the Leapfrog Group volume criteria and the other small, suburban, low-volume community hospital. Interestingly, the study demonstrated that when served by the same high volume surgeons, similar CABG operative and midterm (3-year) outcomes could be achieved in the selected high- and low-volume institutions.[149]

The same study is also relevant to shed light on another hospital-volume related hypothesis in the present study. It was postulated that larger hospitals, with more total discharges would have better outcomes. The attempt was to measure the effect of some institutional attributes that may explain surgical outcomes. Although this hypothesis was not supported, it reinforces the notion that more detailed information is needed to address this question. In the study conducted by Zacharias et al[149] two selected hospitals had committed substantial resources including dedicated personnel, cardiovascular anesthesia, operating rooms, intensive care and step down units. In addition, nursing and surgical assistant teams were similarly trained with equivalent operational guidelines.[149] Therefore, based on this study, it is not possible to draw any conclusions whether similar operative and midterm (3-year) outcomes would have been achievable in the high- and low-volume centers had these characteristics been different. These organizational factors are critically important in performing a successful surgery. It is particularly true about cardiac surgery, which requires a team of experts, participation by a wide array of skilled individuals and involvement with complex specialized physical resources.[66] These unmeasured differences may also be contributing to conflicting evidence about the importance of hospital volume. For example, Hannan et al[151] and Wu and colleagues[152] reported that high-volume hospitals have lower in-hospital mortality and the benefits persist for both low-risk and moderate-to-high-risk CABG.[152]

One interesting hospital-related finding in the current study is higher odds of surgical complications and mortality in the teaching hospitals. Although higher CABG volume, as well as best practices for the management of coronary artery disease, such as use of angiotensin-converting enzyme inhibitors, aspirin and β-blockers, is more common at teaching hospitals[153, 154] patients in teaching hospitals did not have lower risk of adverse outcomes. This may be due to unmeasured illness severity as it has been reported that patients with more disease severity are more likely to seek care at teaching hospitals.[155] Thus, quality of care available at teaching hospitals may be attenuated due to incomplete risk adjustment.

Overall, for all hypotheses the results suggested that patient risks factors are strong predictors of CABG outcomes. Patient risk factors associated with in-hospital mortality and complications included greater age, female sex, emergency or urgent admission, sevaral comorbid conditions and cardiogenic shock.

Existing research provides strong support for these findings. Studies have found that advanced age is the most significant independent correlate of complications and death in general[125] but specifically for CABG, age is also widely recognized as a major risk factor for coronary artery disease.[122] In older patients the response to perioperative stress is reduced due to decrease in heart rate and increase in stroke volume for any given cardiac output, the volumes of the heart chambers tend to enlarge, for both systole and diastole, leading to reduction in left ventricular ejection fraction,[122] one of the most significant predictors of adverse outcomes after CABG surgery.

Although the influence of gender on the risk of coronary artery disease is currently under investigation, it is well-documented that female gender is a risk factor for surgical mortality and complications.[125] Whether this is due to sociologic or physiologic factor is currently under intense investigation.[122]

Similarly, emergency operation has been found to be a major risk factor for perioperative mortality and/or prolonged hospital stay regardless of age.[130] In a study examining thoracic surgery, overall operative mortality was 2.4% rising to 26.4% in emergency patients.[130]

Findings related to the comorbidities in the present study deserve special attention and explanation in the context of study limitations arising from the nature of administrative data. From as early as 1980s investigators have indicated that comorbid diagnoses are frequently underreported in administrative data, which may bias outcome studies.[156-159] Specifically, in multilevel models in this study hypertension and diabetes demonstrate protective effect on in-hospital mortality and complications. These surprising findings are replicated and explained by other studies that have also reported unexpectedly beneficial effects of diabetes, angina, and other comorbidities on short-term mortality using administrative data.[157, 159-161] Several possible reasons have been suggested to explain the phenomenon: coders seem to be underreporting chronic conditions as they discard chronic codes to generate truncated fields or they substitute acute complications for comorbidities.[157] In addition, Romano et al[157] have found that sensitivity of comorbidty coding was lowest for hypertension compared to other conditions. It is also conceivable that hypertensive patients are taking some medications e.g. β-blockers, calcium channel blockers, nitrates which would be contributing to a favorable outcome. In a study with periprocedural myocardial infarction as an end-point hypertension was found to be a weak correlate of the outcome.[125]

Studies have also found no evidence that mild-to-moderate hypertension independently increases perioperative risk[122] so without the ability to distinguish between the hypertension class we may be diluting the effect of severe hypertension.

