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Characterizing Patient-Centered Postoperative Recovery After Adult Cardiac Surgery: A Systematic Review

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***Background*—**Improving postoperative recovery is important, with a national focus on postacute care, but the volume and quality of evidence in this area are not well characterized. We conducted a systematic review to characterize studies on postoperative recovery after adult cardiac surgery using patient-reported outcome measures.

***Methods and Results*—**From MEDLINE and Web of Science, studies were included if they prospectively assessed postoperative recovery on adult patients undergoing cardiac surgery using patient-reported outcome measures. Six recovery domains were defined by prior literature: nociceptive symptoms, mental health, physical function, activities of daily living, sleep, and cognitive function. Of the 3432 studies, 105 articles met the inclusion criteria. The studies were small (median sample size, 119), and mostly conducted in single-center settings (n=81; 77%). Study participants were predominantly men (71%) and white (88%). Coronary artery bypass graft was included in 93% (n=98). Studies commonly selected for elective cases (n=56; 53%) and patients with less comorbidity (n=67; 64%). Median follow-up duration was 91 (interquartile range, 42–182) days. Studies most commonly assessed 1 domain (n=42; 40%). The studies also varied in the instruments used and differed in their reporting approach. Studies commonly excluded patients who died during the follow-up period (n=48; 46%), and 45% (n=47) did not specify how those patients were analyzed.

***Conclusions*—**Studies of postoperative patient-reported outcome measures are low in volume, most often single site without external validation, varied in their approach to missing data, and narrow in the domains and diversity of patients. The evidence base for postoperative patient-reported outcome measures needs to be strengthened. **(*J Am Heart Assoc*. 2019;8:e013546. DOI: 10.1161/JAHA.119.013546.)**

Key Words: recovery • surgery • systematic review

Postoperative recovery is a complex, time-dependent process with multiple relevant domains, including physiological, nociceptive, mental health, cognitive, sleep, mobility, and activities of daily living.[1–3] Understanding postoperative recovery after cardiac surgery is pertinent, as there is increasing emphasis on readmission and outcomes of postacute care, with implementation of national publicly reported measures and incentive systems, such as bundled payments and the Hospital Readmissions Reduction Program.[4,5] There are increasing calls for the use of patient-reported outcome measures (PROMs) to improve recovery, as well as digital health tools to assess function and activity.[3,6] In fact, the Centers for Medicare and Medicaid Services is now paying for such remote monitoring.[7] However, the quality and volume of the evidence base guiding this effort in the cardiac surgery population are unknown.

To inform strategies to study and improve postoperative recovery, it is important to systematically evaluate the volume, quality, and content of existing literature. Of particular interest is the use of standardized methods to assess various domains relevant to recovery and inclusion of diverse patient populations. Additionally, characterizing approaches to reporting PROM scores is important, as variable reporting of raw measured scores, relative change from the preoperative measurements, or other ways may impede generalizable

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Accompanying Data S1, Tables S1 through S4, Figures S1, S2 are available at https://www.ahajournals.org/doi/suppl/10.1161/JAHA.119.013546

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Clinical Perspective

What Is New?

- This systematic review identified that studies of postoperative patient-reported outcomes are low in volume, narrow in domains and diversity of patients, and varied significantly in instruments used and ways in which outcomes were reported.

What Are the Clinical Implications?

- For efforts to improve postoperative recovery to be data-driven, study methodology must be standardized and improve in its rigor.

synthesis of the literature. However, to date, there is no extensive review of the magnitude and quality of the studies, how prior studies have used PROM instruments, and what patient populations are being studied.

Accordingly, we performed a systematic review to (1) describe the methods used in existing studies that evaluated postoperative recovery after cardiac surgery using PROMs and (2) assess the populations studied. The findings will help prioritize future research by identifying areas of postoperative recovery that currently lack data.

Methods

The data that support the findings of this study are available from the first author (makoto.mori@yale.edu) upon reasonable request.

Search Strategy and Study Selection

We developed the protocol according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement.[8] To identify prospective studies on the cardiac surgical population that evaluated postoperative recovery using PROMs, publications were searched on Medline and Web of Science using a combination of key terms and index headings related to cardiac surgery and postoperative recovery. We consulted a librarian experienced in systematic review on methodology and refining search terms. We did not include specific PROM terms or domain terms to increase the search sensitivity. We reviewed all publications indexed through January 10, 2019. The list of MeSH terms (permutations of "postoperative," "cardiac surgery," and "recovery") and other search strategies are outlined in Data S1. We reviewed search results to confirm inclusion of 5 validation articles[9–14] that we identified before the search.

We included only prospective studies in adult patients (age 18 years or older) who underwent any type of cardiac surgery that reported any PROMs following surgery. We excluded case reports and review articles. We excluded studies including patients who underwent left ventricular assist device implantation, extracorporeal membrane oxygenation support, orthotopic heart transplant, and congenital or adult congenital patients, as these populations likely experience distinct recovery trajectories different from the majority of adult cardiac surgical populations, which are those undergoing coronary artery bypass grafting (CABG) and valve and aortic operations. We also excluded studies with follow-up durations of fewer than 4 postoperative days, as the aim of this study was to characterize the recovery beyond the acute phase of care. To focus on studies evaluating patient-centered recovery, we excluded studies not reporting PROMs, with the exception of studies measuring physical function using accelerometers. Additionally, studies measuring PROMs at unspecified time points were not included. We added this criterion to exclude studies that obtained PROMs at undefined time points from the index operation, which can have a considerable time range and is challenging to interpret considering the time-dependent nature of recovery.

Screening and Data Collection

We organized the articles using Endnote 8 (Clarivate Analytics, Philadelphia, PA), and 2 authors (MM and SA) screened the titles and abstracts of all search results to locate potentially eligible articles for full-text review. Both authors then reviewed the full text to identify the final list of eligible articles, and all disagreements were resolved by consensus.

Data Extraction

For each article, we recorded publication characteristics (first author, year of publication, and journal), study characteristics (instruments used to evaluate recovery, such as the 36-Item Short Form Health Survey [SF-36],[15] Quality of Recovery score,[16] or battery of neurocognitive tests; number of assessments performed; longest time of patient follow-up; timing of each follow-up in terms of days since the operation; the domains of recovery evaluated; inclusion/exclusion criteria; enrollment approach; missing data treatment; and how death during the follow-up was analyzed), and patient characteristics (age, sex, race, number of patients in the study, and cardiac surgery type). Patient follow-up duration was defined as the duration between the operation and the time when the latest PROM recording was obtained. Values for the timing of measurement were collected in days since the operation. To assign a numeric value for visual representation of when the measurements were taken, the timing of measurements obtained at hospital discharge was defaulted

to postoperative day 7, if the study did not report specific timing of postoperative discharge. Day 7 was chosen on the basis of the mean postoperative length of stay of 6.9 days reported by the national Society of Thoracic Surgeons database for patients undergoing isolated CABG.[17] Journal type was grouped into 6 categories: nursing, surgical, psychology/behavioral, anesthesia, cardiology, and other. We categorized journals on the basis of the journal title including the name of the specialty (eg, anesthesiology, nursing) and professional society's affiliations to the journal (Table S1).

