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Complete List of Authors:	Crandall, Marie; University of Florida College of Medicine - Jacksonville, Department of Surgery Sharp, Douglas ; Northwestern University, Mental Health Services and Policy Program Wei, Xiong; Sunnybrook Health Sciences Centre, Department of Surgery Nathens, Avery; Sunnybrook Health Sciences Centre, Department of Surgery Hsia, Renee; University of California, San Francisco, Department of Emergency Medicine
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Effects of Closure of an Urban Level I Trauma Center on Adjacent Hospitals and Local Injury Mortality

Marie Crandall, MD, MPH,[1] Douglas Sharp, MURP, PhD,[2] Xiong Wei, MSc,[3] Avery Nathens, MD, PhD, MPH,[3] Renee Y. Hsia, MD, MSc[4]

[1]Department of Surgery, University of Florida College of Medicine; Jacksonville, Florida, USA

[2]Mental Health Services and Policy Program, Northwestern University; Chicago, Illinois, USA

[3]Department of Surgery, Sunnybrook Health Sciences Centre; Toronto, Ontario, Canada

[4]Department of Emergency Medicine and Philip R. Lee Institute for Health Policy Studies, University of California, San Francisco; San Francisco, California, USA

Corresponding author:
Marie Crandall, MD, MPH, FACS
Professor of Surgery, Department of Surgery
University of Florida College of Medicine Jacksonville
655 W. 8th Street
Jacksonville, FL 32209
O: 904-244-6631
F: 904-244-3415
marie.crandall@jax.ufl.edu

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ABSTRACT

Objective: To determine the association of the Martin Luther King, Jr. Hospital (MLK) closure on the distribution of admissions on adjacent trauma centers and injury mortality rates in these centers and within the county.

Design: Observational, retrospective study.

Setting: Non-public patient-level data from the state of California were obtained for all trauma patients from 1999-2009. Geospatial analysis was used to visualize the redistribution of trauma patients to other hospitals after MLK closed. Variance of observed to expected injury mortality using multivariate logistic regression was estimated for the study period.

Participants: A total of 37,131 trauma patients were admitted to the five major south Los Angeles trauma centers from the MLK service area between 1999 and 2009.

Main outcome measures: (1) number and type of trauma admissions to trauma centers in closest proximity to MLK; (2) in-hospital injury mortality of trauma patients after the trauma center closure.

Results: During and after the MLK closure, trauma admissions increased at three of four nearby hospitals, particularly admissions for gunshot wounds (GSWs). This redistribution of patient load was accompanied by a dramatic change in the payer mix for surrounding hospitals; one hospital's share of uninsured more than tripled from 12.9% in 1999 to 44.6% by 2009. Overall trauma mortality did not significantly change, but GSW mortality steadily and significantly increased after the closure from 5.0% in 2007 to 7.5% in 2009.

Conclusions: Though local hospitals experienced a dramatic increase in trauma patient volume, overall mortality for trauma patients did not significantly change after MLK closed.

ARTICLE SUMMARY

Strengths and Limitations of this study:

- The study utilized geospatial analysis to identify a boundary of 32 contiguous zip codes to define the MLK service area, which contained over 80% of the trauma admissions to MLK during the study period.
- Zip codes were utilized instead of predetermined drawn catchment areas to simplify the quantitative data analysis.
- The analysis captured the years leading up to the MLK closure, the closure transition period including trauma center des-designation, and two years after the hospital closure.
- The study is unique to one particular trauma system in a local context, and thus the findings cannot be extrapolated to all areas of the country that have experienced closures of trauma centers.

INTRODUCTION

Trauma is the leading cause of death for all Americans ages 1-44, claiming more than 180,000 lives annually, and injury is a leading cause of death and disability among children and adults.[1] There are currently more than 1,000 trauma centers in the U.S., which are hospitals that have committed resources to the care of the injured patient. California trauma centers are designated as Level I-IV. All centers must have a multidisciplinary trauma team and an ED, and all must have personnel, services, and equipment necessary to care for trauma patients. Trauma centers, as part of organized trauma systems, have been shown to improve injury mortality by 10-20% compared with areas that do not have specialized trauma care.[2-4]

Current literature documenting hospital[5,6] and emergency department (ED) closures[7-10] has produced controversial findings; some studies have shown associations with higher mortality due to deteriorating access,[7] while others have shown no association with poorer outcomes.[6] Several studies have specifically examined closures of trauma centers,[11,12] but to our knowledge, few have discussed the population effects on outcomes as a result of trauma center closures.[13]

Given the conflicting evidence for hospital and ED closures, and the paucity of evidence of how trauma center closures specifically affect outcomes, the goal of this study was to focus on one trauma center closure in a specific context, using it as a case study to show how there may be different effects based on particular contexts. We studied Martin Luther King Jr./Drew Medical Center, currently a multi-service ambulatory care center in the southwest region of Los Angeles County, serving the communities of Compton, Watts, and Willowbrook.[14]

In response to the lack of sufficient access to health care and opportunities in this low-income area,[15] the Martin Luther King Jr. Hospital (MLK) was opened in 1972, then designated as a Level I trauma center in 1983.[16] Despite the hospital's assets, a series of highly publicized deaths led to the closure of the cardiac monitoring unit in 2003, and then MLK's re-designation as a Level II trauma center in early 2004. Trauma center designation was removed completely from MLK by the end of 2004, but the inpatient and emergency services remained open in the hopes of improving existing services. By 2006, more patient deaths at MLK were reported as attributable to medical errors, and all inpatient and emergency services were closed in 2007. Following this closure, a provision plan was created for emergency transport and staffing at nearby public and private hospitals, given that the closure of the second-busiest trauma center in Los Angeles might adversely affect both neighboring hospitals and local communities.[17,18] Subsequent impact analyses were also reported, noting challenges and highlighting the need for a comprehensive care plan for the area.[18-21]

This study seeks to fill this gap in literature by evaluating the redistribution of the volume of injured patients on neighboring hospitals as well as trauma mortality of admitted patients within these hospitals and overall mortality in the county. We hypothesized that the MLK closure in 2007 significantly impacted the volume of trauma patients at other south Los Angeles hospitals and potentially increased the trauma mortality for south Los Angeles.

METHODS

Study Design and Data Sources

The authors used non-public patient-level data from the California Office of Statewide Health Planning and Development (OSHPD) for all patients admitted to general, acute, non-federal hospitals in the state of California. We limited the dataset to all trauma patients in south Los Angeles during the study period from 1999-2009. We performed an observational, retrospective study of Patient Discharge Data (PDD) for the years leading up to the MLK closure

(1999-2003), the closure transition period including trauma center de-designation (2004-2007), and two years after hospital closure (2008-2009).

Patient Population

We first characterized the patient sample with simple descriptive statistics, including trauma admissions, demographics, and injury mortality. We then utilized geospatial analysis to identify a boundary of 32 contiguous zip codes to define the MLK service area. This service area contained over 80% of the trauma admissions to MLK during the study period. We utilized zip codes instead of predetermined drawn catchment areas to simplify the quantitative data analysis. This boundary included the 31 zip codes that had the largest number of total admissions of any kind to MLK and the 29 zip codes that had the largest number of trauma admissions to MLK while it was in operation.

Trauma admissions included those defined by the International Classification of Disease, Ninth Revision (ICD-9) diagnosis codes 800–904.9, 910–929.9, and 950–959.9 in either the principal diagnosis or in any of the 24 secondary diagnoses in our dataset (N=117,161), excluding visits with ICD-9 codes indicating drowning, burns, bites and stings, overexertion, poisonings, foreign body, suffocation or late effects of injury, as well as those with a sole traumatic ICD-9 diagnosis of strains and sprains, or contusions with intact skin surface.[22] Burns were excluded because definitive care is provided at LA County-USC, a specialized burn center. Patients who did not have an injury mechanism as denoted by an E-code (external cause of injury) were excluded (N=854), leaving a total of 82,019 admissions for the analysis.

Main Outcome Measures

The primary outcome of interest was the number and type of trauma admissions to trauma centers in closest proximity to MLK. The trauma centers (TCs) within 10 miles of MLK were: TC1 (Level II, 2.3 miles from MLK), TC2 (Level I, 7.0 miles from MLK), TC3 (Level II, 7.9 miles from MLK), and TC4 (Level I, 9.6 miles from MLK).

The secondary outcome of interest was in-hospital injury mortality of trauma patients after the trauma center closure. The observed mortality rate was compared to expected mortality rate using a risk-adjusted model incorporating age, injury severity, survival risk, injury mechanism, gender, year, patient insurance status, and race for each hospital and for the MLK service area.

Statistical Methods

We used descriptive analyses to evaluate the primary outcome of number and type of trauma admissions to different facilities. For our secondary outcome, predicted mortality for the region was calculated using separate models for each of the most common mechanisms of injury (stab wounds, gunshot wounds, falls, and motor vehicle collisions), and overall. Model covariates included age, gender, insurance status, race, ISS>16, Survival Risk Rate, and year. All of these variables are known to have an effect on injury mortality.

Injury severity was measured by the Injury Severity Score (ISS). We used ICDPIC v3.0 for Stata v11[23] (StataCorp, College Station, TX) to calculate the ISS from ICD-9 codes. We used the accepted standards of categorizing injury severity by creating a binary variable denoting severe (ISS>16) and less severe (ISS≤16).[24,25]

Survival Risk Ratios (SRRs) associated with each of the relevant ICD-9 codes were obtained from the American College of Surgeons Trauma Quality Improvement Program (TQIP) for both blunt and penetrating trauma. These rates were calculated from 2011 nationwide injury survival statistics, then matched to the ICD-9 codes recorded for each case. The lowest rate for each case was then used in the model. Of note, a proportion of diagnostic codes did not match SRRs.

We first estimated mortality models for each common injury mechanism and traumas overall in the MLK service area. To do this, we utilized pre-closure mortality data from all hospitals that served the MLK catchment area. We controlled for age, race, gender, insurance status, ISS, SRR, and a continuous time variable.[26] The time variable was included to account for secular trends in trauma incidence, mechanism, and mortality rates. We then compared observed mortality rates with rates predicted by the risk-adjusted model for hospitals serving the MLK catchment area. Confidence intervals for predicted mortality were calculated based on the standard errors associated with the predicted values.