In the context of CABG surgery it is also possible to suggest that hypertension provides protection from perioperative ischemia, which is one of the frequent adverse effects of CABG. This thought is supported by the existing evidence demonstrating that reduction of blood pressure intraoperatively was associated with increased risk of perioperative ischemia.[122]

In unadjusted analysis, comorbidities were coded as number of conditions present on each discharge record. The odds ratios derived from the analysis confirmed significant statistical relationship between the comorbidities and adverse patient outcomes. However, of interest was the inverse direction of the association, i.e. patients with higher number of comrobid conditions had lower odds of adverse outcomes. The results were only ‘typical’ (i.e. meeting the expectation of higher likelihood of mortality and complications with the increased number of comorbid conditions) if four excluded variables, described in the study methods section in more detail, other neurological disorders, coagulopathy, renal failure, and fluid and electrolyte disorders were included in the analysis. This finding warrants additional research to explain how the nature (not the number) of comorbid conditions contributes to the risk of adverse outcomes.

Strengths and Limitations

The main strength of this study came from using individual surgeon identifiers and corresponding information. As noted by other researchers, hospital volume-outcome effects are confounded by independent surgeon volume effect.[45, 151, 152] Thus, it was important to separate individual surgeon experience with two different CABG techniques. In addition, multilevel modeling utilized for the hierarchical data used for the study allowed to separate the impact of a surgeon's skill and the parameters related to the hospital staff, systems, and resources.**[149]**

Several important study limitations should be noted. As with all research using administrative data, the study was unable to examine and control for clinical detail such as coronary anatomy, left ventricular systolic function, time on CPB, other clinical measures and the severity of the comorbid conditions, which may considerably affect the outcomes. Although many studies using clinical data have also shown a significant effect of volume on outcome,[2, 46, 162] these unmeasured differences in patient populations operated on by surgeons with different volumes and caseload may result in confounding. Moreover, when clinically important information is available in the administrative data the lack of important details contributes to the inability to identify subgroups of patients at a higher risk. Hannan et al[163] provide a good example: ICD-9-CM code for "acute myocardial infarction (heart attack)," specifies that the heart attack occurred in the previous eight weeks. However, patients who had a heart attack within a few hours prior to the surgery are at greatly increased risk compared to those suffering the acute myocardial infarction (AMI) within a few days prior to the procedure, and it is not possible based on administrative data to separate these two groups of patients.[163] This could be an explanation why such an important clinical variable was not statistically significant in this study and therefore was not retained in the final models.

In addition, there is a likelihood that miscodes in the data have occurred, especially with regard to extremely low-volume surgeons. It is possible that in some discharge records the admitting physician may have been recorded as operating physician, which may explain one or two surgeries performed over the seven year study period. Problems in identifying physicians accountable for care have also been reported by other studies using administrative data.[164] However, there is no possibility to determine if the procedure is a miscode or actually performed by a surgeon. This creates a significant barrier for studying the characteristics and outcomes of extremely low-volume surgeons. A systematic review of literature has identified that providers with the lowest volume had markedly worse results compared to providers in other volume categories.[2]

Some methodological challenges involved in the study should be also noted. As previous studies have acknowledged, no validated volume thresholds have been established. Moreover, Halm et[2] al noted that the cut-off points used to define high and low volume overlapped substantially among studies: the same number of procedures was defined as high volume in one study and low volume in another.[2] This wide variation in the definition of low vs. high volume creates considerable methodological challenges.

The lack of information on conversion from off-pump to on-pump CABG and corresponding lack of adjustment for conversion is also a limitation. It has been reported that those who converted to CPB intraoperately had higher mortality rates (converters 3.47% [95% CI 3.16%-3.77%] vs. nonconverters 2.53% [95% CI 2.46%-2.61%]).[165]

In addition, the analysis accounts for only a limited number of organizational factors, which are often likely to contribute to improved surgical outcomes (multidisciplinary team, staffing ratios, availability of technology and specialized equipment including specialized intensive care units and operating rooms, preoperative risk assessments and recommendations by other physicians, etc).

