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Review

Quality metrics in coronary artery bypass grafting

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ABSTRACT

Studies on the association between care quality, case volume, and outcomes in coronary artery bypass grafting (CABG) have concluded that consistent adherence to quality measures improves mortality rates and outcomes. However, the quality metrics are not well-defined, and their significance to surgeons and healthcare providers remains uncertain. We review the concept of “quality and quality metrics” and discuss their importance in the context of CABG.

1. Introduction

The incidence of postoperative surgical complications continues to be high [1,2]. In addition to directly affecting patients, these complications pose economic and logistic burden to healthcare providers [3]. To improve patient outcomes and overall quality of surgical healthcare, the criteria for identifying high-quality hospitals and surgeons for individual procedures have been widely debated. While there is evidence showing operator volume to improve mortality for some procedures [4,5], critics have considered volume to be a weak measure of individual hospital and procedure quality [6,7].

The quality of coronary artery bypass grafting (CABG) has been addressed and studies exploring the association between care quality, case volume and outcomes [8–10] in CABG have concluded that consistent adherence to quality measures yields better mortality rates and outcomes regardless of hospital or surgeon volume.

In recent years, cardiac surgery programs in the US have been graded for quality by different public and private domains, such as the Society of Thoracic Surgeons (STS) [11,12], the University Healthcare Consortium (UHC) [13], the Joint Commission [14], and individual state quality collaborative efforts [15], spawning multiple proposals and quality measures aimed at improving CABG. However, the complex and subjective nature of these measures continue to restrict surgeons and hospitals to the more traditional volume and outcome scales of grading surgical efficacy. In this review, we aim to address the concept of “quality and quality metrics” in the context of CABG.

2. Definition of quality in surgery

“Quality in surgery” has for long been interpreted differently by surgeons and healthcare providers. The confusion mainly stems from the exact parameters entailing quality surgical care. Fifty years ago, Donabedian [16] described a classical three-component model to examine health services and define quality of care, which is applicable to CABG as well. The three components are *structure*, *process*, and *outcome*. Although these components address different parts of patients' perioperative experience, they are inherently interconnected and a comprehensive approach to improve surgical quality must include and balance each of these measures.

Structure refers to the attributes of the provider or setting where surgery is performed and can be summarized as the foundation from which *process* is initiated. *Process* addresses the dynamics of care, and the way procedural details reflect on *outcome*. *Outcomes* are the ultimate results of the surgery and are perceived as the most tangible component of the quality improvement chain. In the following sections, these three-quality metrics are elaborated further in the context of CABG (Table 1).

2.1. Structure

Structural measures for quality assess the healthcare setting and provide information on the provider's capacity, logistics, staff expertise and coordination, doctor-to-patient ratio, and access to latest technology [17].

Authors studying CABG quality have linked procedure volume to

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Table 1
Summary of the CABG quality measures, their advantages and disadvantages.

	Structure	Process	Outcome
Variables	- Doctor/patient ratio - Provider capacity - Access to latest technology - Subspecialized nursing care	Evidence based recommendations including: - Prophylactic antibiotics - Use of beta blocker - Use of internal thoracic artery	- Mortality - Length of stay - Incidence of complications - Readmission rate - Patient satisfaction - Quality of life
Advantages	- Easy access - Convenient	- More practical to implement - Stronger supporting evidence with improved outcomes	- Directly reflect results of surgery
Disadvantages	- Difficult to implement - Unable to reflect larger variability of care	- Non-patient specific - Limited adherence - Difficult to measure	- Heavily dependent on sample size - Outliers not well detected

outcomes with different conclusions. In one of the earliest comprehensive studies exploring volume-outcome relationship in CABG, Shroyer et al. [18] observed a statistically significant relationship between annual hospital volumes and decreased CABG mortality ($p < 0.02$). Interestingly, when adjusted for risk-factors, CABG volume was not significantly related to mortality ($p > 0.10$). In 2002, Birkmeyer et al. [4] used the national Medicare claim database and Nationwide Inpatient Sample to study volume-outcome relationship for 2.5 million procedures performed in the USA between 1994 and 1998. While mortality generally decreased with volume for all the 14 different procedures that were studied, the relevance of volume to outcome was relative to the type of procedure. Notably, the lowest absolute difference in adjusted mortality rate (< 2%) between very-low-volume and very-high-volume hospitals was observed for CABG. Similarly, summarizing the STS data for the period 2000–2001, Peterson et al. [19] observed volume/outcome association for CABG to be weak among 439 investigated US hospitals, with operative mortality decreasing only 0.07% for every 100 additional CABG procedures (adjusted odds ratio [OR] 0.98, 95% confidence interval [CI] 0.96–0.99, $p = 0.004$). Auerbach et al. [10] explored this further and confirmed that when quality measures are maximized, CABG mortality outcomes at very-low-volume hospitals (adjusted mortality rate, 1.05% [CI, 0.81%–1.29%]) are similar to very-high-volume hospitals (adjusted mortality rate, 0.98% [CI, 0.72%–1.25%]). These disparities emanate from other factors surrounding CABG such as the complex interaction between surgeons, hospital volume, individual operator experience, level of non-surgical care, and data sourcing and sample selection methodology.