All statistical analyses used Stata v11 (College Station, TX). Geospatial analysis was performed using Arc-GIS 10 software (Esri, Redlands, CA). This study was approved by the University of California, San Francisco Committee on Human Research and the California Committee for the Protection of Human Subjects.

RESULTS

South Los Angeles County trauma volumes across hospitals

Between 1999 and 2009, a total of 37,131 trauma patients were admitted to the five major south Los Angeles trauma centers from the MLK service area. There was no significant change in total annual admissions at the five hospitals over the time period, with 3,236 admissions in 1999, to a peak of 3,546 in 2003, and down to 3,173 by 2009. By contrast, admissions at individual hospitals in the MLK service area experienced marked longitudinal trends. Despite trauma center downsizing and eventual de-designation by the end of 2004, hundreds of injured patients continued to be seen at MLK until its closure. TC4, the busiest trauma center in the area, had a significant drop in admissions over the study period. However, the three other nearby centers experienced increases in trauma volumes after the MLK closure. TC3, which had not been a trauma center prior to MLK's closure, but was given a Level II designation to increase local capacitance, saw a 10-fold increase in trauma admissions (Figure 1).

Demographic and injury severity redistribution across hospitals

TCs 1-3 experienced marked increases in the proportion of gunshot wound admissions after MLK closed; a 2-fold increase at TCs 1 & 2 (approximately 150 to 300 patients annually) and a 10-fold increase at TC 3 (from 10 to 300 patients annually), which were all statistically significant (p-values for all <0.001). Over the entire time period, injury severity as measured by the proportion of patients with an ISS>16 also increased at TCs 1 (9.1% to 14.8%, p <0.001) and 3 (3.1% to 11.1%, p <0.001). Gender mix and mean age of trauma patients only changed significantly at TC3, transitioning to an overall younger (mean age dropped from 54.1 to 39.9 years) and more male (from 38.7% to 68.3%) population (p-value for gender <0.001, p-value for change in mean age <0.001). Payer mix changed substantially at TCs 1 and 3, with an annual increase in uninsured patients (Figure 2). TC1 originally began in 1999 with 24.1% of their trauma patients as uninsured, which increased to 44.6% by 2009. TC3 saw an even more dramatic increase, with 12.9% of their trauma patients uninsured in 1999, and more than tripling to 44.6% in 2009.

Over 85% percent of trauma admissions in the MLK service area during the study period were African American or Latino. None of the 5 TCs in the study cared for a trauma patient population that was more than 15% Caucasian. TC1 saw an increase of non-white patients from 84.9% to 95.4% during the study period ($p< 0.001$). TC2 saw an increase of non-white patients from 91.9% to 97.0% ($p< 0.001$). TC3 saw an increase from 97.5% to 98.5% ($p= 0.179$).

Injury mortality

Unadjusted mortality

Though total trauma admissions generally remained constant during the study period, overall injury mortality for individual centers experienced wide year-to-year variations in unadjusted mortality, particularly at TCs 1, 2, and 3, beginning with the transition to MLK closure.

Adjusted mortality

We first created a model to predict injury mortality in the MLK service area by utilizing pre-closure admissions data from all hospitals that served the area, controlling for age, race, insurance status, ISS, SRR, injury mechanism, and time. Time was accounted for using a continuous variable indicating year of the study period starting with zero for 1999. The four models had pseudo-R^2 ranging from 0.085 for stabbings to 0.369 for motor vehicle collisions, and were used to predict mortality for each patient from 1999-2009. Observed and predicted mortality within each year of the study period were calculated by aggregating actual and predicted deaths annually. Predicted annual mortality was calculated with 99% confidence intervals. In all models, SRRs were the variables most strongly associated with mortality. We found a small but statistically significant improvement in observed compared to predicted mortality rates from 2004-2009 (3.0% vs. 2.8% and 2.8% vs. 2.4%) for the overall trauma population (Figure 3). However, there was a statistically significant increase in GSW mortality beginning in 2004. The observed mortality increased from 5.0% to nearly 7.5% ($p < 0.001$) in the years after the closure, and was nearly double the predicted mortality (Figure 4). As a sensitivity analysis, we also graphed observed versus predicted mortality rates for individual centers and found the same results.

DISCUSSION

Our findings show that after the MLK closure in 2007, trauma volumes rose significantly at all adjacent hospitals except for TC4, with a marked increase in patient volumes at TCs 1 and 3 in particular from 1999-2009. The substantial redistribution of the patient load was also accompanied by an increase in the severity of injured patients at hospitals that previously cared for less severely injured patients. In addition, certain hospitals experienced an extensive shift in the payer mix of their trauma populations, with one particular trauma center more than tripling its initial 1999 share of uninsured patients. In general, risk-adjusted mortality for trauma patients overall did not significantly change during the study period. However, we found a persistent and significant increase in mortality from GSWs after the closure. These findings may be explained by longer travel times and associated higher mortality for patients injured by GSWs,[27] random variation, or changes in weaponry. However, the latter is less likely, as our results were risk-adjusted by SRR and ISS. Finally, it may be that this increased mortality after the closure indicates particular expertise of the MLK trauma center in management of GSWs. Our conclusions cannot be necessarily extrapolated to other trauma center closures, since this particular closure was in the context of having overlapping and well-coordinated efforts by the county to provide adequate services. Our study does show that in these types of contexts, a trauma center closure may not necessarily lead to poorer outcomes.

Overall, violent crime rates decreased steadily during the study period, and homicide rates in LA County decreased from 9.1/100,000 to 6.7/100,000 by 2009. Given that the homicide rate overall was decreasing, it is also possible that the increased mortality for GSW victims in south Los Angeles could be linked to MLK closure.

Our findings have several implications for policymakers and health system planners. The MLK closure was not undertaken lightly and a transitional period of several years that included multiple efforts to improve quality outcomes was undertaken. These data demonstrate that the efforts of LA County to anticipate and forestall adverse events helped increase capacitance and decrease potentially negative impacts on trauma mortality despite dramatic increases in trauma volumes at nearby centers. An example of measures that were put in place included the creation of a new Level II Trauma Center in center of the MLK catchment area (TC3) to help safeguard this vulnerable population from excess injury mortality during and after the closure. Our findings are consistent with one previous study evaluating the effects of the MLK trauma center de-designation on Harbor-UCLA, which did not show an increase in mortality of the trauma admissions despite an increase in volume and injury severity.[28] A recent paper discussing trauma closures in California overall showed that trauma patients experiencing an increased distance to the nearest trauma center after a closure had higher inpatient mortality;[13] our findings within this local context showed that this was only true for a subset of patients with GSWs.

Given that penetrating injury is particularly time-sensitive, this could provide some explanation of the nuances of our findings.

This study raises an important question of whether hospital quality measures, which are aimed to serve as proxies for patient care and outcomes, are effective for evaluating trauma outcomes across hospitals. The decision to close MLK was based on its failure to meet minimal federal standards on hospital quality measures. These quality measures include many aspects of inpatient and outpatient care, including cardiovascular disease, end-stage renal disease, and respiratory care.[29] Though deaths and injuries related to medical errors are included in the Centers for Medicare & Medicaid Services (CMS) appraisal, measurements of trauma care were not, and are still not included in these quality indicators. Other investigators have found that CMS quality indicators do not correlate with risk-adjusted mortality rates at trauma centers.[30] Of concern for our particular study is that GSW mortality steadily rose after redistribution of care to other hospitals, which was one of the objections voiced by opponents to the trauma center closure. Moreover, the increase in mortality from GSWs is counter to national trends in trauma mortality and raises concerns about unanticipated effects, particularly in areas disproportionately burdened by gun violence. In the future, metrics such as those included in the TQIP, in addition to CMS quality measures, might be beneficial to help guide decisions about trauma center closures.[26,31]

Finally, this study highlights the potential financial implications faced by neighboring hospitals after a closure. It has been well-documented that "safety-net hospitals"[32] such as MLK that provide disproportionate amounts of care to low-income and poorly insured patients are vulnerable to closure,[12,33] and that trauma centers are more likely to close in areas with higher proportions of non-white individuals and a poorer payer mix.[10,11] As seen in our study, the reallocation of thousands of poorly-insured patients to nearby hospitals inevitably requires that they absorb the financial implications of caring for this population as well. Further research into these financial consequences, and how a health system can help minimize the shock on the system, is crucial.

This study has several limitations. It is a retrospective, observational study that includes only basic patient demographics and a calculated measurement of ISS. It also does not include pre-hospital data, such as measurements of systolic blood pressure and transport times, nor data about procedures performed, blood transfusions given, or other patient- and hospital-level data. However, it would be very difficult to undertake this type of study prospectively across multiple hospitals and a complicated EMS system in a large, urban setting. In addition, our findings that mortality was not impacted after the MLK closure does not take into account occurred fatalities that did not present to a trauma center, such as individuals pronounced dead at the scene. Furthermore, our dataset does not capture deaths occurring in the ED. Because the state began collecting ED data in 2005, we are unable to include ED deaths in our study. Our findings may actually be conservative in the sense that there may be a survival bias in patients who survived the transport to hospitals that were located farther away than MLK. Lastly, it also may be that these findings are unique to this particular trauma system in this local context. Contextual factors likely play an important role in the impact of these closures on the surrounding communities and our findings cannot be extrapolated to all areas of the country that have experienced trauma center closures.

CONCLUSIONS

Our study showed there was a significant redistribution of trauma patients to nearby hospitals after the MLK closure, with a marked increase of uninsured patients at certain hospitals. Overall, injury mortality did not change for trauma patients in south central Los Angeles, though concerns remain about the post-closure outcomes for GSW victims. Our findings shed hope on how careful planning, including using available technology such as geocoding methodology to map road traffic patterns and ambulance diversions to nearby hospitals, might anticipate potential pitfalls and inform decision-making with respect to resource allocation, ultimately to provide optimal patient care.