Due to the nature of administrative data the distinction between hospital-acquired problems and prehospitalization problems was hard to make.[166] The data used for the analysis did not contain a “present on admission” (POA) indicator, which was legislatively mandated to be added to administrative claims data in 2007.[97] However, eight PSIs used in this study (PSI 5, PSI 6, PSI 7, PSI 9, PSI 10, PSI 11, PSI 13, and PSI 15) have been found to remain potential patient safety problems after eliminating conditions reported as POA.[97, 98] The only patient safety indicator used for the analysis with less likelihood to be still considered a potential patient safety problem after eliminating conditions reported as POA is PSI 12 - postoperative pulmonary embolism or deep vein thrombosis.[97] Thus, PSIs selected for the analysis in this study are adequate measures of in-hospital complications.

Similarly, as noted in the example of AMI the lack of clinical details contributes to the inability to distinguish between risk factors and complications. For example, if intra-aortic balloon pump is inserted prior to the CABG surgery it would be a risk factor arising from the problems present at admission to the hospital but if it was inserted and necessitated by the CABG surgery it would suggest surgical complication.[163]

In addition, the well-accepted outcome measures used in this study may no longer capture the differences at a deeper level. For example, one of the study outcomes – mortality is argued to most reflect technical skills but not necessarily familiarity with and use of contemporary medical knowledge.[150] Moreover, the processes of care in general have been standardized and advances in CABG surgery have been universally adopted so measuring in-hospital mortality may no longer be able to capture subtle differences in quality of care. Some surgeons argue that the ability to rescue most patients who have a complication and keep most everyone alive confounds the mortality statistics.[150]

Finally, the study used data from one state and therefore findings may not be generalizable to other states especially those without certificate of need (CON), which most likely is affecting the distribution of CABG surgery among Florida hospitals.

Policy and Practice Implications

This study has suggested that performance of a specific type of CABG (CCABG vs. OPCABG) is associated with better outcomes. This finding may suggest the need of specialized and focused training of cardiac surgeons as well as specific CABG outcomes reporting protocols so that there is sufficient differentiation in outcomes of two different types of CABG. So far, OPCABG has received minimal attention with respect to outcome evaluation and reporting.

Future directions for CABG research should be focused on collecting richer data with more clinical information to address the concerns about important contributing factors for improved patient outcomes. Some quite specific recommendations can be made to fill the gap: 1) it should be possible to introduce coding of off-pump to on-pump conversion in the administrative data. This information alone would substantially inform the CABG research and practice; 2) clear and validated CABG volume thresholds should be established not only for hospitals but more importantly for surgeons; 3) information on surgical training (residency, fellowship, type of medical program) should be systematized and made available to researchers to fully evaluate the effect of training and specialization on surgical outcomes.

Like many other studies, present analysis emphasized the importance of rigorous risk adjustments, which is a complex construct involving patient's socio-demographic factors (e.g. age, gender, race/ethnicity), clinical stability, severity of primary disease, functional status, and burden of comorbidity.[167] Many methods have been developed to measure and control comorbidities, the Elixhauser comorbidity measure being one of the most commonly used instruments for risk adjustment. However, findings of many studies, with the current one included, suggest the need of revalidation of the measures, perhaps specifically for some major procedures/primary disease. In addition, incomplete or incorrect coding in administrative data should be reduced, if not eliminated, as a source of bias for risk models and hospitals should be encouraged to address the issue of selective underreporting and therefore improve reporting of coexisting conditions on discharge abstracts and claims.[168]

This study should be viewed in the light of the current historical events related to health care reform. Affordable Care Act of 2010 (ACA) is expected to change the face of medicine in the United States. With expanded health coverage for over 30 million individuals, insurance reforms, potential implementation of different models for delivery of health services, the ACA is going to fundamentally change nearly every aspect of the US health care. These major changes offer both challenges and opportunities. The opportunity is long awaited - to improve health care for vulnerable populations, reduce racial and ethnic disparities in health, and practice medicine without worrying about whether patients will be able to pay for needed care.[169] However, to achieve this several important challenges will need to be addressed. Superb medical/surgical education and training of competent, and sufficient workforce, which has made the US system the best in the world, needs to be sustained and optimized.[170] The ACA has no provisions to ensure adequate workforce training and retention. Attention is only given to creating incentives for primary care to address the declining number of physicians in this field. This may create an additional challenge for many specialty areas including thoracic surgery. Physician extenders who have compensated for the deficit of primary care physicians cannot play the same role for surgical specialties – they cannot operate.[170]The problem of workforce shortage is further exacerbated by the fact that the funding for resident training comes from Medicare – each accredited training program receives approximately $100,000 per trainee per year, around $9.5 billion a year spent by the federal government.[170] So, potential reduction in these funds, which will not be noticeable for public as it happens, will most likely have a major negative impact on resident education, number of residents being trained, as well as on hospital budgets.[170]

Although not directly evaluated by the current study, the impact of age on surgical workforce is important. Advanced age of surgeons may contribute to adverse patient outcomes or workforce shortage as they retire. Currently, thirty-five percent of the surgical workforce is over 55 years, by 2014 that number is predicted to be 42 percent.[170] These implications need to be seriously considered by the government and policy makers to ensure sustainable quality care, handle the increased workload, including CABG surgeries and balance supply and demand.