PROM Domains

Six domains that characterize postoperative recovery were identified on the basis of a previous literature review[3]: Nociceptive symptoms, physical function, activities of daily living, sleep, cognitive function, and mental health domains. Depression, anxiety, and psychosocial function were categorized into the mental health domain. The nociceptive symptoms domain included reporting of pain, physical discomfort, shortness of breath, and nausea. The physical function domain included measurement obtained using either objective tools, such as accelerometer, or PROMs. This criterion was set to avoid excluding studies that used a more rigorous tool to measure the domains. Similarly, studies using polysomnography for sleep were included to capture studies on postoperative sleep pattern, although polysomnography is likely not applicable for clinical home monitoring.

Definition of Outcomes Reporting Methodology

To evaluate how PROM values are analyzed and reported, we categorized reportings into the following 7 categories: raw score, percentage of patients with or without symptoms or dysfunction (according to each study's definition of categorizations), difference from baseline values, percentage of patients achieving baseline values, frequency of symptoms, fitting a model over raw scores, and others. To the best of our knowledge, there is no existing categorization of PROM reporting for the postoperative period. Therefore, we identified common reporting patterns by (1) reviewing the reporting of all included studies, (2) defining major categories, and (3) conducting a second review to categorize the studies by reporting approaches. Raw score indicates reporting of mean/median value of the PROM score obtained at a given time point and represents the simplest form of reporting. All other reporting categories involve processing of the raw score, such as calculating relative changes from baseline, or proportion of the patients reaching the baseline value at given time points.

Patient Characteristics, Enrollment Approach, and Inclusion/Exclusion Criteria

We then evaluated demographic data, enrollment approach, and inclusion/exclusion criteria to characterize the breadth of patient populations studied. Enrollment approach was categorized into convenience sampling, consecutive enrollment, or unspecified. Inclusion and exclusion criteria of interests were those specifically outlining age, sex, comorbidity criteria, and whether studies excluded patients on the basis of case acuity status (elective versus nonelective).

Treatment of Death and Missing Data

Finally, we evaluated how patients who died during the follow-up period were treated in the analysis, to understand common analytical practice and existing knowledge of the recovery process before death. To characterize potential bias attributable to missing data, we recorded how missing data were being handled because in longitudinal studies with decline in study participation over time, the population retained to the completion of the study may represent a biased cohort.[18]

Analysis

Studies were summarized using descriptive statistics by the sample size, procedure types, duration and timing of follow-up, number of measurements obtained, and the number of domains evaluated. Each variable was summarized either by the percentage or by the median, interquartile range, and range. Distributions of the studies in each component were summarized in a bubble plot. The most frequently used PROM instruments were selected to visualize the timing in days from operation and frequency of measurements obtained.

Results

Selected Studies

The search criteria yielded 3432 studies that potentially addressed postoperative recovery after cardiac surgery. Title and abstract screening excluded 3267 studies. Common reasons for exclusion included studies addressing the congenital heart disease population, animal studies, and studies not assessing PROMs. The remaining 165 potentially eligible articles underwent full-text review. This process excluded an additional 60 studies, consisting of studies with measures obtained at inconsistent time points, studies without full text, follow-up duration <4 days, and those evaluating the same study sample used in other included publications. Finally, 105 articles were included for analyses (Figure 1).

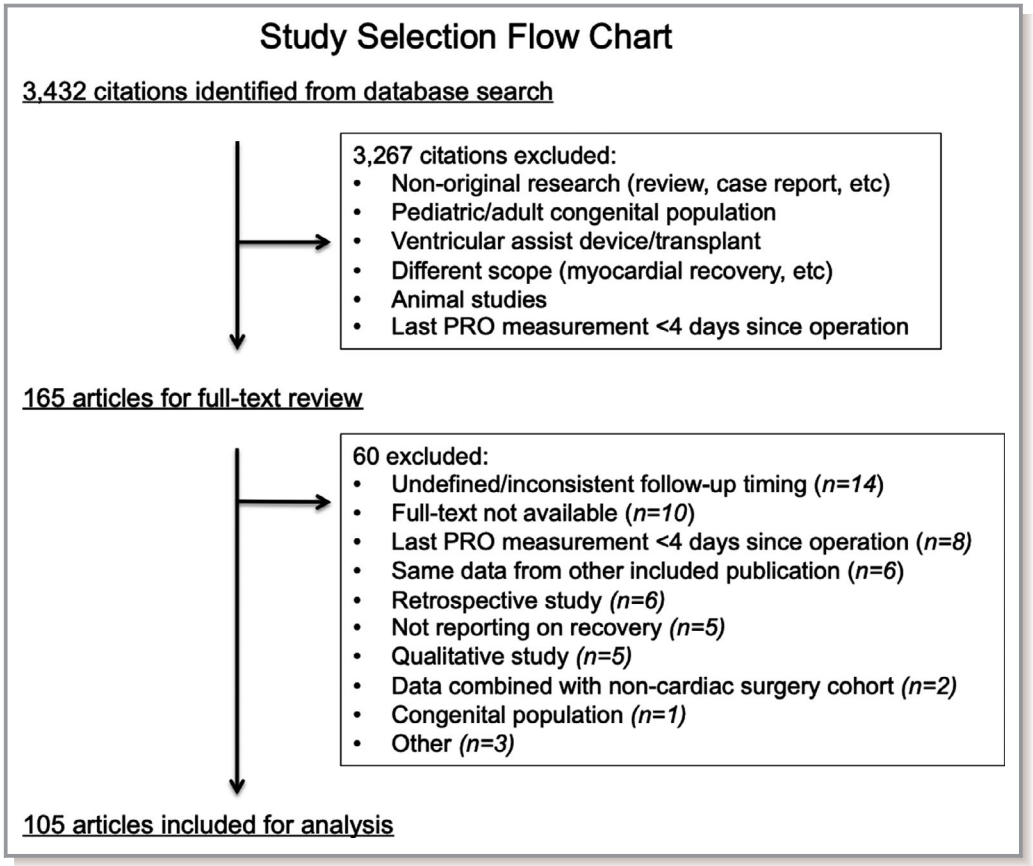

Figure 1. Study selection flow chart. Study selection process to arrive at the 110 articles analyzed. Studies were excluded on the basis of case types (ventricular assist device or heart transplant) and patient population (congenital, adult congenital) because the course of recovery may differ in these populations compared with common adult cardiac surgical population. PRO indicates patient-reported outcomes.

Study Characteristics

For the 105 included articles, the sample size of the studies tended to be small with a median of 119 patients (interquartile range, 62–229; range, 14–7321). Thirty-five percent (n=37) of the studies were intervention-based, comparing recovery between the specific intervention and control groups. Twenty-five percent of the studies (n=26) were randomized controlled clinical trials, in all of which the interventions were hypothesized to improve recovery, including less invasive surgical approach[19] and the use of special undergarments for women's incisional discomfort.[20] Seventy-seven percent (n=81) were conducted in single-center settings. Median follow-up duration was 91 (interquartile range, 42–182) days. Frequent follow-ups (measurements at ≥5 time points) were obtained in 15% (n=15). Studies most commonly assessed 1 domain (n=42; 40%). The nociceptive symptom domain was the most commonly measured (n=60; 57%), followed by the mental health (n=58; 55%) domain. One study that met the inclusion criteria evaluated postoperative taste change,[21] which did not meet any of our prespecified domain categories (Table 1). Of note, studies with the largest sample size (N=7321) evaluated only 1 domain, with 1 study having only 2 follow-ups,[22] while another had 7 follow-ups but spanned only 7 days (Study 17; Table S2).