CONTRIBUTORSHIP

Study concept and design: Crandall, Sharp, Hsia, Nathens, Wei

Acquisition of data: Hsia

Analysis and interpretation of data: Crandall, Sharp, Hsia

Drafting of manuscript: Crandall

Critical revision of manuscript for important intellectual content: Crandall, Sharp, Hsia, Nathens, Wei

Statistical analysis: Sharp

Obtained funding: Crandall

Administrative, technical, or material support: Crandall, Sharp, Hsia, Nathens, Wei

Study supervision: Crandall

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COMPETING INTEREST

None declared.

DATA SHARING

Not applicable

REFERENCES

1. Injury Center: Overview. 2010; 2011. Available from: http://www.cdc.gov/injury/overview/.

2. Rutledge R, Fakhry SM, Meyer A, et al. An analysis of the association of trauma centers with per capita hospitalizations and death rates from injury. *Ann Surg* 1993;218:512-21.

3. Nathens AB, Jurkovich GJ, Cummings P, et al. The effect of organized systems of trauma care on motor vehicle crash mortality. *JAMA* 2000;283:1990-4.

4. Nathens AB, Jurkovich GJ, Rivara FP, et al. Effectiveness of state trauma systems in reducing injury-related mortality: a national evaluation. *J Trauma* 2000;48:25-30.

5. Buchmueller TC, Jacobson M, Wold C. How far to the hospital?: the effect of hospital closures on access to care. *J Health Econ* 2006;25:740-61.

6. Joynt KE, Chatterjee P, Orav EJ, et al. Hospital closures had no measurable impact on local hospitalization rates or mortality rates, 2003–11. *Health Aff (Millwood)* 2015;34:765-72.

7. Liu C, Srebotnjak T, Hsia RY. California emergency department closures are associated with increased inpatient mortality at nearby hospitals. *Health Aff (Millwood)* 2014;33:1323-9.

8. Shen YC, Hsia RY. Does decreased access to emergency departments affect patient outcomes? analysis of acute myocardial infarction population 1996–2005. *Health Serv Res* 2012;47:188-210.

9. Hsia RY, Kanzaria HK, Srebotnjak T, et al. Is emergency department closure resulting in increased distance to the nearest emergency department associated with increased inpatient mortality? *Ann Emerg Med* 2012;60:707-15.e4.

10. Hsia RY, Kellermann AL, Shen YC. Factors associated with closures of emergency departments in the United States. *JAMA* 2011;305:1978-85.

11. Shen YC, Hsia RY, Kuzma K. Understanding the risk factors of trauma center closures: do financial pressure and community characteristics matter? *Med Care* 2009;47:968-78.

12. Dailey JT, Teter H, Cowley RA. Trauma center closures: a national assessment. *J Trauma.*1992;33:539-46.

13. Hsia RY, Srebotnjak T, Maselli J, et al. The association of trauma center closures with increased inpatient mortality for injured patients. *J Trauma Acute Care Surg* 2014;76:1048-54.

14. Martin Luther King, Jr. Multi-service ambulatory care center. Los Angeles County Health Services;2011. Accessed on September 9, 2011. Available from: http://www.ladhs.org/wps/portal/KingHomepage.

15. McCone J. Report of the Governor's Commission on the Los Angeles Riots. Los Angeles;1965.

16. Designated Trauma Centers;2007. Accessed on September 9, 2011. Available from: http://www.emsa.ca.gov/systems/files/trauma/trma_ctr.pdf.

17. Critical Condition: Examining the scope of medical services in South Los Angeles. Los Angeles: The California Endowment;2007.

18. HASC Report: King-Harbor closure hospital inpatient impact analysis. Fact Sheet. Los Angeles: Hospital Association of Southern California;2008. Available from: http://www.lahealthaction.org/library/LADHS_Board_Report_and_HASCReportFactSheet032708.pdf

19. Achieving the vision: healthcare options for Los Angeles County. Los Angeles;2009.

20. Lott J. King-Harbor closure hospital inpatient impact analysis. Communication to Hospital Executives, Los Angeles County Region. Los Angeles: Hospital Association of Southern California;2008. Available from: http://www.hasc.org/.

21. Chernof B. Status of the implementation of the contingency services plan and Martin Luther King, Jr.--harbor hospital. Communication to the Los Angeles County Board of Supervisors. Los Angeles: Department of Health Services Los Angeles County;2008.

22. CDC. External cause-of-injury mortality matrix based on ICD-9 cause of injury codes. Atlanta, GA: Center for Disease Control;1997.

23. ICDPIC v3.0 for Stata. 2008;2011. Available from: http://ideas.repec.org/c/boc/bocode/s457028.html.

24. Ashkenazi I, Kessel B, Khashan T, et al. Precision of in-hospital triage in mass-casualty incidencts after terror attacks. *Prehosp Disaster Med* 2006;21:20-3.

25. Geiger AA, deRoon-Cassini T, Brasel KJ. Considering the patient's perspective in the injury severity score. *J Surg Res* 2011;170:133-8.

26. Shafi S, Nathens AB, Parks J, et al. Trauma quality improvement using risk-adjusted outcomes. *J Trauma* 2008;64:599-604.

27. Crandall M, Sharp D, Unger E, et al. Trauma deserts: distance from a trauma center, transport times, and mortality from gunshot wounds in Chicago. *Am J Public Health* 2013;103:1103-9.

28. Yaghoubian A, Lewis RJ, Putnam BA, et al. Impact on patient outcomes after closure of an adjacent trauma center. *Am Surg* 2008;74:930-4.

29. Roadmap for Quality Measurement in the Traditional Medicare Fee-for Service Program. In: Centers for Medicaire & Medicaid Services. Washington, D.C.;2008.

30. Shafi S, Parks J, Ahn C, et al. Centers for Medicare and Medicaid services quality indicators do not correlate with risk-adjusted mortality at trauma centers. *J Trauma* 2010;68:771-7.

31. Shafi S, Nathens AB, Cryer HG, et al. The trauma quality improvement program of the American College of Surgeons Committee on Trauma. *J Am Coll Surg* 2009;209:521-30 e1.

32. Baxter RJ, Mechanic RE. The status of local health care safety nets. *Health Aff (Millwood)* 1997;16:7-23.

33. Mansuri O, Hoonpongsimanont W, Vaca F, et al. The crisis in emergency and trauma care in california and the United States. *Cal J Emerg Med* 2006;7:81-6.

Figure 1. Annual Admissions, Trauma Centers Serving MLK Service Area

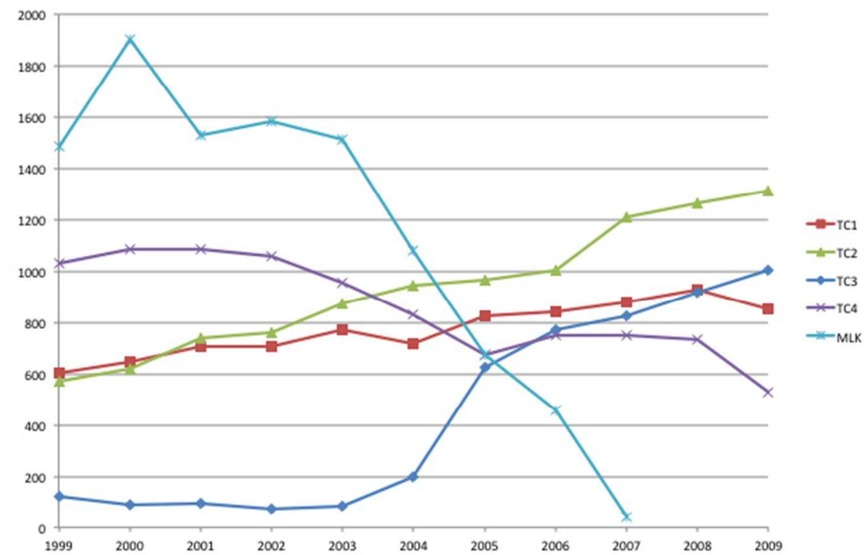

Figure 1. Annual Admissions, Trauma Centers Serving MLK Service Area
60x45mm (300 x 300 DPI)

Figure 2. MLK Area Trauma Centers, Percent Uninsured Patients

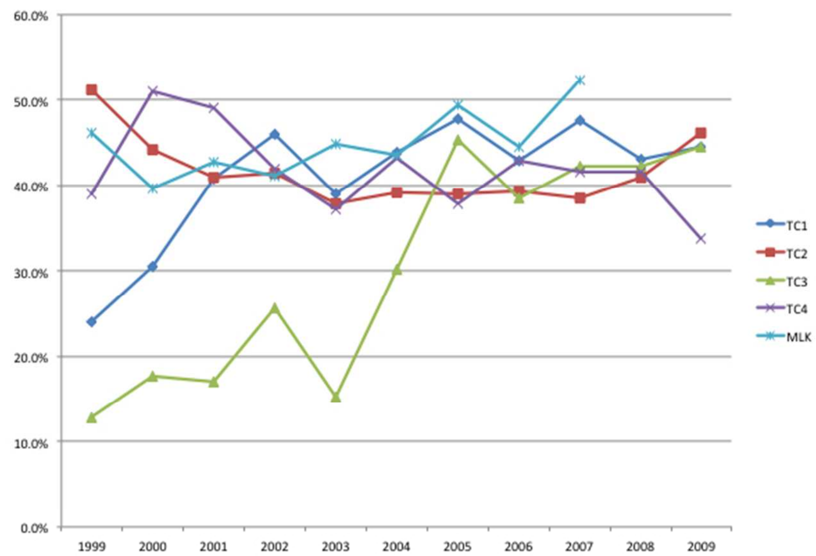

Figure 2. MLK Area Trauma Centers, Percent Uninsured Patients
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Figure 3. Overall Trauma Mortality Rates, 1999-2009

