Improving Quality of postoperative pain care through innovative use of electronic health records

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Structured Abstract

Purpose. Millions of Americans undergo surgery every year, and postoperative pain is common and too often poorly managed, which may cause severe functional impairment, adverse events, impaired care of the underlying diseases, transition to chronic pain, and decreased quality of life. The goal of this project was to measure quality of various care processes for postoperative pain, assess proposed evidence-based interventions, develop a framework for the systematic assessment of pain-control using electronic health records (EHRs) and produce population-based evidence to guide acute pain management.

Scope. This project started with a national assessment of inpatient and emergency department opioid-related use and abuse claims in the United States and a systematic review of non-pharmaceutical pain management interventions. Using these national statistics, we assessed adherence to important pain management clinical guidelines and described prescribing patterns at an academic medical center and the veterans' health administration.

Methods. We develop standardized electronic definitions of pain-related care processes and outcomes (e.g. prolonged opioid use, readmission for pain, etc.) and extracted these data from both structured and unstructured data in EHR. We further examined the relationship between recommended care processes and outcomes for postoperative pain. Models were externally validated.

Results. We have developed a framework to use real-world data to assess pain management and prescription prescribing patters. This framework allows us to quickly and accurately generate evidence on pain management practices and associated patient outcomes for clinical assertions.

Key words: pain; opioids; pain management; postoperative pain; medical informatics; electronic health records

Purpose (Objectives of Study). This project seeks to measure quality of various care processes for postoperative pain, assess proposed evidence-based interventions from randomized controlled trials, lay the ground work for systematic pain-related research using EMRs, and produce population-based evidence for a nationally-endorsed postoperative pain management quality metric.

Scope

Background. There are 53 million surgeries performed in the United States every year and the majority of patients experience moderate to severe postoperative pain, which is often poorly managed. The acute negative impacts of poor postoperative pain control are profound: including immune system suppression, decreased mobility increasing deep vein thrombosis and pulmonary embolism rates, myocardial infarction, and pneumonia. There are also long term impacts of poor postoperative pain control including transition to chronic pain; 20% of surgical patients end up with chronic pain after surgery and poor immediate pain control is strongly correlated with pain long after the incisions have healed. Inappropriate postoperative pain management can result in prescription opioid dependence an epidemic in the US; opioid overdose deaths are more common than heroin and cocaine overdoses combined. Despite the increased national awareness of the importance of appropriate postoperative pain management, there has been little change in the incidence and severity of postoperative pain. Inappropriate management of postoperative pain can lead to chronic pain, which significantly and persistently reduce quality of life. *Postoperative pain is an important public health problem and offers opportunities for improving the quality of care delivery.* Appropriate postoperative pain care will reduce complications, the transition to chronic pain and reduce healthcare costs.

There have been substantial resources spent on research and policy strategies to improve postoperative pain. In the 1990's, policies focused on routine pain measurement: pain the 5th vital sign was initiated. Pain scores are now routinely recorded, however the utilization of the 5th vital sign is not clear from a policy, clinician or research point of view. Researchers have completed many randomized controlled trials [RCT] assessing interventions focused on improving postoperative pain. These studies have defined benefits of a variety of interventions from gabapentinoids, intraoperative ketamine, and physical therapy as effective postoperative pain interventions. However the translation of this information from bench to bedside is not clear. Too commonly, surgical pain management consists only of general anesthesia and discharge with an opioid prescription. Professional societies have attempted to synthesize the available information and develop practice guidelines. This has resulted in a wide array of guidelines for different practioners, which are often cumbersome and difficult to implement in real life practice. For example, the VA postoperative guidelines are 232 pages long and the summary is ten pages. *No unifying and simple practice guidelines are available*. To ensure the best postoperative pain care, we need clear and simple quality guidelines, a "*checklist*" for pain management, preferably one with associated metrics to encourage widespread adoption of practices that work.