Physician-hospital alignment is likely to change as a result of new law. A “work-shop” model, also seen in this study, where surgeons operate on patients in multiple hospitals may no longer exist as payment reforms (e.g., bundled payments, performance-based incentives) and legal compliance obligations impose increased financial and legal liability burden on physician practice. This will likely lead to an increase in administrative costs for required infrastructure and quality measurement and will compel physicians to consolidate with other practitioners, become hospital employees, or align with large entities and health systems for capital, administrative and technical resources.[171] Such alignment is expected to better handle the shift of the risk, or "accountability," for care from insurers to providers. Some, however, speculate that physicians will decide to exit to administrative roles in hospitals or leave practices alltogether,[171] which will further exacerbate workforce shortage discussed above.

The present study has found that low-volume surgeons provide care to higher proportion of vulnerable populations. With more than 30 million previously uninsured individuals added to the patient load two things can happen: (1) volumes of surgeons may increase across the board for all volume categories, (2) workload of low volume surgeons may increase substantially which can contribute to improved surgical outcomes through the mechanism of “practice makes perfect”. In general, we may see a reversal of the CABG trends described previously – after more than 10 years of steady decline CABG rates may go up. This expectation is based on the perception that population, which was uninsured for years and therefore could not access costly cardiac care, may have severe CAD, presumably going untreated for a long time, which would require surgical intervention.

Provided that access to health care challenges are addressed, quality of care is likely to benefit from the changes imposed by the ACA. The law includes provisions that reward quality/efficiency performance such as shared savings contracts with Accountable Care Organizations (ACO), and reporting and tracking system for improved quality metrics. Incentive payments for physicians voluntarily participating in Medicare's Physician Quality Reporting Initiative (PQRI) and in Maintenance of Certification Program are provided under the law. In addition, starting from 2015, physicians will be penalized 1.5 percent of Medicare payment and 2.0 percent of payment in following years if they do not successfully participate in the PQRI.[171] This may be the best time for health services researchers and policy makers to help improve reporting protocols and thereby generate richer and improved data with robust measurement capabilities. The need for such improvement has been once again emphasized in the current study as it related to risk-adjustment and provider profiling. The latter has even greater potential for improvement as Department of Health and Human Services plans to create a web site showing quality metrics on physicians. Physician Compare website will contain information on physicians participating in the PQRI program. It is also required to make information on physician performance publicly available by 2013. As discussed above, this information needs to include details on physician training and practice.

Taken together, the implications of the ACA for policy practice and health care delivery is enormous although as *White Paper Examining the Effects of The Patient Protection and Affordable Care Act on Physician Practices in the United States* puts it, "direction apparent, details pending".[172] It is clear that changes imposed by the healthcare reform law are substantial and will be phased in over many years to come. The implications related to the current study as outlined above undoubtedly are just few among multiple that will influence the cardiac care.

In concusion, this study has the advantage of being comprehensive (with more than 119,59 patients) and population-based (including all patients undergoing CABG procedures in the State of Florida hospitals between 2000 and 2006). Beneficial effect of high volume of CABG found in this study supports existing evidence on the protective effect of procedure volume but takes one more step further suggesting that procedure-specific, i.e. proportional volume is more important in determining improved surgical outcomes.

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APPENDIX A: PUBLICLY AVAILABLE INFORMATION ON SURGICAL VOLUME

Name of Source	Sponsor	Area Represented	Source of data
Health Grades	Proprietary	United States	National Medicare database
Leapfrog Group	Business roundtable	United States	Self-reported by hospital
Hospital Quality Reports	BlueCross BlueShield	Upstate New York	State hospital discharge database
Indicators of Inpatient Care in Texas Hospitals, 2000	Texas Health Care Information Council	Texas	State hospital discharge database
Pennsylvania Hospital Performance	Pennsylvania Health Care	Pennsylvania	State hospital discharge database
Reports	Cost Containment Council		

Source: Dimick et al. World J. Surg. Vol. 29, No. 10, October 2005.[162]