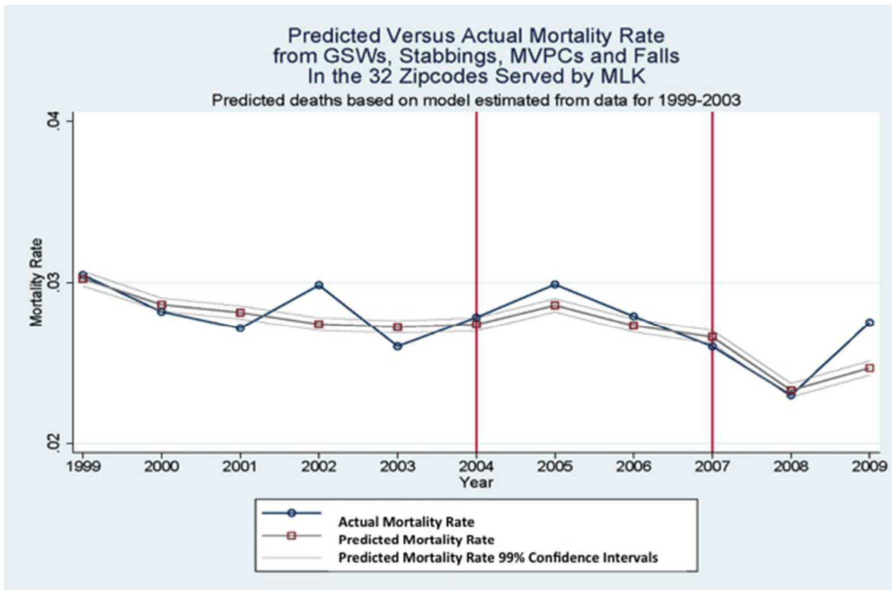

Figure 3. Overall Trauma Mortality Rates, 1999-2009
60x45mm (300 x 300 DPI)

Figure 4. Trauma Mortality for Gunshot Wounds, 1999-2009

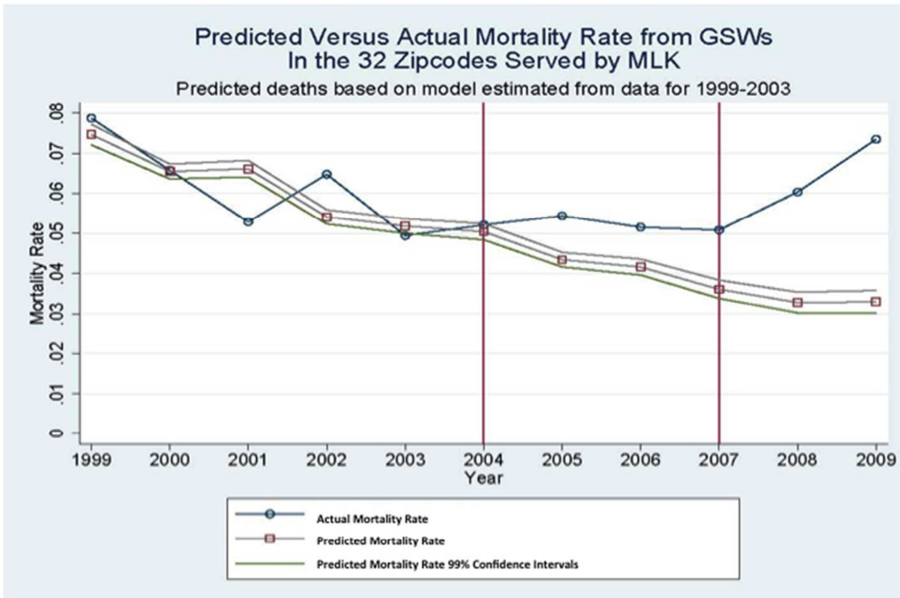

Figure 4. Trauma Mortality for Gunshot Wounds, 1999-2009
60x45mm (300 x 300 DPI)

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Marie Crandall, MD, MPH,[1] Douglas Sharp, MURP, PhD,[2] Xiong Wei, MSc,[3] Avery Nathens, MD, PhD, MPH,[3] Renee Y. Hsia, MD, MSc[4]

[1]Department of Surgery, University of Florida College of Medicine; Jacksonville, Florida, USA

[2]Mental Health Services and Policy Program, Northwestern University; Chicago, Illinois, USA

[3]Department of Surgery, Sunnybrook Health Sciences Centre; Toronto, Ontario, Canada

[4]Department of Emergency Medicine and Philip R. Lee Institute for Health Policy Studies, University of California, San Francisco; San Francisco, California, USA

Corresponding author:
Marie Crandall, MD, MPH, FACS
Professor of Surgery, Department of Surgery
University of Florida College of Medicine Jacksonville
655 W. 8th Street
Jacksonville, FL 32209
O: 904-244-6631
F: 904-244-3415
marie.crandall@jax.ufl.edu

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ABSTRACT

Objective: To determine the association of the Martin Luther King, Jr. Hospital (MLK) closure on the distribution of admissions on adjacent trauma centers and injury mortality rates in these centers and within the county.

Design: Observational, retrospective study.

Setting: Non-public patient-level data from the state of California were obtained for all trauma patients from 1999-2009. Geospatial analysis was used to visualize the redistribution of trauma patients to other hospitals after MLK closed. Variance of observed to expected injury mortality using multivariate logistic regression was estimated for the study period.

Participants: A total of 37,131 trauma patients were admitted to the five major south Los Angeles trauma centers from the MLK service area between 1999 and 2009.

Main outcome measures: (1) number and type of trauma admissions to trauma centers in closest proximity to MLK; (2) in-hospital injury mortality of trauma patients after the trauma center closure.

Results: During and after the MLK closure, trauma admissions increased at three of four nearby hospitals, particularly admissions for gunshot wounds (GSWs). This redistribution of patient load was accompanied by a dramatic change in the payer mix for surrounding hospitals; one hospital's share of uninsured more than tripled from 12.9% in 1999 to 44.6% by 2009. Overall trauma mortality did not significantly change, but GSW mortality steadily and significantly increased after the closure from 5.0% in 2007 to 7.5% in 2009.

Conclusions: Though local hospitals experienced a dramatic increase in trauma patient volume, overall mortality for trauma patients did not significantly change after MLK closed.

ARTICLE SUMMARY

Strengths and Limitations of this study:

- The study utilized geospatial analysis to identify a boundary of 32 contiguous zip codes to define the MLK service area, which contained over 80% of the trauma admissions to MLK during the study period.
- Zip codes were utilized instead of predetermined drawn catchment areas to simplify the quantitative data analysis.
- The analysis captured the years leading up to the MLK closure, the closure transition period including trauma center des-designation, and two years after the hospital closure.
- The study is unique to one particular trauma system in a local context, and thus the findings cannot be extrapolated to all areas of the country that have experienced closures of trauma centers.

INTRODUCTION

Trauma is the leading cause of death for all Americans ages 1-44, claiming more than 180,000 lives annually, and injury is a leading cause of death and disability among children and adults.[1] There are currently more than 1,000 trauma centers in the U.S., which are hospitals that have committed resources to the care of the injured patient. California trauma centers are designated as Level I-IV. All centers must have a multidisciplinary trauma team and an ED, and all must have personnel, services, and equipment necessary to care for trauma patients. Trauma centers, as part of organized trauma systems, have been shown to improve injury mortality by 10-20% compared with areas that do not have specialized trauma care.[2-4]

Current literature documenting hospital[5,6] and emergency department (ED) closures[7-10] has produced controversial findings; some studies have shown associations with higher mortality due to deteriorating access,[7] while others have shown no association with poorer outcomes.[6] Several studies have specifically examined closures of trauma centers,[11,12] but to our knowledge, few have discussed the population effects on outcomes as a result of trauma center closures.[13] Given the conflicting evidence for hospital and ED closures, and the paucity of evidence of how trauma center closures specifically affect outcomes, the goal of this study was to focus on one trauma center closure in a specific context, using it as a case study to show how there may be different effects based on particular contexts. We studied Martin Luther King Jr./Drew Medical Center, currently a multi-service ambulatory care center in the southwest region of Los Angeles County, serving the communities of Compton, Watts, and Willowbrook.[14] South Los Angeles is a distinct region of Los Angeles County that comprises 25 neighborhoods and three unincorporated districts. The population is approximately 95% African American and Latino, and despite being home to the University of Southern California and the Los Angeles Coliseum, the area is generally economically distressed and suffers high rates of trauma, particularly penetrating trauma such as gunshot wounds.

In response to the lack of sufficient access to health care and opportunities in this low-income area,[15] the Martin Luther King Jr. Hospital (MLK) was opened in 1972, then designated as a Level I trauma center in 1983.[16] Despite the hospital's assets, a series of highly publicized deaths led to the closure of the cardiac monitoring unit by December 2003, and then MLK's re-designation as a Level II trauma center in February 2004. Trauma center designation was removed completely from MLK in December 2004, but the inpatient and emergency services remained open in the hopes of improving existing services. By 2006, more patient deaths at MLK were reported as attributable to medical errors, and all inpatient and emergency services were closed in August 2007. Following this closure, a provision plan was created for emergency transport and staffing at nearby public and private hospitals, given that the closure of the second-busiest trauma center in Los Angeles might adversely affect both neighboring hospitals and local communities.[17,18] Subsequent impact analyses were also reported, noting challenges and highlighting the need for a comprehensive care plan for the area.[18-21]

This study seeks to fill this gap in literature by evaluating the redistribution of the volume of injured patients on neighboring hospitals as well as trauma mortality of admitted patients within these hospitals and overall mortality in the county. We hypothesized that the MLK closure in 2007 significantly impacted the volume of trauma patients at other south Los Angeles hospitals and potentially increased the trauma mortality for south Los Angeles.

METHODS

Study Design and Data Sources

We used non-public patient-level data from the California Office of Statewide Health Planning and Development (OSHPD) for all patients admitted to general, acute, non-federal hospitals in the state of California. We limited the dataset to all trauma patients in south Los Angeles during the study period from 1999-2009 using zip codes for this defined area. We performed an observational, retrospective study of Patient Discharge Data (PDD) for the years leading up to the MLK closure (1999-2003), the closure transition period including trauma center de-designation (2004-2007), and two years after hospital closure (2008-2009).