Context. Opioids are currently a first-line treatment of postoperative pain, regardless of prior opioid-related problems. Most surgical patients receive opioids, regardless of co-morbidities, prior opioid-related problems, or possible drug-drug interactions and perioperative opioid exposure may be a gateway to opioid misuse and addiction. Recent studies suggest that 3-10% of opioid naïve surgical patients continue to request opioids one year post discharge – even for low-risk surgeries. Studies show clinicians have limited ability to predict which patients will misuse opioid medications. In the US, prescription opioid overdose deaths are more common than heroin and cocaine overdoses combined. The majority of people who misuse opioids obtain them from leftover pills of a legitimate prescription. In 2010, federal initiatives urged more judicious opioid

prescribing and recent trends suggest prescription opioid misuse began decreasing shortly thereafter. This study generates evidence to support pain-related and opioid prescribing federal initiatives and clinical guidelines

Settings and Participants. The settings and participants for this project varied across studies. The two main study sites included Stanford University and the Veterans Health Administration, as described below.

Stanford Health Care. Patients were identified in a clinical data warehouse. The data warehouse included information collected from Stanford Health Care (SHC), a tertiary-care academic medical center using the Epic EHR system (Epic Systems, Verona, WI) and managed in an EHR-based relational database, the clinical data warehouse. The clinical data warehouse contains structured data, including diagnosis and procedure codes, drug exposures and laboratory results, as well as unstructured data, such as discharge summaries, progress notes, anesthesia reports and operative reports. Structured data elements are mapped to standardized terminologies including RxNorm, SNOMED, International Classification of Disease (ICD) 9 or 10 codes and Current Procedural Terminology (CPT). The cohort included all patients seeking treatment at SHC between 2005-2019. Patients were excluded if they had less than two clinical visits, as these patients were likely patients seeking secondary opinions and not receiving treatment at our site. All studies received the approval from the institute's Institutional Review Board (IRB) and were conducted in accordance with recognized ethical guidelines.

Certain patient cohorts were also analyzed in the Veterans Health Administration (VHA). In the VHA cohort, data were obtained from the VA Corporate Data Warehouse (CDW), a national data repository from several VA clinical and administrative systems between 2009 and 2015. In the VHA, medication information was obtained using both the Bar Code Medication Administration data and the Decision Support System National Data Extract pharmacy dataset.

Results

Drug-Free Interventions to Reduce Pain or Opioid Consumption After Total Knee Arthroplasty: A Systematic Review and Meta-analysis. There is increased interest in nonpharmacological treatments to reduce pain after total knee arthroplasty. Yet, little consensus supports the effectiveness of these interventions. The objective of this study was to systematically review and meta-analyze evidence of nonpharmacological interventions for postoperative pain management after total knee arthroplasty. We performed database searches of MEDLINE (PubMed), EMBASE (OVID), Cochrane Central Register of Controlled Trials (CENTRAL), Cochrane Database of Systematic Reviews, Web of Science (ISI database), Physiotherapy Evidence (PEDRO) database, and ClinicalTrials.gov for the period between January 1946 and April 2016. Studies included randomized clinical trials comparing nonpharmacological interventions with other interventions in combination with standard care. Two reviewers independently extracted the data from selected articles using a standardized form and assessed the risk of bias. A random-effects model was used for the analyses. The main outcomes and measures were postoperative pain and consumption of opioids and analgesics. Of

5509 studies, 39 randomized clinical trials were included in the meta-analysis (2391 patients). The most commonly performed interventions included continuous passive motion, preoperative exercise, cryotherapy, electrotherapy, and acupuncture. Moderate-certainty evidence showed that electrotherapy reduced the use of opioids (mean difference, -3.50; 95% CI, -5.90 to -1.10 morphine equivalents in milligrams per kilogram per 48 hours; P = .004; I2 = 17%) and that acupuncture delayed opioid use (mean difference, 46.17; 95% CI, 20.84 to 71.50 minutes to the first patient-controlled analgesia; P < .001; I2 = 19%). There was low-certainty evidence that acupuncture improved pain (mean difference, -1.14; 95% CI, -1.90 to -0.38 on a visual analog scale at 2 days; P = .003; I2 = 0%). Very low-certainty evidence showed that cryotherapy was associated with a reduction in opioid consumption (mean difference, -0.13; 95% CI, -0.26 to -0.01 morphine equivalents in milligrams per kilogram per 48 hours; P = .03; I2 = 86%) and in pain improvement (mean difference, -0.51; 95% CI, -1.00 to -0.02 on the visual analog scale; P < .05; I2 = 62%). Low-certainty or very low-certainty evidence showed that continuous passive motion and preoperative exercise had no pain improvement and reduction in opioid consumption: for continuous passive motion, the mean differences were -0.05 (95% CI, -0.35 to 0.25) on the visual analog scale (P = .74; I2 = 52%) and 6.58 (95% CI, -6.33 to 19.49) opioid consumption at 1 and 2 weeks (P = .32, I2 = 87%), and for preoperative exercise, the mean difference was -0.14 (95% CI, -1.11 to 0.84) on the Western Ontario and McMaster Universities Arthritis Index Scale (P = .78, I2 = 65%). In this meta-analysis, electrotherapy and acupuncture after total knee arthroplasty were associated with reduced and delayed opioid consumption.(1)