Studies were most commonly published in nursing journals (n=30; 30%), followed by surgical journals (n=25; 24%) (Table S3). The oldest study was published in 1980, and 88% and 40% of the included studies were published after 2000 and 2010, respectively (Figure S1).

Reporting Methodology

Of the 105 studies, 71 (68%) reported only the raw scores obtained from measurement tools. Fourteen (13%) defined presence of symptoms or dysfunction in a binary form and reported proportion of patients experiencing the symptoms or dysfunction at each time point. Ten (10%) studies reported measurement values in relation to the baseline values, either as the absolute or relative difference or proportion of patients achieving the baseline value at each measured time points

Table 1. Study Characteristics of 105 Studies

Variables	N or Median	% or Q1–Q3 (range)
Sample size (n)	119	62–29 (14–7321)
Randomized trial	26	25%
Intervention-based*	37	35%
Multicenter study	24	23%
Follow-up duration (d)	91	42–182 (4–1825)
Number of follow-ups		
1	7	7%
2	27	26%
3	35	33%
4	21	20%
5	7	7%
6–9	8	8%
Domains		
Nociceptive symptoms	60	57%
Activities of daily living	51	49%
Cognitive	18	17%
Mental health	58	55%
Physical function	55	52%
Sleep	11	10%
Number of domains assessed		
1	42	40%
2	14	13%
3	17	16%
4	23	22%
5	8	8%
6	0	0%

IQR indicates interquartile range.
*Intervention-based refers to studies that examined patient-reported outcome measures according to different process of care (robotic vs. sternotomy approach, telehealth follow-up vs. usual care, etc.).

(Table 2). Only 60 (57%) studies obtained the first measurement before the operation (Figure 2).

Most of the studies with 1 to 2 follow-up assessments examined duration of <30 days. Three studies reported 5 measurements within a 50-day period,[11,13,23] representing the highest temporal resolution (Figure 3 and Figure S2).

Figure 4 summarizes the measurement timing and frequencies by the studies using the SF-36,[10,13,14,24–42] which was the most commonly used tool among the studies analyzed. Among the studies using the SF-36, the total number of measurements obtained ranged from 1 to 6, with highly variable timing of measurements among the studies. Preoperative, 42 days (6 weeks), 91 days (3 months), and 182 days (6 months) after surgery were common time points to obtain the measurement.

Table 2. Outcomes Reporting Methodology

Reporting Methods	N (%)
Raw score values*	71 (68)
Percentage of patients with and without symptoms/dysfunction	14 (13)
Difference from baseline	6 (6)
Percentage of patients achieving baseline	4 (4)
Function-based (fit over raw score values)	4 (4)
Frequency of symptom	3 (3)
Other	3 (3)

*Raw score values include 1 study reporting number of steps measured by a tracker.

Patient Characteristics, Selection Criteria, and Missing Values

Of the 100 studies that reported sex, men represented 71% (n=27,308) of the patients. Only 26% (n=27) of the studies reported race, and of those that reported race, white race comprised 88% (n=4852). The most common procedure type evaluated was isolated or concomitant CABG only (n=60; 57%), followed by studies including both CABGs and other non-CABG procedures (n=38; 36%); studies focusing solely on valve surgery cohort comprised 6% of the studies (n=6). Studies commonly excluded patients who died during the follow-up period (46%) and 45% did not specified how people who died were analyzed (Table 3). Only one study evaluated recovery in relation to mortality as an outcome.[22]

Over half of the studies did not specify whether enrollment was consecutive or on a convenience basis. Studies commonly set criteria to select for elective cases (53%) and patients with less comorbidity (64%). Ten percent of the

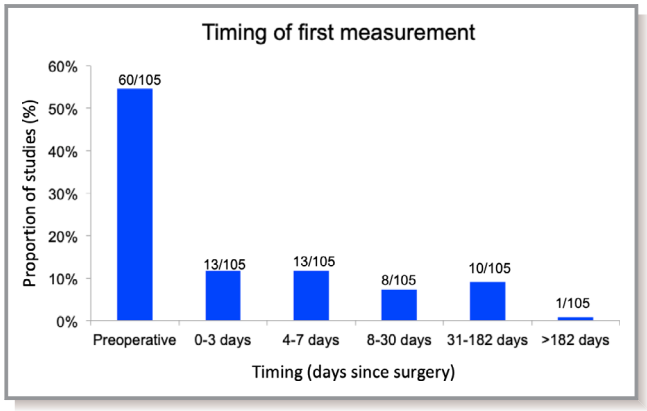

Figure 2. Timing of the first measurement obtained. Distribution of the timing of first measurement reported by the studies. Fifty-seven percent of the studies obtained the first measurement before surgery.

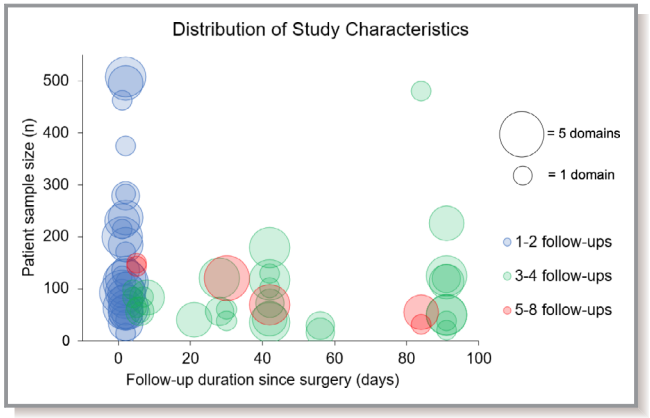

Figure 3. Bubble chart of studies by the study characteristics. Studies by the duration of follow-up (*x* axis) up to 100 days, sample size (*y* axis) up to 500 patients, number of domains evaluated (bubble size), and number of follow-ups at which time the measurements were obtained (color). Six possible domains are: nociceptive symptoms, activities of daily living, cognitive, sleep, mental health, and physical function.

studies set criteria to select for an older patient population (age ≥60 years), and 5% of the studies specified inclusion of women only (Table 3).

Study Findings

The variability in methodologies used across studies precluded synthesis of the existing evidence. Therefore, we summarized interventions and clinical characteristics associated with postoperative recovery that studies identified (Table S4), although interpretation of such claims is difficult in the context of limited quality of studies included in this analysis.

Discussion

In this systematic review, we identified that the body of literature on postoperative recovery after cardiac surgery is small (105 studies) and limited in quality, mostly single-center studies focusing on narrow diversity of patients. Patients studied were predominantly men, and of 26% of the studies reporting race, 88% were white. Measurement and reporting methods varied widely among the studies, with no standardized use of instruments. Although studies reported predictors of recovery, most lacked external validation, were low in quality, and limited in breadths of the population studied. A significant implication of our findings is in highlighting the