Patient Population

We first characterized the patient sample with simple descriptive statistics, including trauma admissions, demographics, and injury mortality. We then utilized geospatial analysis to identify a boundary of 32 contiguous zip codes to define the MLK service area for trauma incidents. This service area contained over 80% of the trauma admissions to MLK during the study period. We utilized zip codes instead of predetermined drawn catchment areas to simplify the quantitative data analysis. This boundary included the 31 zip codes that had the largest number of total admissions of any kind to MLK and the 29 zip codes that had the largest number of trauma admissions to MLK while it was in operation. We did not limit the population by age, though MLK was not a pediatric trauma center, because patients 15 and older would have been seen routinely, and younger patients may have been seen due to age uncertainty or self-transport.

Trauma admissions included those defined by the International Classification of Disease, Ninth Revision, Clinical Modification (ICD-9-CM) diagnosis codes 800–904.9, 910–929.9, and

950–959.9 in either the principal diagnosis or in any of the 24 secondary diagnoses in our dataset (N=117,161), excluding visits with ICD-9-CM codes indicating drowning, burns, bites and stings, overexertion, poisonings, foreign body, suffocation or late effects of injury, as well as those with a sole traumatic ICD-9-CM diagnosis of strains and sprains, or contusions with intact skin surface.[22] Burns were excluded because definitive care is provided at LA County-USC, a specialized burn center. Patients who did not have an injury mechanism as denoted by an E-code (external cause of injury) were excluded (N=854), leaving a total of 82,019 admissions for the analysis.

Main Outcome Measures

The primary outcome of interest was the number and type of trauma admissions to trauma centers in closest proximity to MLK. The trauma centers (TCs) within 10 miles of MLK were: TCA (Level II, 2.3 miles from MLK), TCB (Level I, 7.0 miles from MLK), TCC (Level II, 7.9 miles from MLK), and TCD (Level I, 9.6 miles from MLK).

The secondary outcome of interest was in-hospital injury mortality of trauma patients after the trauma center closure. The observed mortality rate was compared to expected mortality rate using a risk-adjusted model incorporating age, injury severity, survival risk, injury mechanism, gender, year, patient insurance status, and race for each hospital and for the MLK service area.

Statistical Methods

We used descriptive analyses to evaluate the primary outcome of number and type of trauma admissions to different facilities. For our secondary outcome, predicted mortality for the region was calculated using separate models for each of the most common mechanisms of injury (stab wounds, gunshot wounds, falls, and motor vehicle collisions), and overall. Model covariates included age, gender, insurance status, race, ISS>16, Survival Risk Ratio, and year. All of these variables are known to have an effect on injury mortality. Insurance status was categorized into self-pay, public, and private. Race was categorized into African American, Latino, Asian American, and White.

Injury severity was measured by the Injury Severity Score (ISS). We used ICDPIC v3.0 for Stata v11[23] (StataCorp, College Station, TX) to calculate the ISS from ICD-9 codes. We used the accepted standards of categorizing injury severity by creating a binary variable denoting severe (ISS>16) and less severe (ISS≤16).[24,25]

Survival Risk Ratios (SRRs) associated with each of the relevant ICD-9 codes were obtained from the American College of Surgeons Trauma Quality Improvement Program (TQIP) for both blunt and penetrating trauma. These values were calculated from 2011 nationwide injury survival statistics, then matched to the ICD-9 codes recorded for each case. The lowest ratio for each case was then used in the model. Of note, a proportion of diagnostic codes did not match SRRs. We deliberately used nationwide survival risk ratios to have the largest available sample to predict expected outcomes and to decrease any potential impact of regional variability.

We first estimated mortality models for each common injury mechanism and traumas overall in the MLK service area. To do this, we utilized pre-closure mortality data from all hospitals that served the MLK catchment area. We controlled for age, race, gender, insurance status, ISS, SRR, and a continuous time variable.[26] The time variable was included to account for secular trends in trauma incidence, mechanism, and mortality rates. We specifically examined mortality for GSWs, as MLK had historically cared for most of the GSW victims in the area, and the effects of MLK closure might be borne disproportionately by this group. We then compared observed mortality rates with rates predicted by the risk-adjusted model for hospitals serving the MLK catchment area. Confidence intervals for predicted mortality were calculated based on the standard errors associated with the predicted values.

All statistical analyses used Stata v11 (College Station, TX). Geospatial analysis was performed using Arc-GIS 10 software (Esri, Redlands, CA). This study was approved by the University of California, San Francisco Committee on Human Research and the California Committee for the Protection of Human Subjects.

RESULTS

South Los Angeles County trauma volumes across hospitals

Between 1999 and 2009, a total of 37,131 trauma patients were admitted to the five major south Los Angeles trauma centers from the MLK service area. There was no significant change in total annual admissions at the five hospitals over the time period, with 3,236 admissions in 1999, to a peak of 3,546 in 2003, and down to 3,173 by 2009. By contrast, admissions at individual hospitals in the MLK service area experienced marked longitudinal trends. Despite trauma center catchment area downsizing and eventual de-designation between February and December of 2004, over 1000 trauma patients were seen at MLK in 2004, more than 500 in 2005, and over 450 in 2006. TCD, the busiest trauma center in the area, had a significant drop in admissions over the study period. However, the three other nearby centers experienced increases in trauma volumes after the MLK closure. TCC, which had not been a trauma center prior to MLK's closure, but was given a Level II designation to increase local capacitance, saw a 10-fold increase in trauma admissions (Figure 1).

Demographic and injury severity redistribution across hospitals

Patient mechanisms of injury at the five area trauma centers were very different from each other during the study period (Table 1), with MLK seeing much higher numbers and percentages of penetrating trauma. Several centers saw significant changes after the closure of MLK. TCs A, B, & C experienced marked increases in the proportion of gunshot wound admissions after MLK closed; a 2-fold increase at TCs A & B (approximately 150 to 300 patients annually) and a 10-fold increase at TCC (from 10 to 300 patients annually), which were all statistically significant (p-values for all <0.001).

Over the entire time period, injury severity as measured by the proportion of patients with an ISS>16 also increased at TCA (9.1% to 14.8%, p <0.001) and TCC (3.1% to 11.1%, p <0.001). Gender mix and mean age of trauma patients only changed significantly at TCC, transitioning to an overall younger (mean age dropped from 54.1 to 39.9 years) and more male (from 38.7% to 68.3%) population (p-value for gender <0.001, p-value for change in mean age <0.001). Payer mix changed substantially at TCA and TCC, with an annual increase in uninsured patients (Figure 2). TCA originally began in 1999 with 24.1% of their trauma patients as uninsured, which increased to 44.6% by 2009. TCC saw an even more dramatic increase, with 12.9% of their trauma patients uninsured in 1999, and more than tripling to 44.6% in 2009.

Over 85% percent of trauma admissions in the MLK service area during the study period were African American or Latino. None of the five TCs in the study cared for a trauma patient population that was more than 15% Caucasian. TCA saw an increase of non-white patients from 84.9% to 95.4% during the study period (p< 0.001). TCB saw an increase of non-white patients from 91.9% to 97.0% (p< 0.001). TCC saw an increase from 97.5% to 98.5% (p= 0.179).

Injury mortality

Unadjusted mortality

Though total trauma admissions generally remained constant during the study period, overall injury mortality for individual centers experienced wide year-to-year variations in unadjusted mortality, particularly at TCs 1, 2, and 3, beginning with the transition to MLK closure.

Adjusted mortality

We first created a model to predict injury mortality in the MLK service area by utilizing pre-closure admissions data from all hospitals that served the area, controlling for age, race, insurance status, ISS, SRR, injury mechanism, and time. Time was accounted for using a continuous variable indicating year of the study period starting with zero for 1999. The four models had pseudo-R^2 ranging from 0.085 for stabbings to 0.369 for motor vehicle collisions, and were used to predict mortality for each patient from 1999-2009. Observed and predicted mortality within each year of the study period were calculated by aggregating actual and predicted deaths annually. Predicted annual mortality was calculated with 99% confidence intervals. In all models, SRRs were the variables most strongly associated with mortality. We found a small but statistically significant improvement in observed compared to predicted mortality rates from 2004-2009 (3.0% vs. 2.8% and 2.8% vs. 2.4%) for the overall trauma population (Figure 3). However, there was a statistically significant increase in GSW mortality beginning in 2004. The observed mortality increased from 5.0% to nearly 7.5% ($p < 0.001$) in the years after the closure, and was nearly double the predicted mortality (Figure 4). As a sensitivity analysis, we also graphed observed versus predicted mortality rates for individual centers and found the same results.

DISCUSSION

Our findings show that after the MLK closure in 2007, trauma volumes rose significantly at all adjacent hospitals except for TCD, with a marked increase in patient volumes at TCs 1 and 3 in particular from 1999-2009. The substantial redistribution of the patient load was also accompanied by an increase in the severity of injured patients at hospitals that previously cared for less severely injured patients. In addition, certain hospitals experienced an extensive shift in the payer mix of their trauma populations, with one particular trauma center more than tripling its initial 1999 share of uninsured patients. In general, risk-adjusted mortality for trauma patients overall did not significantly change during the study period. However, we found a persistent and significant increase in mortality from GSWs after the closure. These findings may be explained by longer travel times and associated higher mortality for patients injured by GSWs,[27] random variation, or changes in weaponry though the latter is less likely, as our results were risk-adjusted by SRR and ISS. Finally, it may be that this increased mortality after the closure indicates particular expertise of the MLK trauma center in management of GSWs. However, given the relative lack of granularity of our risk stratification (the data set lacked ED blood pressure, transfusion data, base deficit, and other predictors of survival), we cannot make a definitive statement about this. Our conclusions cannot be necessarily extrapolated to other trauma center closures, since this particular closure was in the context of having overlapping and well-coordinated efforts by the county to provide adequate services. Our study does show that in these types of contexts, a trauma center closure may not necessarily lead to poorer outcomes.

Overall, violent crime rates decreased steadily during the study period, and homicide rates in LA County decreased from 9.1/100,000 to 6.7/100,000 by 2009. Given that the homicide rate overall was decreasing, it is also possible that the increased mortality for GSW victims in south Los Angeles could be linked to MLK closure.