Opioid Abuse And Poisoning: Trends In Inpatient And Emergency Department Discharges. The US opioid epidemic has been termed the 'worst drug crisis' in America and deaths due to opioid abuse have now surpassed those due to automobile accidents. One postulated cause of this crisis is the easing of availability of prescription opioids in the mid 1990's to address perceived undertreatment of pain. A decade later, scientific reports started to highlight a significant increase in opioid-related deaths, and in 2010 President Obama and others urged more judicious opioid prescribing to help control the epidemic. In this work, we presented national trends in inpatient and emergency department (ED) discharges for opioid abuse, dependence, and poisoning using publicly available national datasets. Although overall data showed increasing rates of opioid-related discharges, the rate of poisoning from prescribed opioids was not a monotonic trend. Poisonings involving prescription opioids increased annually until 2010 among inpatient and ED settings (8.0% and 5.0%, respectively) and then significantly decreased in both settings from 2010-2014 (-5.1% and -5.0%, respectively). In contrast, heroin and methadone poisonings sharply increased in EDs after 2008 with an annual increase of 25.2% ($p<.001$). These data support national initiatives targeting opioid prescriptions and could guide future policies directed at clinician prescribing patterns.(2)

Thirty-day unplanned postoperative inpatient and emergency department visits following thoracotomy. Unplanned visits to the emergency department (ED) and inpatient setting are expensive and associated with poor outcomes in thoracic surgery. We assessed 30-d postoperative ED visits and inpatient readmissions following thoracotomy, a high morbidity procedure. We retrospectively analyzed inpatient and ED administrative data

from California, Florida, and New York, 2010-2011. "Return to care" was defined as readmission to inpatient facility or ED within 30 d of discharge. Factors associated with return to care were analyzed via multivariable logistic regressions with a fixed effect for hospital variability. Of 30,154 thoracotomies, 6.3% were admitted to the ED and 10.2% to the inpatient setting within 30 d of discharge. Increased risk of inpatient readmission was associated with Medicare (odds ratio [OR] 1.30; P < 0.001) and Medicaid (OR 1.31; P < 0.0001) insurance status compared to private insurance and black race (OR 1.18; P = 0.02) compared to white race. Lung cancer diagnosis (OR 0.83; P < 0.001) and higher median income (OR 0.89; P = 0.04) were associated with decreased risk of inpatient readmission. Postoperative ED visits were associated with Medicare (OR 1.24; P < 0.001) and Medicaid insurance status (OR 1.59; P < 0.001) compared to private insurance and Hispanic race (OR 1.19; P = 0.04) compared to white race. Following thoracotomy, postoperative ED visits and inpatient readmissions are common. Patients with public insurance were at high risk for readmission, while patients with underlying lung cancer diagnosis had a lower readmission risk. Emphasizing postoperative management in at-risk populations could improve health outcomes and reduce unplanned returns to care.(3)