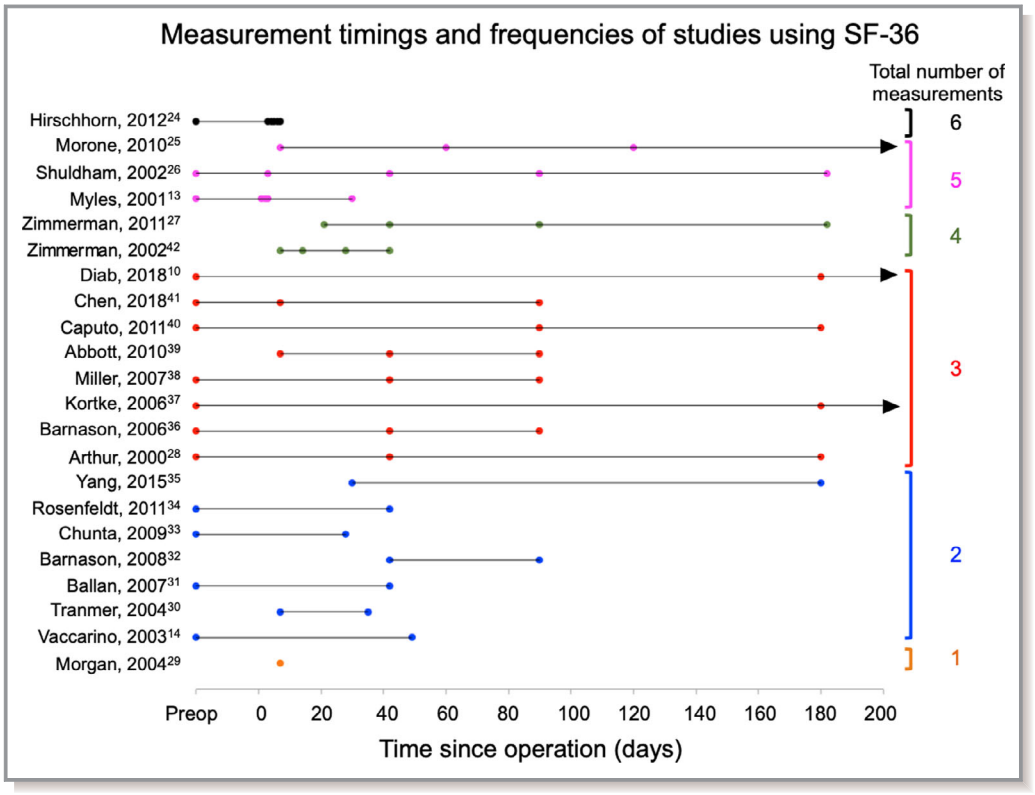

Figure 4. Measurement timings and frequencies of studies using the 36-Item Short-Form Health Survey (SF-36). Each horizontal line represents a study, and each dot represents the time point at which measurements were obtained. Last name of the first author and publication years are displayed in the left column. Studies are clustered by the total number of measurements obtained during the study (right column). Arrows indicate follow-up >200 days.

Table 3. Study Population Characteristics

Criteria	N (%)
Sex reported	100 (95)
Male (of sex reported)	27 308/38 567 (71)
Race reported	27 (26)
White (of race reported)	4852/5509 (88)
Procedure type	
CABG only	60 (57)
CABG+other	38 (36)
Valve only	6 (6)
Other	1 (1)
Death treatment	
Unspecified	47 (45)
Excluded	48 (46)
No death occurred	7 (7)
Other	3 (3)
Enrollment approach	
Unspecified	55 (52)
Convenience	19 (18)
Consecutive	31 (30)
Inclusion/exclusion criteria to select for	
Elective case only	56 (53)
Nonelective case only	0 (0)
Less comorbidity	67 (64)
More comorbidity	4 (4)
Older age (>60 years old)	10 (10)
Younger age (<80 years old)	10 (10)
Female sex only	5 (5)

Total N is 105, except for male and white numbers, which are specified in the table. Older and younger ages were defined by different thresholds to identify studies that focused on extremes of patient age (ie, "older" referred to the exclusion of extremely young population and vice versa). CABG indicates coronary artery bypass grafting.

need for high-quality research using a standardized approach so that recovery can be measured and improved on evidence-based fashion, especially with the current focus on the postacute phase of care.

This review has marked implications to researchers and funding bodies, as it revealed how limited the evidence on postoperative recovery is when significant interest exists in readmission reduction and improving the quality of postacute care. The Centers for Medicare and Medicaid Services is developing PROMs as part of its Quality Payment Program to relate patient experience to hospital reimbursement.[43] This signals the need for the science behind measuring the patient experience to catch up to the practice, and that need is not being fulfilled by current literature. A major implication to clinicians is that interventions to optimize postoperative recovery are based on little evidence at this point, and drawing clinical guidance on this topic from the literature is challenging.

Measurement Methodologies

Significant heterogeneity and methodological weaknesses were noted in the duration of follow-ups, the frequency of measurement, tools used to assess recovery, and the domains that were assessed. Even among 22 studies using the same SF-36 instrument, there was a high variation in when, in relation to the time of surgery, and how frequently the assessments were obtained. Because such variation complicates interpretation of the results across studies, a priority area in studying postoperative recovery may be to identify the standard approach to measurement frequency and timings. In addition, although accounting for individual variations in preoperative level of measurement may be important to contextualize postoperative recovery, measurement of preoperative values was inconsistent, with only 57% of the studies performing preoperative measurement. Furthermore, the review highlighted the low temporal granularity in measurement, with 8 and 9 being the highest numbers of measurements obtained over a relatively long period of 6 months[12] to 1 year.[44] Because digital platforms may allow for a high-frequency measurement of PROM, as frequent as on a daily basis,[45] leveraging such technology provides novel opportunities to obtain granular insights into the process of recovery.

Reporting Methodologies

Reporting of PROMs varied across studies, representing another element that requires standardization to promote cohesive interpretation of the evidence. A majority of the studies (67%) reported results as raw scores, often as the group-level mean or median and standard deviations, without any further processing of the score. Other studies sought to provide more clinically intuitive values, such as the proportion of patients reaching the preoperative values in the measured domains or items.[9,10] Defining the recovery as the time that one reaches preoperative level of function in each of global domains[3,9] may be useful in the clinical setting in providing an estimate of the time it takes for a certain proportion of the cohort to achieve "recovery." However, this approach to reporting may not be as useful in assessing domains that do not have a clear improving or declining trajectory, such as the mental health domain,[10] and is also not possible when the preoperative (baseline) values are not measured. Additionally, the binary categorization of the scores limits the interpretation of recovery to that at the group level and obscures distributional properties, such as the standard deviation, of

the raw scores. Furthermore, improvement of scores beyond baseline are not reflected in this reporting.

Raw scores measured via instruments calibrated to certain population-based distributions may be difficult to interpret in a highly selective cohort, such as those recovering after cardiac surgery, because the clinical characteristics of specific subpopulations may not match that of the population from which the calibration was obtained. The SF-36 score was linearly transformed to have a mean score of 50 and SD of 10,[46] and has been validated by the original authors across 24 patient populations with variable sociodemographic characteristics and disease severity.[47] However, whether this norm holds true in a highly specific subpopulation, such as a postoperative cohort after high-acuity operations recovering from a critical care setting, is uncertain. Taken together, standardization of reporting is needed, which may entail reporting of both raw scores obtained by the instruments and any postprocessing of the scores if they provide additional interpretive advantages.

Underrepresented Population

We identified underrepresented populations in this review. As the vast majority of the studies (92%) selected for CABG or a mixture of CABG and other operations, existing data on postoperative recovery after non-CABG operations are limited. Only 6 studies exclusively evaluated valve operations. Because the mortality and complication incidences vary across case types,[48] the process of recovery is expected to also vary and likely represents an important area of investigation. Expectedly, nonwhite and female patients were underrepresented, but more importantly, only 26% of the studies reported race data. The recovery process is reported to be more protracted in female patients,[14] and racial differences in recovery and the underlying causes likely warrant investigation. Most studies excluded or did not specify the treatment of mortality that occurred during the follow-up. While exclusion may be a practical approach to handling missing data, excluding deceased patients leaves the trajectory or recovery before death unknown. Similarly, a large number of studies excluded patients undergoing nonelective procedures with higher comorbidity levels and enrolled patients on a convenience basis. Although such approaches may improve response rates, they obscure the recovery process of sicker patients. Measuring recovery of this population requires patient engagement and creatively devising ways to simplify patient response.