Subspecialty training is another important structural measure that has been shown to improve outcomes in most surgical fields [20]. Despite being the most common open-heart surgical procedure in the US, CABG has traditionally not been deemed a subspecialty unlike aortic or transplant surgery. However, with the evolving complexity of the procedure involving anaortic CABG and the use of multiple arterial grafts, preliminary evidence suggests improved outcomes in subspecialized coronary surgery units. Watkins et al. [21] observed improved mortality (1.48% versus 2.67%, $p = 0.02$), shorter overall operation time (decreased by 48 min, mean 222 versus 278 min, $p < 0.001$), and increased use of multiple arterial grafts (15% versus 11%, $p < 0.002$) in a subspecialized coronary surgery program. Also, Kogan et al. [22] reported improvement of unadjusted in-hospital mortality from 6.37% to 3.3% ($p < 0.01$) under subspecialized cardiac intensive care unit (ICU) teams and nurses. Similarly, others [23] have also proposed the institution of a CABG subspecialty given the expanding complexity and intricacies of the procedure.

The adoption of structural measures to advance quality is advantageous in terms of convenience and accessibility. These measures can be inexpensively accessed from administrative data and are relatively simpler to recognize at the institutional level. It must be noted, however, that present evidence on the influence of these structural measures on CABG is inadequate and preliminary, and published data has focused on only very limited structural variables and outcomes. Moreover, structural measures reflect average results for large groups of providers and are unable to reflect an even larger variability in care. Structural variables are also difficult to implement by providers and this limits their value in the quality improvement chain.

2.2. Process

Process describes what a provider does to improve the health of patients, and the compliance of providers with evidence-based recommendations established by professional organizations to ensure uniformity in care [24].

Most process variables adopted to measure quality originate from non-surgical specialties and have thus far been applied to cardiac surgery in a limited fashion. The variables have ranged from compliance with screening practices to secondary prevention strategies and desirable practice guidelines. Consequently, process variables that have been replicated in CABG for quality-improvement mainly relate to the non-surgical part of the procedure such as the use of prophylactic antibiotics, beta blockers, and perioperative care. The only notable exception is the use of one internal thoracic artery (ITA) graft for revascularization of the left anterior descending artery due to the almost universally recognized clinical benefits associated with it. Some have gone further to propose the use of multiple arterial grafts as a quality measure. While other CABG-related quality measures such as intraoperative assessment of graft patency and completeness of revascularization [25] have been studied, these have not been widely adopted yet.

Compared to structural measures, process measures are more practical to implement by providers, and evidence supporting their association with improved outcomes is stronger. Also, process variables more closely reflect the actual care that patients receive and are usually perceived as "fairer" measures of quality. However, the often-obvious benefits of implementing process measures can detract healthcare providers from aiming for an all-round approach to improving surgical quality and only focus on limited variables. Moreover, there is a tendency of providers to prefer higher reimbursing process measures over those that are actually most suitable for patients [26].

Despite being theoretically promising, the compliance of providers and patients with process measures, and their impact on quality are difficult to assess. This results from most process measures being non-patient-specific, complicating identification of patients that are eligible (the denominator) to receive the measured therapy [27]. For instance, only some patients benefit from pre-operative beta-blockade, while in other patients this is contraindicated. Although the concept is simple to describe, in practice, the judgement of the candidates for process measures suffers from multiple confounders, and many patients are ineligible for most of the process measures relevant to their condition. Even among eligible patients, adherence is limited [28] and the value of process measures is challenging to assess. Also, most process variables revolve around the perioperative medical management of patients and not the actual technical facet of the procedure.

2.3. Outcome

Outcomes are the most perceptible and intuitive measures of quality. Since the seminal works of Florence Nightingale and Ernest Codman [29,30], assessment of direct outcomes has been the hallmark of measuring quality in surgery. Mortality remains the most important and measured outcome in surgery, but other factors comprising length of stay, incidence of complications, readmission rate, patients' satisfaction, functional health status, and quality of life are being increasingly used.