Our findings have several implications for policymakers and health system planners. The MLK closure was not undertaken lightly and a transitional period of several years that included multiple efforts to improve quality outcomes was undertaken. These data demonstrate that the efforts of LA County to anticipate and forestall adverse events helped increase capacitance and decrease potentially negative impacts on trauma mortality despite dramatic increases in trauma volumes at nearby centers. An example of measures that were put in place included the creation of a new Level II Trauma Center in center of the MLK catchment area (TCC) to help safeguard this vulnerable population from excess injury mortality during and after the closure. Our findings are consistent with one previous study evaluating the effects of the MLK trauma center de-designation on Harbor-UCLA, which did not show an increase in mortality of the trauma admissions despite an increase in volume and injury severity.[28] A recent paper discussing trauma closures in California overall showed that trauma patients experiencing an increased distance to the nearest trauma center after a closure had higher inpatient mortality;[13] our findings within this local context showed that this was only true for a subset of patients with GSWs. Given that penetrating injury is particularly time-sensitive, this could provide some explanation of the nuances of our findings.

This study raises an important question of whether hospital quality measures, which are aimed to serve as proxies for patient care and outcomes, are effective for evaluating trauma outcomes across hospitals. The decision to close MLK was based on its failure to meet minimal federal standards on hospital quality measures. These quality measures include many aspects of inpatient and outpatient care, including cardiovascular disease, end-stage renal disease, and respiratory care.[29] Though deaths and injuries related to medical errors are included in the Centers for Medicare & Medicaid Services (CMS) appraisal, measurements of trauma care were not, and are still not included in these quality indicators. Other investigators have found that CMS quality indicators do not correlate with risk-adjusted mortality rates at trauma centers.[30] Of concern for our particular study is that GSW mortality steadily rose after redistribution of care to other hospitals, which was one of the objections voiced by opponents to the trauma center closure. Moreover, the increase in mortality from GSWs is counter to national trends in trauma mortality and raises concerns about unanticipated effects, particularly in areas disproportionately burdened by gun violence. In the future, metrics such as those included in the TQIP, in addition to CMS quality measures, might be beneficial to help guide decisions about trauma center closures.[26,31]

Finally, this study highlights the potential financial implications faced by neighboring hospitals after a closure. It has been well-documented that “safety-net hospitals”[32] such as MLK that provide disproportionate amounts of care to low-income and poorly insured patients are vulnerable to closure,[12,33] and that trauma centers are more likely to close in areas with higher proportions of non-white individuals and a poorer payer mix.[10,11] As seen in our study, the reallocation of thousands of poorly-insured patients to nearby hospitals inevitably requires that they absorb the financial implications of caring for this population as well. Further research into these financial consequences, and how a health system can help minimize the shock on the system, is crucial.

This study has several limitations. It is a retrospective, observational study that includes only basic patient demographics and a calculated measurement of ISS. It also does not include pre-hospital data, such as measurements of systolic blood pressure and transport times, nor data about procedures performed, blood transfusions given, or other patient- and hospital-level data. However, it would be very difficult to undertake this type of study prospectively across multiple hospitals and a complicated EMS system in a large, urban setting. Also, we deliberately did not limit our study population to adults, in the hopes of providing the most accurate representation of the MLK patient population. However, this inclusion may have actually biased our results to the null if most injured children were being taken to other local pediatric trauma centers, which would make any volume or outcome-related changes after the closure appear smaller overall.

In addition, our findings that mortality was not impacted after the MLK closure does not take into account fatalities that did not present to a trauma center, such as individuals pronounced dead at the scene. Furthermore, our dataset does not capture deaths occurring in the ED. Because the state began collecting ED data in 2005, we are unable to include ED deaths in our study. Our findings may actually be conservative in the sense that there may be a survival bias in patients who survived the transport to hospitals that were located farther away than MLK. Lastly, it also may be that these findings are unique to this particular trauma system in this local context. Contextual factors likely play an important role in the impact of these closures on the surrounding communities and our findings cannot be extrapolated to all areas of the country that have experienced trauma center closures.

CONCLUSIONS

Our study showed there was a significant redistribution of trauma patients to nearby hospitals after the MLK closure, with a marked increase of uninsured patients at certain hospitals. Overall, injury mortality did not change for trauma patients in south central Los Angeles, though concerns remain about the post-closure outcomes for GSW victims. Our findings shed hope on how careful planning, including using available technology such as geocoding methodology to map road traffic patterns and ambulance diversions to nearby hospitals, might anticipate potential pitfalls and inform decision-making with respect to resource allocation, ultimately to provide optimal patient care.

CONTRIBUTORSHIP

Study concept and design: Crandall, Sharp, Hsia, Nathens, Wei

Acquisition of data: Hsia

Analysis and interpretation of data: Crandall, Sharp, Hsia

Drafting of manuscript: Crandall

Critical revision of manuscript for important intellectual content: Crandall, Sharp, Hsia, Nathens, Wei

Statistical analysis: Sharp

Obtained funding: Crandall

Administrative, technical, or material support: Crandall, Sharp, Hsia, Nathens, Wei

Study supervision: Crandall

FUNDING

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COMPETING INTEREST

None declared.

DATA SHARING

No additional data available.

REFERENCES

1. Injury Center: Overview. 2010; 2011. Available from: http://www.cdc.gov/injury/overview/.

2. Rutledge R, Fakhry SM, Meyer A, et al. An analysis of the association of trauma centers with per capita hospitalizations and death rates from injury. *Ann Surg* 1993;218:512-21.

3. Nathens AB, Jurkovich GJ, Cummings P, et al. The effect of organized systems of trauma care on motor vehicle crash mortality. *JAMA* 2000;283:1990-4.

4. Nathens AB, Jurkovich GJ, Rivara FP, et al. Effectiveness of state trauma systems in reducing injury-related mortality: a national evaluation. *J Trauma* 2000;48:25-30.

5. Buchmueller TC, Jacobson M, Wold C. How far to the hospital?: the effect of hospital closures on access to care. *J Health Econ* 2006;25:740-61.

6. Joynt KE, Chatterjee P, Orav EJ, et al. Hospital closures had no measurable impact on local hospitalization rates or mortality rates, 2003–11. *Health Aff (Millwood)* 2015;34:765-72.

7. Liu C, Srebotnjak T, Hsia RY. California emergency department closures are associated with increased inpatient mortality at nearby hospitals. *Health Aff (Millwood)* 2014;33:1323-9.

8. Shen YC, Hsia RY. Does decreased access to emergency departments affect patient outcomes? analysis of acute myocardial infarction population 1996–2005. *Health Serv Res* 2012;47:188-210.

9. Hsia RY, Kanzaria HK, Srebotnjak T, et al. Is emergency department closure resulting in increased distance to the nearest emergency department associated with increased inpatient mortality? *Ann Emerg Med* 2012;60:707-15.e4.

10. Hsia RY, Kellermann AL, Shen YC. Factors associated with closures of emergency departments in the United States. *JAMA* 2011;305:1978-85.

11. Shen YC, Hsia RY, Kuzma K. Understanding the risk factors of trauma center closures: do financial pressure and community characteristics matter? *Med Care* 2009;47:968-78.

12. Dailey JT, Teter H, Cowley RA. Trauma center closures: a national assessment. *J Trauma.*1992;33:539-46.

13. Hsia RY, Srebotnjak T, Maselli J, et al. The association of trauma center closures with increased inpatient mortality for injured patients. *J Trauma Acute Care Surg* 2014;76:1048-54.

14. Martin Luther King, Jr. Multi-service ambulatory care center. Los Angeles County Health Services;2011. Accessed on September 9, 2011. Available from: http://www.ladhs.org/wps/portal/KingHomepage.

15. McCone J. Report of the Governor's Commission on the Los Angeles Riots. Los Angeles;1965.

16. Designated Trauma Centers;2007. Accessed on September 9, 2011. Available from: http://www.emsa.ca.gov/systems/files/trauma/trma_ctr.pdf.

17. Critical Condition: Examining the scope of medical services in South Los Angeles. Los Angeles: The California Endowment;2007.

18. HASC Report: King-Harbor closure hospital inpatient impact analysis. Fact Sheet. Los Angeles: Hospital Association of Southern California;2008. Available from: http://www.lahealthaction.org/library/LADHS_Board_Report_and_HASCReportFactSheet032708.pdf

19. Achieving the vision: healthcare options for Los Angeles County. Los Angeles;2009.

20. Lott J. King-Harbor closure hospital inpatient impact analysis. Communication to Hospital Executives, Los Angeles County Region. Los Angeles: Hospital Association of Southern California;2008. Available from: http://www.hasc.org/.

21. Chernof B. Status of the implementation of the contingency services plan and Martin Luther King, Jr.--harbor hospital. Communication to the Los Angeles County Board of Supervisors. Los Angeles: Department of Health Services Los Angeles County;2008.

22. CDC. External cause-of-injury mortality matrix based on ICD-9 cause of injury codes. Atlanta, GA: Center for Disease Control;1997.

23. ICDPIC v3.0 for Stata. 2008;2011. Available from: http://ideas.repec.org/c/boc/bocode/s457028.html.

24. Ashkenazi I, Kessel B, Khashan T, et al. Precision of in-hospital triage in mass-casualty incidencts after terror attacks. *Prehosp Disaster Med* 2006;21:20-3.

25. Geiger AA, deRoon-Cassini T, Brasel KJ. Considering the patient's perspective in the injury severity score. *J Surg Res* 2011;170:133-8.

26. Shafi S, Nathens AB, Parks J, et al. Trauma quality improvement using risk-adjusted outcomes. *J Trauma* 2008;64:599-604.

27. Crandall M, Sharp D, Unger E, et al. Trauma deserts: distance from a trauma center, transport times, and mortality from gunshot wounds in Chicago. *Am J Public Health* 2013;103:1103-9.

28. Yaghoubian A, Lewis RJ, Putnam BA, et al. Impact on patient outcomes after closure of an adjacent trauma center. *Am Surg* 2008;74:930-4.

29. Roadmap for Quality Measurement in the Traditional Medicare Fee-for Service Program. In: Centers for Medicaire & Medicaid Services. Washington, D.C.;2008.

30. Shafi S, Parks J, Ahn C, et al. Centers for Medicare and Medicaid services quality indicators do not correlate with risk-adjusted mortality at trauma centers. *J Trauma* 2010;68:771-7.