Design and Domain

The use of an objective mobility tracker device in this population was infrequent (3 studies). As the prognostic value of objectively measured mobility has been demonstrated in oncologic[49] and noncardiac surgical populations,[6] it may be an important aspect of global recovery assessment. Sleep and cognitive domains represented the least frequently assessed domains, although both domains undergo significant disturbances postoperatively.[50,51] This relative infrequency may be attributable to the challenge related to resource-intensive cognitive function testing and polysomnography being the gold standards.[52] To generate evidence in a large cohort representing a wide spectrum of patient populations, the use of subjective surrogate measures, such as self-perceived sleep quality and duration, may be a practical alternative.

Limitations

This systematic review should be interpreted in the context of several potential limitations. First, the analysis was dependent on the available published data and is limited by publication bias and applicability of historical publications to contemporary clinical and research practice. However, we evaluated the temporal trend in the publication of included studies to assess contemporariness and found that almost 90% of the eligible studies were published after the year 2000. Second, although we worked with an experienced librarian to define the inclusive search terms and searched 2 large databases, it is possible that relevant studies may not have been identified. Third, the heterogeneity of studies in methodology and reporting precluded meta-analysis. We reported a qualitative summary of the studies in the form of predictors of recovery reported. Fourth, although a systematic review typically includes a risk-of-bias assessment, this study focused on the synthesis of meta-data of broad types of studies, and the heterogeneity of study types precluded systematic assessment of risk of bias applicable to all studies. As the main aim of the study was to describe the characteristics of all existing studies on this topic, we believe the metrics we used to characterize the studies provide a unified view of existing literature.

Conclusions

Our systematic review on postoperative, patient-centered outcomes after adult cardiac surgery revealed that studies are limited in what they assess, most often single site without external validation, varied in their approach to missing data, and narrow in terms of the diversity of patients. The evidence base regarding postoperative patient-centered outcomes needs to be strengthened to guide data-driven improvement of postoperative recovery. Priority areas include augmenting the volume and quality of studies, improving and standardizing the methods and PROM instruments, and focused recruitment of minority populations.

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SUPPLEMENTAL MATERIAL

Data S1.

Search terms

Medline (n=2,851):
(("postoperative period"[MeSH Terms] OR (("postoperative"[All Fields] OR "post-operative"[All Fields]) AND "period"[All Fields]) OR "postoperative period"[All Fields] OR "postoperative"[All Fields] OR “postsurgical”[All Fields]) AND recovery[All Fields] AND ("cardiac surgery"[All Fields] OR "cardiac surgical procedures"[MeSH Terms] OR "cardiac surgical"[All Fields] OR “CABG”[All Fields] OR “coronary artery bypass”[All Fields] OR “valve replacement”[All Fields] OR “valve repair”[All Fields])) AND English[Language]

Web of Science (n=1,921):
(ALL= ((Postoperative OR post-operative OR “post operative” OR postsurgical OR post-surgical OR “post surgical”) AND recovery AND ("cardiac surgery" OR "cardiac surgical" OR CABG OR 'coronary artery bypass' OR 'valve surgery' OR 'valve repair' OR valve replacement)))*AND* LANGUAGE**:** (English)

Final list after de-duplication (n=3,432)

Table S1. Journal categorization by specialty.

Journal Name	Number of articles	Category
Anesthesiology	3	Anesthesiology
J Cardiothorac Vasc Anesth	3	Anesthesiology
Anaesthesia	1	Anesthesiology
Anesth Analg	1	Anesthesiology
Braz J Anesthesiol	1	Anesthesiology
J Clin Anesth	1	Anesthesiology
Circulation	2	Cardiology
Am Heart J	1	Cardiology
Br Heart J	1	Cardiology
Cardiovasc Revasc Med	1	Cardiology
Clin Cardiol	1	Cardiology
Eur Heart J	1	Cardiology
Heart	1	Cardiology
J Am Coll Cardiol	1	Cardiology
Heart Lung	9	Nursing
Int J Nurs Stud	4	Nursing
J Adv Nurs	3	Nursing
Am J Crit Care	2	Nursing
Appl Nurs Res	2	Nursing
Eur J Cardiovasc Nurs	2	Nursing
J Cardiovasc Nurs	2	Nursing
Nurs Res	2	Nursing
Aust J Adv Nurs	1	Nursing
Biol Res Nurs	1	Nursing
Clin Nurs Res	1	Nursing
J Transcult Nurs	1	Nursing
Prog Cardiovasc Nurs	1	Nursing
West J Nurs Res	1	Nursing
Health Psychol	4	Psych/behavioral
Psychosom Med	3	Psych/behavioral
J Psychosom Res	2	Psych/behavioral
Ann Behav Med	1	Psych/behavioral
Behav Med	1	Psych/behavioral
Br J Health Psychol	1	Psych/behavioral
Int J Behav Med	1	Psych/behavioral
J Behav Med	1	Psych/behavioral
Ann Thorac Surg	7	Surgical
Eur J Cardiothorac Surg	6	Surgical
J Thorac Cardiovasc Surg	6	Surgical
Interact Cardiovasc Thorac Surg	2	Surgical
Ann Thorac Cardiovasc Surg	1	Surgical
J Cardiothorac Surg	1	Surgical
J Surg Res	1	Surgical

Thorac Cardiovasc Surg	1	Surgical
Altern Ther Health Med	1	Other
Ann Intern Med	1	Other
BMC Complement Altern Med	1	Other
Chest	1	Other
Eur J Phys Rehabil Med	1	Other
Geriatr Gerontol Int	1	Other
J Am Diet Assoc	1	Other
J Am Geriatr Soc	1	Other
Medicine (Baltimore)	1	Other
N Engl J Med	1	Other
Outcomes Manag	1	Other
Pain Res Treat	1	Other
Qual Life Res	1	Other
Rev Lat Am Enfermagem	1	Other
Telemed J E Health	1	Other

Journals were categorized according to the inclusion of the specialty name in the journal title and the professional society that publishes the journal.

Table S2. List of included studies.