Emergency Department Visits Following Elective Total Hip and Knee Replacement Surgery: Identifying Gaps in Continuity of Care. Major joint replacement surgical procedures are common, elective procedures with a care episode that includes both inpatient readmissions and postoperative emergency department (ED) visits. Inpatient readmissions are well studied; however, to our knowledge, little is known about ED visits following these procedures. We sought to characterize 30-day ED visits following

a major joint replacement surgical procedure using administrative records from California, Florida, and New York to identify adults undergoing total knee and hip arthroplasty, 2010-2012. Factors associated with increased risk of an ED visit were estimated using hierarchical regression models controlling for patient variables with a fixed hospital effect. The main outcome was an ED visit within 30 days of discharge. Among the 152,783 patients who underwent major joint replacement, 5,229 (3.42%) returned to the inpatient setting and 8,883 (5.81%) presented to the ED for care within 30 days. Among ED visits, 17.94% had a primary diagnosis of pain and 25.75% had both a primary and/or a secondary diagnosis of pain. Patients presenting to the ED for subsequent care had more comorbidities and were more frequently non-white with public insurance relative to those not returning to the ED ($p < 0.001$). There was a significantly increased risk ($p < 0.05$) of isolated ED visits with regard to type of insurance when patients with Medicaid (odds ratio [OR], 2.28 [95% confidence interval (CI), 2.04 to 2.55]) and those with Medicare (OR, 1.38 [95% CI, 1.29 to 1.47]) were compared with patients with private insurance and with regard to race when black patients (OR, 1.38 [95% CI, 1.25 to 1.53]) and Hispanic patients (OR, 1.12 [95% CI, 1.03 to 1.22]) were compared with white patients. These increases in risk were stronger for isolated ED visits for patients with a pain diagnosis. ED visits following an elective major joint replacement surgical procedure were numerous and most commonly for pain-related diagnoses. Medicaid patients had almost double the risk of an ED or pain-related ED visit following a surgical procedure. The future of U.S. health-care insurance coverage expansions are uncertain; however, there are ongoing attempts to improve quality across the continuum of care. It is therefore essential to ensure that all patients,

particularly vulnerable populations, receive appropriate postoperative care, including pain management. (4)

Acute pain after breast surgery and reconstruction: A two-institution study of surgical factors influencing short-term pain outcomes. Acute postoperative pain following surgery is known to be associated with chronic pain development and lower quality of life. We sought to analyze the relationship between differing breast cancer excisional procedures, reconstruction, and short-term pain outcomes. Women undergoing breast cancer excisional procedures with or without reconstruction at two systems: an academic hospital (AH) and Veterans Health Administration (VHA) were included. Average pain scores at the time of discharge and at 30-day follow-up were analyzed across demographic and clinical characteristics. Linear mixed effects modeling was used to assess the relationship between patient/clinical characteristics and interval pain scores with a random slope to account for differences in baseline pain. Our study included 1402 patients at AH and 1435 at VHA, of which 426 AH and 165 patients with VHA underwent reconstruction. Pain scores improved over time and were found to be highest at discharge. Time at discharge, 30-day follow-up, and preoperative opioid use were the strongest predictors of high pain scores. Younger age and longer length of stay were independently associated with worse pain scores. Younger age, preoperative opioid use, and longer length of stay were associated with higher levels of postoperative pain across both sites.(5)

Utilization and effectiveness of multimodal discharge analgesia for postoperative pain management. Although evidence-based guidelines recommend a multimodal approach

to pain management, limited information exists on adherence to these guidelines and its association with outcomes in a generalized population. Therefore, we evaluated patients undergoing 4 surgeries associated with high pain in electronic health records from an academic hospital (AH) and Veterans Health Administration(VHA). Multimodal analgesia at discharge was characterized as opioids in combination with acetaminophen (O+A) and non-steroidal anti-inflammatory [NSAIDs] (O+A+N) drugs. Hierarchical models estimated associations of analgesia with 45-day follow-up pain scores and 30–day readmissions. We identified 7,893 patients at AH and 34,581 at VHA. In both settings, the majority of patients were discharged with O+A (60.6% and 54.8% respectively) yet a significant proportion received opioids alone (AH: 24.3% and VHA: 18.8%). Combining acetaminophen with opioids was associated with decreased follow-up pain in VHA [Odds Ratio (OR): 0.86, 95% Confidence Interval (CI): 0.79, 0.93] and readmissions [AH OR: 0.74, CI: 0.60, 0.90; VHA OR: 0.89, CI: 0.82, 0.96]. Further addition of NSAIDs was associated with further decreased follow-up pain [AH OR: 0.71, CI: 0.53, 0.96; VHA OR: 0.77, CI: 0.69, 0.86] and readmissions [AH OR: 0.46, CI: 0.31, 0.69; VHA OR: 0.84, CI: 0.76, 0.93]. In both systems, patients receiving multimodal analgesia received 10-40% less opioids per day compared to opioids only. In conclusion of this study, a majority of surgical patients receive a multimodal pain approach at discharge yet many receive only opioids. Multimodal regimen at discharge was associated with better follow-up pain and all-cause readmissions compared to the opioid-only regimen.(6)