31. Shafi S, Nathens AB, Cryer HG, et al. The trauma quality improvement program of the American College of Surgeons Committee on Trauma. *J Am Coll Surg* 2009;209:521-30 e1.

32. Baxter RJ, Mechanic RE. The status of local health care safety nets. *Health Aff (Millwood)* 1997;16:7-23.

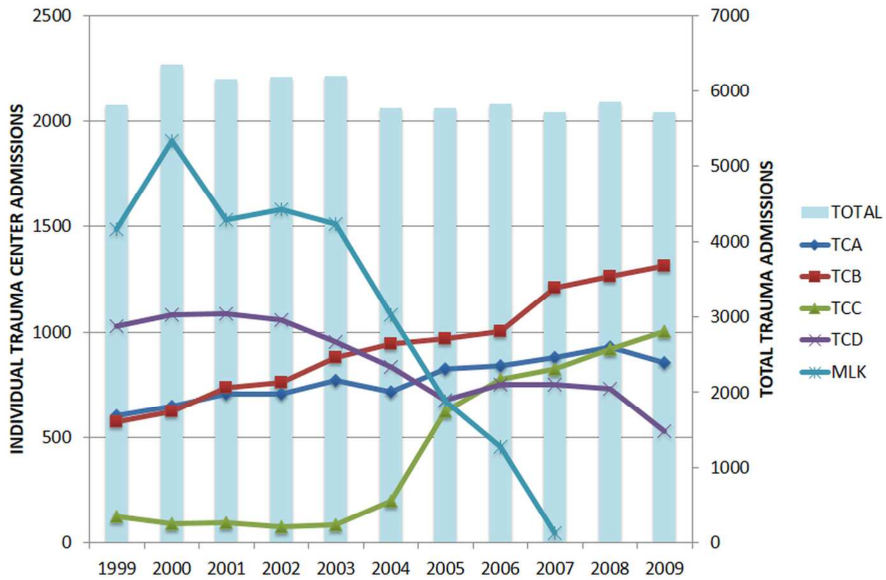
33. Mansuri O, Hoonpongsimanont W, Vaca F, et al. The crisis in emergency and trauma care in california and the United States. *Cal J Emerg Med* 2006;7:81-6.

Table 1: Trauma volumes by hospital and most common mechanisms, 1999-2009

	TCA N (%)	TCB N (%)	TCC N (%)	TCD N (%)	MLK N (%)
GSW*	987 (22)	1841 (22)	1522 (18)	1296 (17)	2752 (33)
SW#	322 (7)	487 (6)	315 (4)	496 (7)	499 (5)
MVC^	1443 (32)	2121 (26)	3272 (39)	2553 (33)	2229 (27)
Falls	1753 (39)	3855 (46)	3346 (40)	3280 (43)	2762 (34)

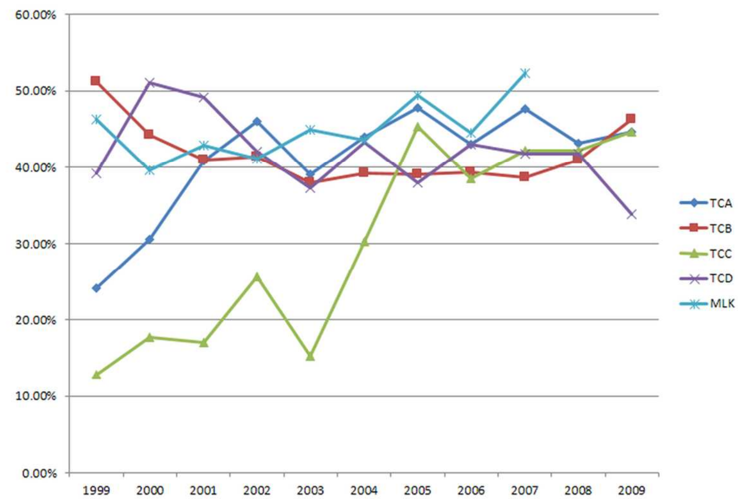
*=gunshot wound, #=stab wound, ^=motor vehicle collision and auto vs. pedestrian

Figure 1: Annual Admissions, Trauma Centers Serving MLK Catchment Area



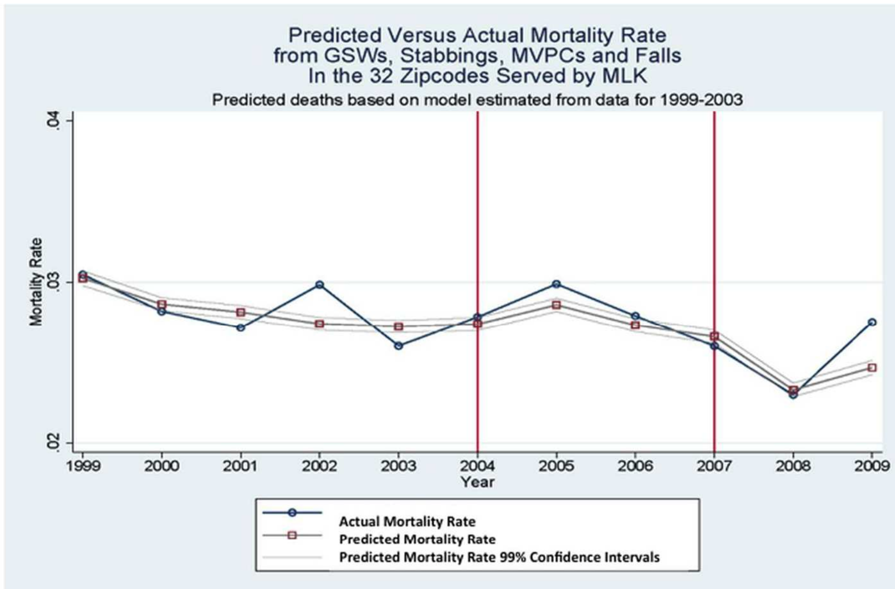
119x90mm (300 x 300 DPI)

Figure 2: MLK Area Trauma Centers, Percent Uninsured Patients



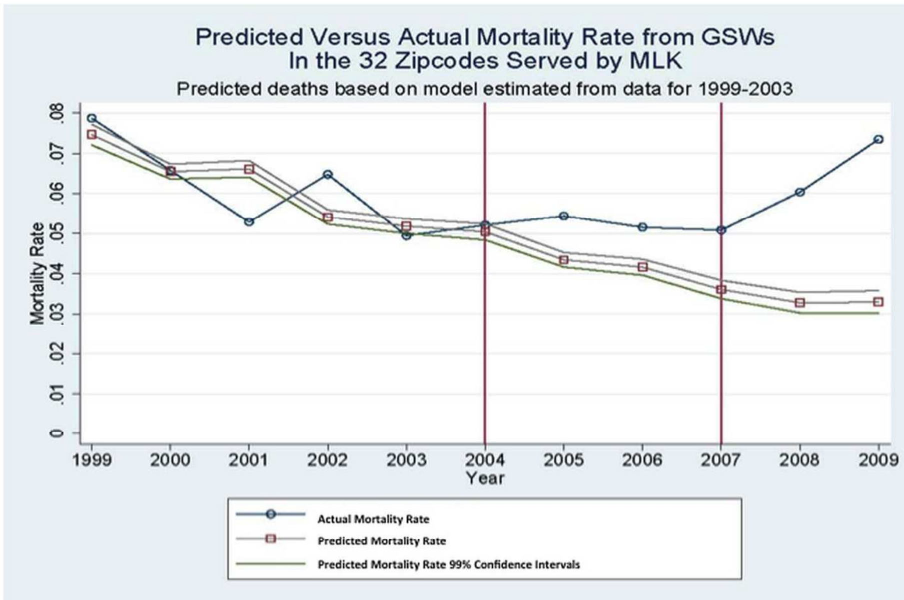
119x90mm (300 x 300 DPI)

Figure 3: Overall Trauma Mortality Rates, 1999-2009



119x90mm (300 x 300 DPI)

Figure 4: Trauma Mortality for Gunshot Wounds, 1999-2009



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STROBE 2007 (v4) checklist of items to be included in reports of observational studies in epidemiology*
Checklist for cohort, case-control, and cross-sectional studies (combined)

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4
Objectives	3	State specific objectives, including any pre-specified hypotheses	5
Methods			
Study design	4	Present key elements of study design early in the paper	6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6-7
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	6-7
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6
Bias	9	Describe any efforts to address potential sources of bias	7-9
Study size	10	Explain how the study size was arrived at	6-7
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7-8
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	7-9
		(*b*) Describe any methods used to examine subgroups and interactions	N/A
		(*c*) Explain how missing data were addressed	6-7
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed	6-7

		Cross-sectional study—If applicable, describe analytical methods taking account of sampling strategy	
		(*e*) Describe any sensitivity analyses	11
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	9
		(b) Give reasons for non-participation at each stage	N/A
		(c) Consider use of a flow diagram	N/A
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	9-11
		(b) Indicate number of participants with missing data for each variable of interest	N/A
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	
		Cross-sectional study—Report numbers of outcome events or summary measures	9-12
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	9-12
		(*b*) Report category boundaries when continuous variables were categorized	9-12
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	11
Discussion			
Key results	18	Summarise key results with reference to study objectives	12-13
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	15-16
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	16
Generalisability	21	Discuss the generalisability (external validity) of the study results	15-16
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	17

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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Effects of Closure of an Urban Level I Trauma Center on Adjacent Hospitals and Local Injury Mortality: A Retrospective, Observational Study

Marie Crandall, MD, MPH,[1] Douglas Sharp, MURP, PhD,[2] Xiong Wei, MSc,[3] Avery Nathens, MD, PhD, MPH,[3] Renee Y. Hsia, MD, MSc[4]

[1]Department of Surgery, University of Florida College of Medicine; Jacksonville, Florida, USA

[2]Mental Health Services and Policy Program, Northwestern University; Chicago, Illinois, USA

[3]Department of Surgery, Sunnybrook Health Sciences Centre; Toronto, Ontario, Canada

[4]Department of Emergency Medicine and Philip R. Lee Institute for Health Policy Studies, University of California, San Francisco; San Francisco, California, USA

Corresponding author:
Marie Crandall, MD, MPH, FACS
Professor of Surgery, Department of Surgery
University of Florida College of Medicine Jacksonville
655 W. 8th Street
Jacksonville, FL 32209
O: 904-244-6631
F: 904-244-3415
marie.crandall@jax.ufl.edu

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ABSTRACT

Objective: To determine the association of the Martin Luther King, Jr. Hospital (MLK) closure on the distribution of admissions on adjacent trauma centers and injury mortality rates in these centers and within the county.