ID	Author	Year	Title	Journal
1	Newell, J. P.	1980	Physical training after heart valve replacement	Br Heart J
2	Kulik, J. A.	1989	Social support and recovery from surgery	Health Psychol
3	Engblom, E.	1992	Quality of life during rehabilitation after coronary artery bypass surgery	Qual Life Res
4	King, K. B.	1993	Social support and long-term recovery from coronary artery surgery: effects on patients and spouses	Health Psychol
5	Artinian, N. T.	1995	Sex differences in patient recovery patterns after coronary artery bypass surgery	Heart Lung
6	Bruggemans, E. F.	1995	Residual cognitive dysfunctioning at 6 months following coronary artery bypass graft surgery	Eur J Cardiothorac Surg
7	Moore, S. M.	1995	A comparison of women's and men's symptoms during home recovery after coronary artery bypass surgery	Heart Lung
8	Treasure, T.	1995	Survival and quality of life in patients with protracted recovery from cardiac surgery. Can we predict poor outcome?	Eur J Cardiothorac Surg
9	Jenkins, C. D.	1996	Predicting completeness of symptom relief after major heart surgery	Behav Med
10	Redeker, N. S.	1996	Sleep patterns in women after coronary artery bypass surgery	Appl Nurs Res
11	Edell-Gustafsson, U. M.	1999	Sleep and quality of life assessment in patients undergoing coronary artery bypass grafting	J Adv Nurs
12	Elizur, Y.	1999	Psychosocial adjustment and mental health two months after coronary artery bypass surgery: a multisystemic analysis of patients' resources	J Behav Med
13	Grossi, E. A.	1999	Comparison of post-operative pain, stress response, and quality of life in port access vs. standard sternotomy coronary bypass patients	Eur J Cardiothorac Surg
14	Arthur, H. M.	2000	Effect of a preoperative intervention on preoperative and postoperative outcomes in low-risk patients awaiting elective coronary artery bypass graft surgery. A randomized, controlled trial	Ann Intern Med
15	Heijmeriks, J. A.	2000	The incidence and consequences of mental disturbances in elderly patients post cardiac surgery--a comparison with younger patients	Clin Cardiol
16	King, K. M.	2000	Gender and short-term recovery from cardiac surgery	Nurs Res

17	Ovrum, E.	2000	Rapid recovery protocol applied to 5,658 consecutive "on-pump" coronary bypass patients	Ann Thorac Surg
18	Parent, N.	2000	A randomized, controlled trial of vicarious experience through peer support for male first-time cardiac surgery patients: impact on anxiety, self-efficacy expectation, and self-reported activity	Heart Lung
19	Ebert, A. D.	2001	Early neurobehavioral disorders after cardiac surgery: a comparative analysis of coronary artery bypass graft surgery and valve replacement	J Cardiothorac Vasc Anesth
20	Fearn, S. J.	2001	Cerebral injury during cardiopulmonary bypass: emboli impair memory	J Thorac Cardiovasc Surg
21	McCrone, S.	2001	Anxiety and depression: incidence and patterns in patients after coronary artery bypass graft surgery	Appl Nurs Res
22	Myles, P. S.	2001	Relation between quality of recovery in hospital and quality of life at 3 months after cardiac surgery	Anesthesiology
23	Newman, M. F.	2001	Longitudinal assessment of neurocognitive function after coronary-artery bypass surgery	N Engl J Med
24	Borkon, A. M.	2002	A comparison of the recovery of health status after percutaneous coronary intervention and coronary artery bypass	Ann Thorac Surg
25	Koivula, M.	2002	Fear and anxiety in patients at different time-points in the coronary artery bypass process	Int J Nurs Stud
26	Mahler, H. I.	2002	Effects of a videotape information intervention for spouses on spouse distress and patient recovery from surgery	Health Psychol
27	Shuldham, C. M.	2002	The impact of pre-operative education on recovery following coronary artery bypass surgery. A randomized controlled clinical trial	Eur Heart J
28	Zimmerman, L.	2002	Comparison of recovery patterns for patients undergoing coronary artery bypass grafting and minimally invasive direct coronary artery bypass in the early discharge period	Prog Cardiovasc Nurs
29	DiMattio, M. J.	2003	A longitudinal study of functional status and correlates following coronary artery bypass graft surgery in women	Nurs Res
30	Jarvinen, O.	2003	Changes in health-related quality of life and functional capacity following coronary artery bypass graft surgery	Eur J Cardiothorac Surg
31	Pierson, L. M.	2003	Recovery of self-reported functional capacity after coronary artery bypass surgery	Chest
32	Stygall, J.	2003	Cognitive change 5 years after coronary artery bypass surgery	Health Psychol
33	Vaccarino, V.	2003	Gender differences in recovery after coronary artery bypass surgery	J Am Coll Cardiol

34	Koch, C. G.	2004	Health-related quality of life after coronary artery bypass grafting: a gender analysis using the Duke Activity Status Index	J Thorac Cardiovasc Surg
35	Kulik, A.	2004	Postoperative naproxen after coronary artery bypass surgery: a double-blind randomized controlled trial	Eur J Cardiothorac Surg
36	Milgrom, L. B.	2004	Pain levels experienced with activities after cardiac surgery	Am J Crit Care
37	Miller, K. H.	2004	Comparison of symptoms of younger and older patients undergoing coronary artery bypass surgery	Clin Nurs Res
38	Tranmer, J. E.	2004	Enhancing postoperative recovery of cardiac surgery patients: a randomized clinical trial of an advanced practice nursing intervention	West J Nurs Res
39	Zimmerman, L.	2004	Symptom management intervention in elderly coronary artery bypass graft patients	Outcomes Manag
40	Doering, L. V.	2005	Depression, healing, and recovery from coronary artery bypass surgery	Am J Crit Care
41	Koch, C. G.	2005	Impact of prosthesis-patient size on functional recovery after aortic valve replacement	Circulation
42	Utriyaprasit, K.	2005	Recovery symptoms and mood states in Thai CABG patients	J Transcult Nurs
43	Barnason, S.	2006	Impact of a telehealth intervention to augment home health care on functional and recovery outcomes of elderly patients undergoing coronary artery bypass grafting	Heart Lung
44	King, K. M.	2006	A randomized controlled trial of women's early use of a novel undergarment following sternotomy: the Women's Recovery from Sternotomy Trial (WREST)	Am Heart J
45	Koch, C. G.	2006	Persistent effect of red cell transfusion on health-related quality of life after cardiac surgery	Ann Thorac Surg
46	Kortke, H.	2006	New East-Westfalian Postoperative Therapy Concept: a telemedicine guide for the study of ambulatory rehabilitation of patients after cardiac surgery	Telemed J E Health
47	Okkonen, E.	2006	Family support, living alone, and subjective health of a patient in connection with a coronary artery bypass surgery	Heart Lung
48	Phillips-Bute, B.	2006	Association of neurocognitive function and quality of life 1 year after coronary artery bypass graft (CABG) surgery	Psychosom Med
49	Ballan, A.	2007	A comparative study of patient perceived quality of life pre and post coronary artery bypass graft surgery	Aust J Adv Nurs

50	Koch, C. G.	2007	Effect of functional health-related quality of life on long-term survival after cardiac surgery	Circulation
51	Lopez, V.	2007	Physical, psychological and social recovery patterns after coronary artery bypass graft surgery: a prospective repeated measures questionnaire survey	Int J Nurs Stud
52	Miller, C.	2007	Impact of an early recovery management intervention on functioning in postoperative coronary artery bypass patients with diabetes	Heart Lung
53	Barnason, S.	2008	Relationships between fatigue and early postoperative recovery outcomes over time in elderly patients undergoing coronary artery bypass graft surgery	Heart Lung
54	Chiu, K. M.	2008	Local infusion of bupivacaine combined with intravenous patient-controlled analgesia provides better pain relief than intravenous patient-controlled analgesia alone in patients undergoing minimally invasive cardiac surgery	J Thorac Cardiovasc Surg
55	King, K. M.	2008	Women's Recovery from Sternotomy-Extension (WREST-E) study: examining long-term pain and discomfort following sternotomy and their predictors	Heart
56	Lena, P.	2008	Fast-track anesthesia with remifentanil and spinal analgesia for cardiac surgery: the effect on pain control and quality of recovery	J Cardiothorac Vasc Anesth
57	MacIntyre, B.	2008	The efficacy of healing touch in coronary artery bypass surgery recovery: a randomized clinical trial	Altern Ther Health Med
58	Panagopoulou, E.	2008	Symptoms of traumatic stress after coronary artery bypass grafting	Int J Behav Med
59	Sandau, K. E.	2008	Health-related quality of life and subjective neurocognitive function three months after coronary artery bypass graft surgery	Heart Lung
60	Chunta, K. S.	2009	Expectations, anxiety, depression, and physical health status as predictors of recovery in open-heart surgery patients	J Cardiovasc Nurs
61	Koster, S.	2009	The long-term cognitive and functional outcomes of postoperative delirium after cardiac surgery	Ann Thorac Surg
62	Rantanen, A.	2009	Health-related quality of life after coronary artery bypass grafting	J Adv Nurs
63	Routledge, F. S.	2009	The influence of coronary artery bypass graft harvest site on women's pain, functional status, and health services utilization throughout the first post-operative year: a longitudinal study	Int J Nurs Stud