For assessing quality in CABG, due to its very low mortality rate, the use of alternative outcome measures seems more acceptable. Potential outcomes that can be measured include the use of skeletonized ITA, postoperative myocardial infarction, completeness of revascularization, use of arterial grafts and graft patency. Although all are heavily linked to what is perceived as the quality of the operation by surgeons, those measures are more heterogenous in definition and have not been generally adopted as standard quality metrics.

Failure to rescue refers to the prognosis of patients experiencing complications, while acute risk change focuses on the change in mortality risk from the preoperative to the postoperative period. Both are increasingly adopted as quality metrics [31,32].

The extensive application of outcome measures to evaluate the quality of CABG is manifested in the multiple state clinical outcomes registries that have been established across the US in New York, Pennsylvania, Northern New England, Michigan and other states. Nationally, the STS Database is the largest registry of cardiac and thoracic outcomes that collects data from 1117 hospitals and 2916 surgeons in the US [33]. Table 2 summarizes quality measures adopted by the STS for Coronary Artery Bypass procedures.

Operative outcomes as quality indicators in CABG are advantageous and appeal to surgeons and patients since they directly reflect results of surgery. Kogan et al. [17] demonstrated further that the measurement of outcomes alone improves outcomes in cardiac surgery. However, the downside of measuring outcomes for quality is that the detection of outliers is heavily dependent on sample size, such that statistical estimates for low volume surgeons and/or hospitals are usually underpowered with wide confidence intervals and the definition of outliers problematic. This problem is particularly evident in the current era of reduction in the overall volume of CABG and increasing decentralization of care. Volume cut-offs and aggregation of CABG procedures data have been attempted to expand sample size and evade this limitation but results remain inconclusive.

Finally, composite measures combine individual quality metrics, weighting each measure based on its reliability and correlation with the outcome. Although evidence is limited, they may outperform conventional quality metrics [34].

Table 2
Quality measures adopted by the Society of Thoracic Surgeons for CABG.

Perioperative medication domain, scored all-or-none and consisting of:
- Preoperative beta blockade
- Beta blockade at discharge
- Anti-platelet medication at discharge
- Anti-lipid treatment at discharge
Operative care process domain:
- Use of an internal mammary artery
Risk-adjusted operative mortality:
- Risk-adjusted operative mortality
Risk-adjusted morbidity, scored any-or-none and consisting of:
- Stroke/cerebrovascular accident
- Surgical re-exploration
- Deep sternal wound infection rate
- Post-operative renal failure
- Prolonged intubation (ventilation)

2.4. Outliers

The definition of outliers comparing observed and expected event rate is key in the process of quality monitoring. Unfortunately, there are no clear guidelines for the definition of the outliers and current registries vary substantially in the distributional assumptions, confidence levels of accepting the null hypothesis, and time windows for outliers' definition.

This may result in substantially different classification of the same provider or institution according to different systems and may have potentially important implications. In general more conservative methods increase the risk of false negatives, while more liberal approaches increase the false positive rate. Both approaches may or may not be appropriate at a patient- or provider-level.

Among the statistical processes used for quality assessment, control charts is one of the oldest. Different types of data can be included in the model. However it has limited efficacy in low volume settings. An alternative method is the CUSUM charts based on sequential monitoring of performance over time or the use of funnel plots where performance is plotted against the target outcome [35].

3. Quality initiatives improve quality

The New York State Cardiac Surgery Reporting System (CSRS), the pioneer and longest running statewide program, publicly reports systematic data on cardiac surgery (and CABG in particular) [36]. Since its establishment in 1989, the CSRS has published annual data on risk adjusted post-CABG mortality by hospitals and individual surgeons. While initial anecdotal reports [37] and news [38] on CSRS' public reporting of outcome data raised concerns about surgeons being biased in terms of patient selection and favoring "healthy" patients to improve their ratings in mortality reports, over the long term, this initiative has generally promoted "healthy" competition among hospitals and surgeons that has improved the quality of CABG. In its first fourteen years from inception, the New York State CSRS decreased risk-adjusted mortality by 41% in the state of New York. By 1992, New York reported the lowest risk-adjusted mortality rate for CABG in the United States [36].

The Northern New England Cardiovascular Study Group (NNECVDSG). This interdisciplinary network of physicians and administrators founded in 1987 analyzes the outcomes of CABG patients operated in Maine, New Hampshire and Vermont. In 1990, the NNECVDSG initiated a regional intervention aimed at reducing CABG mortality. The three major components of this program were feedback on outcomes data, training in quality improvement, and site visits aimed at optimizing procedural aspects, processes, decision-making, and evaluation of care. Due to these interventions, CABG mortality significantly reduced in all patient categories [39]. Following this landmark effort, the NNECVDSG grew in size and aims and has published several very important quality analyses on different aspects of CABG [40,41].