Integrating Adjuvant Analgesics into Perioperative Pain Practice: Results from an Academic Medical Center. Opioid-sparing postoperative pain management therapies

are important considering the opioid epidemic. Total knee arthroplasty (TKA) is a common and painful procedure accounting for a large number of opioid prescriptions. Adjuvant analgesics, nonopioid drugs with primary indications other than pain, have shown beneficial pain management and opioid-sparing effects following TKA in clinical trials. We evaluated the adjuvant analgesic gabapentin for its usage patterns and its effects on opioid use, pain, and readmissions. This retrospective, observational study included 4,046 patients who received primary TKA between 2009 and 2017 using electronic health records from an academic tertiary care medical institute. Descriptive statistics and multivariate modeling were used to estimate associations between inpatient gabapentin use and adverse pain outcomes as well as inpatient oral morphine equivalents per day (OME). Overall, there was an 8.72% annual increase in gabapentin use ($P < 0.001$). Modeled estimates suggest that gabapentin is associated with a significant decrease in opioid consumption (estimate = 0.63, 95% confidence interval = 0.49-0.82, $P < 0.001$) when controlling for patient characteristics. Patients receiving gabapentin had similar discharge pain scores, follow-up pain scores, and 30-day unplanned readmission rates compared with patients receiving no adjuvant analgesics ($P > 0.05$). When assessed in a real-world setting over a large cohort of TKA patients, gabapentin is an effective pain management therapy that is associated with reduced opioid consumption-a national priority in this time of opioid crisis-while maintaining the same quality of pain management.(7)

Trajectory analysis for postoperative pain using electronic health records: A nonparametric method with robust linear regression and K-medians cluster analysis. Postoperative pain scores are widely monitored and collected in the electronic health

record, yet current methods fail to fully leverage the data with fast implementation. To improve the analysis of pain scores collected in the EHR, we develop a novel methos to assess pain trajectories. A robust linear regression was fitted to describe the association between the log-scaled pain score and time from discharge after total knee replacement. The estimated trajectories were used for a subsequent K-medians cluster analysis to categorize the longitudinal pain score patterns into distinct clusters. For each cluster, a mixture regression model estimated the association between pain score and time to discharge adjusting for confounding. The fitted regression model generated the pain trajectory pattern for given cluster. Finally, regression analyses examined the association between pain trajectories and patient outcomes. A total of 3442 surgeries were identified with a median of 22 pain scores at an academic hospital during 2009-2016. Four pain trajectory patterns were identified and one was associated with higher rates of outcomes. In conclusion, we described a novel approach with fast implementation to model patients' pain experience using electronic health records. In the era of big data science, clinical research should be learning from all available data regarding a patient's episode of care instead of focusing on the "average" patient outcomes. (8)

Predicting inadequate postoperative pain management in depressed patients: A machine learning approach. Widely-prescribed prodrug opioids (e.g., hydrocodone) require conversion by liver enzyme CYP-2D6 to exert their analgesic effects. The most commonly prescribed antidepressant, selective serotonin reuptake inhibitors (SSRIs), inhibits CYP-2D6 activity and therefore may reduce the effectiveness of prodrug opioids. For this study, we used a machine learning approach to identify patients