64	Abbott, A. A.	2010	Symptom burden clusters and their impact on psychosocial functioning following coronary artery bypass surgery	J Cardiovasc Nurs
65	Hudetz, J. A.	2010	Preoperative dispositional optimism correlates with a reduced incidence of postoperative delirium and recovery of postoperative cognitive function in cardiac surgical patients	J Cardiothorac Vasc Anesth
66	Juergens, M. C.	2010	Illness beliefs before cardiac surgery predict disability, quality of life, and depression 3 months later	J Psychosom Res
67	Keith, M.	2010	Evaluation of taste sensitivity in patients undergoing coronary artery bypass graft surgery	J Am Diet Assoc
68	Morone, N. E.	2010	The impact of pain and depression on recovery after coronary artery bypass grafting	Psychosom Med
69	Rudolph, J. L.	2010	Delirium: an independent predictor of functional decline after cardiac surgery	J Am Geriatr Soc
70	Utriyaprasit, K.	2010	Recovery after coronary artery bypass surgery: effect of an audiotape information programme	J Adv Nurs
71	Caputo, M.	2011	Thoracic epidural anesthesia improves early outcomes in patients undergoing off-pump coronary artery bypass surgery: a prospective, randomized, controlled trial	Anesthesiology
72	Fedak, P. W.	2011	Adhesive-enhanced sternal closure to improve postoperative functional recovery: a pilot, randomized controlled trial	Ann Thorac Surg
73	Rosenfeldt, F.	2011	Physical conditioning and mental stress reduction--a randomised trial in patients undergoing cardiac surgery	BMC Complement Altern Med
74	Zimmerman, L.	2011	Gender differences in recovery outcomes after an early recovery symptom management intervention	Heart Lung
75	Chapman, C. R.	2012	Postoperative pain trajectories in cardiac surgery patients	Pain Res Treat
76	Guo, P.	2012	A preoperative education intervention to reduce anxiety and improve recovery among Chinese cardiac patients: a randomized controlled trial	Int J Nurs Stud
77	Hirschhorn, A. D.	2012	Does the mode of exercise influence recovery of functional capacity in the early postoperative period after coronary artery bypass graft surgery? A randomized controlled trial	Interact Cardiovasc Thorac Surg
78	Kopp, M.	2012	Psychomotor car-driving abilities after robotically assisted totally endoscopic coronary artery bypass grafting	Thorac Cardiovasc Surg
79	Martin, L. M.	2012	Health-related quality of life after coronary artery bypass grafting surgery and the role of gender	Cardiovasc Revasc Med

80	Bruce, K. M.	2013	Recovery of cognitive function after coronary artery bypass graft operations	Ann Thorac Surg
81	Cook, D. J.	2013	Functional recovery in the elderly after major surgery: assessment of mobility recovery using wireless technology	Ann Thorac Surg
82	Fontes, M. T.	2013	Predictors of cognitive recovery after cardiac surgery	Anesth Analg
83	DiMaria-Ghalili, R. A.	2014	Inflammation, functional status, and weight loss during recovery from cardiac surgery in older adults: a pilot study	Biol Res Nurs
84	Jonsson, M.	2014	Self-reported physical activity and lung function two months after cardiac surgery--a prospective cohort study	J Cardiothorac Surg
85	Mello, L. C.	2014	Assessment of pain during rest and during activities in the postoperative period of cardiac surgery	Rev Lat Am Enfermagem
86	Poole, L.	2014	Preoperative sleep complaints are associated with poor physical recovery in the months following cardiac surgery	Ann Behav Med
87	Ronaldson, A.	2014	Optimism measured pre-operatively is associated with reduced pain intensity and physical symptom reporting after coronary artery bypass graft surgery	J Psychosom Res
88	Min, L.	2015	Longitudinal functional recovery after geriatric cardiac surgery	J Surg Res
89	Monteleone, S.	2015	Recovery of deambulation after cardiothoracic surgery: a single center experience	Eur J Phys Rehabil Med
90	Yang, M.	2015	Comparison of postoperative quality of life for patients who undergo atrial myxoma excision with robotically assisted versus conventional surgery	J Thorac Cardiovasc Surg
91	Amofah, H. A.	2016	Sleep in octogenarians during the postoperative phase after transcatheter or surgical aortic valve replacement	Eur J Cardiovasc Nurs
92	Guimaraes-Pereira, L.	2016	Quality of recovery after anaesthesia measured with QoR-40: a prospective observational study	Braz J Anesthesiol
93	Kidd, T.	2016	Attachment anxiety predicts depression and anxiety symptoms following coronary artery bypass graft surgery	Br J Health Psychol
94	Lin, Y.	2016	Cardiac Valve Noise Reduction by Non-Drug Interventions Improves the Sleep Quality of Patients after Mechanical Cardiac Valve Implantation	Ann Thorac Cardiovasc Surg
95	Niemeyer-Guimaraes, M.	2016	Course of functional status in elderly patients after coronary artery bypass surgery: 6-month follow up	Geriatr Gerontol Int

96	Petersen, J.	2016	Physical and mental recovery after conventional aortic valve surgery	J Thorac Cardiovasc Surg
97	Rasmussen, L. A.	2016	Ultrashort acting remifentanil is not superior to long-acting sufentanil in preserving cognitive function-a randomized study	J Clin Anesth
98	Hansen, L. S.	2017	Early, dedicated follow-up and treatment of pleural effusions enhance the recovery rate after open cardiac surgery: results from a randomized, clinical trial	Eur J Cardiothorac Surg
99	Knipp, S. C.	2017	Early and long-term cognitive outcome after conventional cardiac valve surgery	Interact Cardiovasc Thorac Surg
100	Royse, C. F.	2017	Impact of Methylprednisolone on Postoperative Quality of Recovery and Delirium in the Steroids in Cardiac Surgery Trial: A Randomized, Double-blind, Placebo-controlled Substudy	Anesthesiology
101	Salzmann, S.	2017	Effects of Preoperative Psychological Interventions on Catecholamine and Cortisol Levels After Surgery in Coronary Artery Bypass Graft Patients: The Randomized Controlled PSY-HEART Trial	Psychosom Med
102	Bowyer, A. J.	2018	Validation of the cognitive recovery assessments with the Postoperative Quality of Recovery Scale in patients with low-baseline cognition	Anaesthesia
103	Chen, Y. C.	2018	Validating the 6-minute walk test as an indicator of recovery in patients undergoing cardiac surgery: A prospective cohort study	Medicine (Baltimore)
104	Colella, T. J.	2018	The effect of a peer support intervention on early recovery outcomes in men recovering from coronary bypass surgery: A randomized controlled trial	Eur J Cardiovasc Nurs
105	Diab, M. S.	2018	The influence of prolonged intensive care stay on quality of life, recovery, and clinical outcomes following cardiac surgery: A prospective cohort study	J Thorac Cardiovasc Surg

Given few studies with extremely large samples compared to the median sample size, we qualitatively described studies with the largest sample sizes to evaluate whether we could make a strong inference on normative recovery pattern. The largest study (n= 7,321), Study 45, obtained measurements at only two time points, first of which was 180 days after the operation. The second largest study (n=5,658), Study 17, obtained measurements in a single-center setting at 7 time points but only within the first 7 days, and only assessed the proportion of patients ambulating on each day.