The Michigan Society of Thoracic and Cardiovascular Surgeons Quality Collaborative (MSTCVS-QC) sees the participation of all 33 hospitals that perform adult cardiac surgery in the state of Michigan. This collaboration has quarterly reviewed the outcomes of all patients in four face-to-face meetings of representative physicians and data managers from each participating hospital and maintained continual contact with each through conference calls, site visits, and emails in its 17 years of existence. The MSTCVS-QC has contributed to substantial improvements in healthcare and outcomes for patients undergoing cardiac surgery, including the internal mammary artery utilization to rates that are higher than the STS average [42], 20% reductions in packed red blood cells transfusion rates from 2008 to 2012 [43], and developments of multidimensional analytic tool to capture avoidable mortality events and identify an area for further improvement [44].

Continuous quality improvement (CQI) is a principle that involves the repetitive cycle of assessing the effect of processes on outcomes, and evaluating how interventions translate into improvement in quality of care. Between 2000 and 2002, Ferguson et al. [45] performed a large randomized trial to demonstrate the benefit of CQI measures in improving the adoption of care process in CABG, although the effect was very modest for the only surgical measure they considered (use of the internal thoracic artery): the use of internal thoracic artery was 8.7% (standard deviation [SD] 17.5%) at intervention sites versus 5.4% (SD 15.8%) ($p = 0.11$) at control sites. Despite the low clinical impact of their quality improvement measures, their trial was mainly aimed at demonstrating feasibility, and targeted only two process quality measures (pre-operative beta-blockade therapy and internal thoracic artery grafting) and a limited patient population (patients 75 years or older). Similar results have been reported at the single institution level by Scheinerman et al. [46].

3.1. The role of the Society of Thoracic Surgeons (STS) in quality

The current STS national database has four major areas: adult cardiac surgery, general thoracic surgery, congenital heart surgery, and mechanical circulatory support with the recent addition of the STS-Intermacs database a year ago. There are approximately 1079 United States adult programs participating in the adult database, 119 in the congenital database, and about 312 in the general thoracic database at this time. The adult participating centers currently perform more than 95% of the adult cardiac operations in the United States each year [47].

There are 35 National Quality Forum endorsed outcome measures in the United States, as well as a unique program initiated in 2010 for voluntary public reporting of outcomes. This voluntary program has 76% of congenital heart surgery programs, 67% of adult cardiac surgical programs, and nearly 30% of the general thoracic surgical programs participating.

Enhancing the validity of the database are the STS database risk models, created with active surgeon participation and assessing each variable for clinical importance for inclusion in the risk model [48]. Along with these models, random data audits of 10% of adult cardiac surgical programs are performed each year by an external service for appropriateness of data entry and credibility with approximately 95% agreement rate between the auditors and the institution's data entry.

There have been remarkable "relative reductions" in rates of adverse outcomes in mortality, renal failure, stroke, reoperations, sternal infections, and prolonged ventilation. Process measures such as internal mammary artery use, preoperative beta blockers, discharge anti-platelets drugs, and discharge anti-lipid drugs have also shown an increase in compliance.

3.2. European association of Cardio-Thoracic Surgery (EACTS) and the Quality Improvement Programme (QUIP)

The EACTS established a Quality Improvement Programme (QUIP) in 2012 to improve clinical outcomes for patients and to promote the importance of integrating quality improvement initiatives into daily clinical practice. Since its inception, the Adult Cardiac Database (ACD) and the European Registry for Patients with Mechanical Circulatory Support (EUROMACS) have become the highlights of QUIP with cardiothoracic centers across Europe collaborating to collect data to create benchmarking tools for local quality improvement initiatives.

The ACD parallels the STS database in Europe by providing adult cardiac surgical outcomes data and serves as a reference tool for participating hospitals. The ACD now contains more than 100,000 cardiac surgical procedures in the benchmarking tool. Participating European hospitals have been submitting cardiac surgical data from 2010 onwards [49].

4. Pros and cons of quality metrics

Several studies [50–52] have suggested that the use of bilateral internal thoracic artery (BITA) may improve long-term survival. Despite the suggested advantage, BITA grafting is practiced by fewer than 4% in the US [53].