prescribed a combination of SSRIs and prodrug opioids postoperatively and to examine the effect of this combination on postoperative pain control. Using EHR data from an academic medical center, we identified patients receiving surgery over a 9-year period. We developed and validated natural language processing (NLP) algorithms to extract depression-related information (diagnosis, SSRI use, symptoms) from structured and unstructured data elements. The primary outcome was the difference between preoperative pain score and postoperative pain at discharge, 3-week and 8-week time points. We developed computational models to predict the increase or decrease in the postoperative pain across the 3 time points by using the patient's EHR data (e.g. medications, vitals, demographics) captured before surgery. We evaluate the generalizability of the model using 10-fold cross-validation method where the holdout test method is repeated 10 times and mean area-under-the-curve (AUC) is considered as evaluation metrics for the prediction performance. We identified 4,306 surgical patients with symptoms of depression. A total of 14.1% were prescribed both an SSRI and a prodrug opioid, 29.4% were prescribed an SSRI and a non-prodrug opioid, 18.6% were prescribed a prodrug opioid but were not on SSRIs, and 37.5% were prescribed a non-prodrug opioid but were not on SSRIs. Our NLP algorithm identified depression with a F1 score of 0.95 against manual annotation of 300 randomly sampled clinical notes. On average, patients receiving prodrug opioids had lower average pain scores ($p<0.05$), with the exception of the SSRI+ group at 3-weeks postoperative follow-up. However, SSRI+/Prodrug+ had significantly worse pain control at discharge, 3 and 8-week follow-up ($p < .01$) compared to SSRI+/Prodrug- patients, whereas there was no difference in pain control among the SSRI- patients by prodrug opioid ($p>0.05$). The

machine learning algorithm accurately predicted the increase or decrease of the discharge, 3-week and 8-week follow-up pain scores when compared to the pre-operative pain score using 10-fold cross validation (mean area under the receiver operating characteristic curve 0.87, 0.81, and 0.69, respectively). Preoperative pain, surgery type, and opioid tolerance were the strongest predictors of postoperative pain control. We provide the first direct clinical evidence that the known ability of SSRIs to inhibit prodrug opioid effectiveness is associated with worse pain control among depressed patients. Current prescribing patterns indicate that prescribers may not account for this interaction when choosing an opioid. The study results imply that prescribers might instead choose direct acting opioids (e.g. oxycodone or morphine) in depressed patients on SSRIs. (9)

Secondary use of electronic medical records for clinical research: Challenges and Opportunities. With increasingly ubiquitous electronic medical record (EMR) implementation accelerated by the adoption of the HITECH Act, there is much interest in the secondary use of collected data to improve outcomes and promote personalized medicine. A plethora of research has emerged using EMRs to investigate clinical research questions and assess variations in both treatments and outcomes. However, whether because of genuine complexities of modeling disease physiology or because of practical problems regarding data capture, data accuracy, and data completeness, the state of current EMR research is challenging and gives rise to concerns regarding study accuracy and reproducibility. This work explores challenges in how different experimental design decisions can influence results using a specific example of breast cancer patients undergoing excision and reconstruction surgeries from EMRs in an

academic hospital and the Veterans Health Administration (VHA) We discuss emerging strategies that will mitigate these limitations, including data sharing, application of natural language processing, and improved EMR user design.(10)

Pending Work

There is one remaining project in preparation, *Gaps in Standardized Postoperative Pain Management Quality Measures.* To help improve healthcare quality and safety, quality measures/indicators have been used for monitoring, quality improvement, public reporting, and pay for performance programs. The purpose of such quality measures is to promote and standardize clinical best practices. In the current opioid crisis, it is unclear which quality measures are used to guide and monitor safe and effective postoperative pain management. We conducted a systematic review of currently available quality metrics specific to postoperative pain management. We performed database searches of MEDLINE (PubMed), ProQuest, and TRIP for the period between January 1946 and March 11 2020. We also searched the National Quality Forum (NQF), Agency for Healthcare Research and Quality (AHRQ), and Centers for Medicare & Medicaid Services (CMS) search tools for quality measures. Two reviewers independently extracted the data from selected articles using a standardized form. Of the 206 articles meeting criteria, total of 17 post-operative pain quality measures were identified and four of these were endorsed by the National Quality Forum. These results underscore the need to create valid quality measures to guide safe and effective opioid prescriptions for acute postoperative pain management.

List of Publications and Products

1. Tedesco D, Gori D, Desai KR, Asch S, Carroll IR, Curtin C, McDonald KM, Fantini MP, Hernandez-Boussard T. Drug-Free Interventions to Reduce Pain or Opioid Consumption After Total Knee Arthroplasty: A Systematic Review and Meta-analysis. JAMA Surg. 2017;152(10):e172872. doi: 10.1001/jamasurg.2017.2872. PubMed PMID: 28813550; PMCID: PMC5831469.
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