Table S3. Number of articles by journal category.

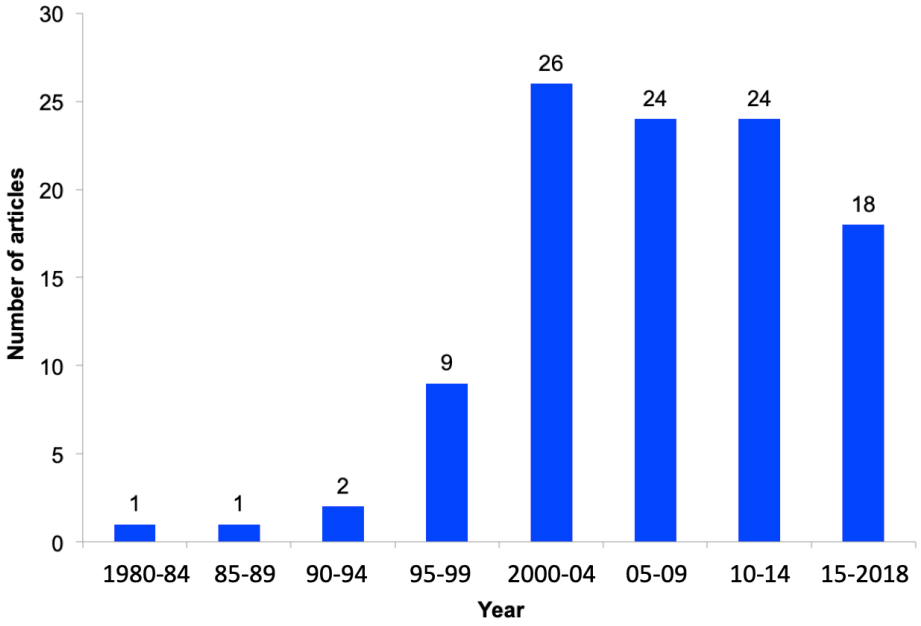
Journal category	N (105)	%
Nursing	32	30
Surgical	25	24
Psych/behavioral*	14	13
Anesthesia	10	10
Cardiology	9	9
Other	15	14

*Psych/behavioral category includes psychology, psychiatry, and behavioral medicine.

Table S4. Qualitative summary of predictors and interventions associated with improved recovery.

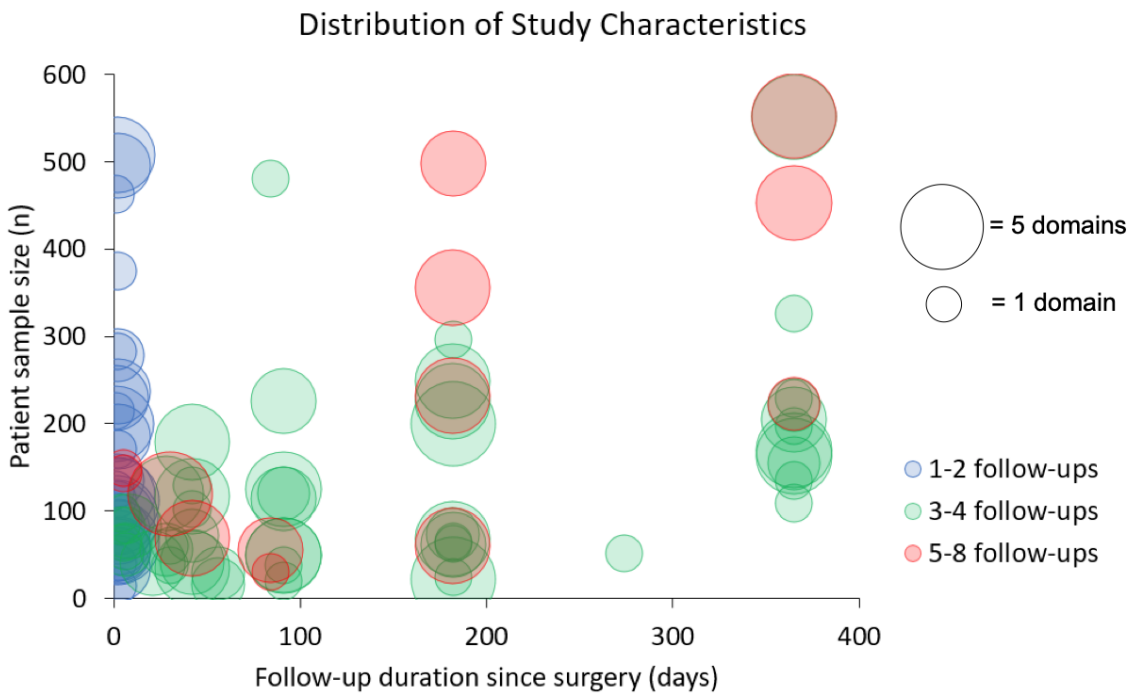
Factors related to better recovery	Categories	Predictors/Intervention
Interventions	Surgical	Adhesive-enhanced sternal closure, not using cardiopulmonary bypass, minimally-invasive access surgery, CABG without internal mammary artery use
	Medical	High-dose methylprednisolone, postoperative patient-controlled analgesia, postoperative naproxen, epidural anesthesia, fast-track anesthesia protocol, avoiding blood transfusion
	Other	Preoperative patient education, preoperative exercise training, use of special undergarment for women, telehealth follow-up, rehabilitation facility use compared to hospital rehabilitation, ear plug use after mechanical valve replacement, dyadic support, discharge instruction audiotape, additional follow up, healing touch, preoperative psychological intervention
Predictors		Men, women, younger age, shorter ICU stay, better baseline physical and cognitive function, higher number of steps taken after operation, lack of depression and baseline pain, better early recovery (predicts better late recovery), having social support, lower number of microemboli during operation, lower symptom burden, lower stress/anxiety/depression, lack of postoperative delirium, preoperative optimism, lack of preoperative sleep problems

Figure S1. Number of publications by year.



Number of articles published by 5-year increment of calendar year. No publication published prior to 1980 met the inclusion criteria. The latest bin (2015-2018) includes only 4-year period.

Figure S2. Bubble chart of studies by the study characteristics up to 400 follow-up days.



Studies by the duration of follow-up (x-axis) up to 400 days, sample size (y-axis) up to 600 patients, number of domains evaluated (bubble size), and number of follow-ups at which time the measurements were obtained (color). Six possible domains are: nociceptive symptoms, activity of daily living, cognitive, sleep, mental health, and physical function.