The use of BITA increases the risk of mediastinitis due to the devascularization of the sternum. A large meta-analysis [54] has demonstrated BITA grafting to significantly increase the incidence of sternal wound complications compared to single ITA grafting (relative risk [RR] of a single ITA: 0.62; 95% CI: 0.55–0.71). In patients with diabetes and pulmonary morbidity, this risk is even higher. Also, interim results from the Arterial Revascularization Trial (ART) [51] have shown a 1.3% increase in the risk of sternal wound infections in BITA versus single ITA grafts.

In the US, mediastinitis has been defined as a "never event" by the Centers for Medicare and Medicaid Services for which payment to hospitals is restricted [55]. This has very likely created a negative incentive for providers across the US to consider bilateral IMA grafting despite its potential clinical benefits.

Risk aversion (withholding care to the sickest patients to avoid operative deaths) is a potential risk of quality measurement and public reporting, although no clear evidence of its occurrence in cardiac surgery has been published to date [56].

5. Quality is an all-or-none property

Although the promotion of adherence to individual quality measures may impact patient outcomes, the limited and inconsistent benefits associated with focusing on isolated measures [57,58] highlights the need of a more wholesome approach [8,10]. The Centers for Medicare and Medicaid Services has adopted an all-or-none approach in defining the appropriate care measure in its 8th Scope of Work [59]. This approach to quality has several advantages over an item-by-item or composite measurement of quality. First, it is inherently natural and may better reflect patients' expectation of consistency in care. Second, an all-or-none scale for measuring quality is more sensitive than an item-level scale for gauging progress. Third, such an approach offers a systemic perspective that addresses the complete process of patient care and hand-offs, and not just parts of it. This ensures that healthcare providers tackle the toughest problems in care and do not defer the implementation of difficult quality measures while still ranking high in performance.

6. Importance of adoption of quality metrics

6.1. Mortality benefits

Comprehensive adherence to quality measures improves mortality in CABG regardless of hospital case volume [10]. This is an important consideration because implementing quality measures can be done at all institutions regardless of case volume and is practical wherever CABG is performed. This principle has been demonstrated at a hospital in New York State [46] that had higher valve/CABG mortality rates (14.77) than the statewide average (5.19). By rigorously adhering to quality improvement interventions and clinical excellence, in only 5 years, this hospital achieved the lowest risk-adjusted valve/CABG mortality rate (2.10, 95% CI 1.17–3.46) in adult patients in New York State (statewide average 4.22). Post-CABG quality improvement initiatives in patient care have also been shown to improve mortality [22]. As long as no quality measure is sacrificed, a bundled quality-improvement approach can be robust in improving mortality even if some of these individual quality measures are less robust and/or negatively associated with mortality [10].

6.2. Standardization of care

It is common knowledge that the adoption of standardized patient management protocols in different fields of medicine improves quality of healthcare and reduces cost. This holds true for cardiac surgery [60,61] in general, and CABG [10]. Complications surrounding CABG fall under limited categories and the adoption of a structured quality-controlled protocol to promptly manage these complications enables healthcare providers to properly manage them. Certain domains of CABG care have already been standardized for quality such as the cardiac ICU, where specific protocols have been instituted to guide anesthesia, analgesia, and delirium management [22]. Similarly, there are other protocols that relate to extubation, perioperative medication, transfusion triggers, and prevention and treatment of bleeding complications [62,63]. Evidence demonstrates that hospitals following these measures offer better patient prognosis [64], and that minimal variability among healthcare providers improves performance [65–67].

6.3. Cost management

With the surging cost of healthcare and recent deductions in government reimbursements for procedure-related complications, centers providing Medicare and Medicaid services began implementing measures to reduce reimbursements for certain complication-related admissions occurring in the immediate post-operative period in compliance with the Affordable Care Act of 2012 [68]. Furthermore, over the past decade, patients' disease severities and morbidities have also worsened increasing the risk of post-CABG complications. Consequently, addressing CABG quality metrics has become more important than ever to limit potential periprocedural complications that are cost-intensive to both patients and healthcare providers.

7. Conclusion

To conclude, quality of care has been associated with improved clinical outcomes, lower readmission rates, and improved efficiency of care following CABG. Quality is an all-or-none property and the association between quality measures and outcomes is strongest when all the quality measures are implemented together. While a "bundled measures" approach to improve, quality should be prioritized in all institutions practicing CABG, further work is needed to better describe the complex relationship between the different quality measures.

Ethical approval

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Author contribution

All authors listed have made contributions to the review. FMK and IH contributed equally to the study. MG designed the study. FMK, IH, MM, MW, KK, LNG, RLP, and MG participated in collecting the data, analyzing the data, drafting the manuscript, and revising the manuscript. All authors read the final manuscript and approved it.

Conflicts of interest

None.

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