Design: Observational, retrospective study.

Setting: Non-public patient-level data from the state of California were obtained for all trauma patients from 1999-2009. Geospatial analysis was used to visualize the redistribution of trauma patients to other hospitals after MLK closed. Variance of observed to expected injury mortality using multivariate logistic regression was estimated for the study period.

Participants: A total of 37,131 trauma patients were admitted to the five major south Los Angeles trauma centers from the MLK service area between 1999 and 2009.

Main outcome measures: (1) number and type of trauma admissions to trauma centers in closest proximity to MLK; (2) in-hospital injury mortality of trauma patients after the trauma center closure.

Results: During and after the MLK closure, trauma admissions increased at three of four nearby hospitals, particularly admissions for gunshot wounds (GSWs). This redistribution of patient load was accompanied by a dramatic change in the payer mix for surrounding hospitals; one hospital's share of uninsured more than tripled from 12.9% in 1999 to 44.6% by 2009. Overall trauma mortality did not significantly change, but GSW mortality steadily and significantly increased after the closure from 5.0% in 2007 to 7.5% in 2009.

Conclusions: Though local hospitals experienced a dramatic increase in trauma patient volume, overall mortality for trauma patients did not significantly change after MLK closed.

ARTICLE SUMMARY

Strengths and Limitations of this study:

- The study utilized geospatial analysis to identify a boundary of 32 contiguous zip codes to define the MLK service area, which contained over 80% of the trauma admissions to MLK during the study period.
- Zip codes were utilized instead of predetermined drawn catchment areas to simplify the quantitative data analysis.
- The analysis captured the years leading up to the MLK closure, the closure transition period including trauma center des-designation, and two years after the hospital closure.
- The study is unique to one particular trauma system in a local context, and thus the findings cannot be extrapolated to all areas of the country that have experienced closures of trauma centers.

INTRODUCTION

Trauma is the leading cause of death for all Americans ages 1-44, claiming more than 180,000 lives annually, and injury is a leading cause of death and disability among children and adults.[1] There are currently more than 1,000 trauma centers in the U.S., which are hospitals that have committed resources to the care of the injured patient. California trauma centers are designated as Level I-IV. All centers must have a multidisciplinary trauma team and an ED, and all must have personnel, services, and equipment necessary to care for trauma patients. Trauma centers, as part of organized trauma systems, have been shown to improve injury mortality by 10-20% compared with areas that do not have specialized trauma care.[2-4]

Current literature documenting hospital[5,6] and emergency department (ED) closures[7-10] has produced controversial findings; some studies have shown associations with higher mortality due to deteriorating access,[7] while others have shown no association with poorer outcomes.[6] Several studies have specifically examined closures of trauma centers,[11,12] but to our knowledge, few have discussed the population effects on outcomes as a result of trauma center closures.[13] Given the conflicting evidence for hospital and ED closures, and the paucity of evidence of how trauma center closures specifically affect outcomes, the goal of this study was to focus on one trauma center closure in a specific context, using it as a case study to show how there may be different effects based on particular contexts. We studied Martin Luther King Jr./Drew Medical Center, currently a multi-service ambulatory care center in the southwest region of Los Angeles County, serving the communities of Compton, Watts, and Willowbrook.[14] South Los Angeles is a distinct region of Los Angeles County that comprises 25 neighborhoods and three unincorporated districts. The population is approximately 95% African American and Latino, and despite being home to the University of Southern California and the Los Angeles Coliseum, the area is generally economically distressed and suffers high rates of trauma, particularly penetrating trauma such as gunshot wounds.

In response to the lack of sufficient access to health care and opportunities in this low-income area,[15] the Martin Luther King Jr. Hospital (MLK) was opened in 1972, then designated as a Level I trauma center in 1983.[16] Despite the hospital's assets, a series of highly publicized deaths led to the closure of the cardiac monitoring unit by December 2003, and then MLK's re-designation as a Level II trauma center in February 2004. Trauma center designation was removed completely from MLK in December 2004, but the inpatient and emergency services remained open in the hopes of improving existing services. By 2006, more patient deaths at MLK were reported as attributable to medical errors, and all inpatient and emergency services were closed in August 2007. Following this closure, a provision plan was created for emergency transport and staffing at nearby public and private hospitals, given that the closure of the second-busiest trauma center in Los Angeles might adversely affect both neighboring hospitals and local communities.[17,18] Subsequent impact analyses were also reported, noting challenges and highlighting the need for a comprehensive care plan for the area.[18-21]

This study seeks to fill this gap in literature by evaluating the redistribution of the volume of injured patients on neighboring hospitals as well as trauma mortality of admitted patients within these hospitals and overall mortality in the county. We hypothesized that the MLK closure in 2007 significantly impacted the volume of trauma patients at other south Los Angeles hospitals and potentially increased the trauma mortality for south Los Angeles.

METHODS

Study Design and Data Sources

We used non-public patient-level data from the California Office of Statewide Health Planning and Development (OSHPD) for all patients admitted to general, acute, non-federal hospitals in the state of California. We limited the dataset to all trauma patients in south Los Angeles during the study period from 1999-2009 using zip codes for this defined area. We performed an observational, retrospective study of Patient Discharge Data (PDD) for the years leading up to the MLK closure (1999-2003), the closure transition period including trauma center de-designation (2004-2007), and two years after hospital closure (2008-2009).

Patient Population

We first characterized the patient sample with simple descriptive statistics, including trauma admissions, demographics, and injury mortality. We then utilized geospatial analysis to identify a boundary of 32 contiguous zip codes to define the MLK service area for trauma incidents. This service area contained over 80% of the trauma admissions to MLK during the study period. We utilized zip codes instead of predetermined drawn catchment areas to simplify the quantitative data analysis. This boundary included the 31 zip codes that had the largest number of total admissions of any kind to MLK and the 29 zip codes that had the largest number of trauma admissions to MLK while it was in operation. We did not limit the population by age, though MLK was not a pediatric trauma center, because patients 15 and older would have been seen routinely, and younger patients may have been seen due to age uncertainty or self-transport.

Trauma admissions included those defined by the International Classification of Disease, Ninth Revision, Clinical Modification (ICD-9-CM) diagnosis codes 800–904.9, 910–929.9, and

950–959.9 in either the principal diagnosis or in any of the 24 secondary diagnoses in our dataset (N=117,161), excluding visits with ICD-9-CM codes indicating drowning, burns, bites and stings, overexertion, poisonings, foreign body, suffocation or late effects of injury, as well as those with a sole traumatic ICD-9-CM diagnosis of strains and sprains, or contusions with intact skin surface[22] (Appendix Table 1). Burns were excluded because definitive care is provided at LA County-USC, a specialized burn center. Patients who did not have an injury mechanism as denoted by an E-code (external cause of injury) were excluded (N=854), leaving a total of 37,131 admissions for the analysis.

Main Outcome Measures

The primary outcome of interest was the number and type of trauma admissions to trauma centers in closest proximity to MLK. The trauma centers (TCs) within 10 miles of MLK were: TCA (Level II, 2.3 miles from MLK), TCB (Level I, 7.0 miles from MLK), TCC (Level II, 7.9 miles from MLK), and TCD (Level I, 9.6 miles from MLK).

The secondary outcome of interest was in-hospital injury mortality of trauma patients after the trauma center closure. The observed mortality rate was compared to expected mortality rate using a risk-adjusted model incorporating age, injury severity, survival risk, injury mechanism, gender, year, patient insurance status, and race for each hospital and for the MLK service area.

Statistical Methods

We used descriptive analyses to evaluate the primary outcome of number and type of trauma admissions to different facilities. For our secondary outcome, predicted mortality for the region was calculated using separate models for each of the most common mechanisms of injury (stab wounds, gunshot wounds, falls, and motor vehicle collisions), and overall. Model covariates included age, gender, insurance status, race, ISS>16, Survival Risk Ratio, and year. All of these variables are known to have an effect on injury mortality. Insurance status was categorized into self-pay, public, and private. Race was categorized into African American, Latino, Asian American, and White.

Injury severity was measured by the Injury Severity Score (ISS). We used ICDPIC v3.0 for Stata v11[23] (StataCorp, College Station, TX) to calculate the ISS from ICD-9-CM codes. We used the accepted standards of categorizing injury severity by creating a binary variable denoting severe (ISS>16) and less severe (ISS≤16).[24,25]

Survival Risk Ratios (SRRs) associated with each of the relevant ICD-9-CM codes were obtained from the American College of Surgeons Trauma Quality Improvement Program (TQIP) for both blunt and penetrating trauma. These values were calculated from 2011 nationwide injury survival statistics, then matched to the ICD-9-CM codes recorded for each case. The lowest ratio for each case was then used in the model. Of note, a proportion of diagnostic codes did not match SRRs. We deliberately used nationwide survival risk ratios to have the largest available sample to predict expected outcomes and to decrease any potential impact of regional variability.

We first estimated mortality models for each common injury mechanism and traumas overall in the MLK service area. To do this, we utilized pre-closure mortality data from all hospitals that served the MLK catchment area. We controlled for age, race, gender, insurance status, ISS, SRR, and a continuous time variable.[26] The time variable was included to account for secular trends in trauma incidence, mechanism, and mortality rates. We specifically examined mortality for GSWs, as MLK had historically cared for most of the GSW victims in the area, and the effects of MLK closure might be borne disproportionately by this group. We then compared observed mortality rates with rates predicted by the risk-adjusted model for hospitals serving the MLK catchment area. Confidence intervals for predicted mortality were calculated based on the standard errors associated with the predicted values.

All statistical analyses used Stata v11 (College Station, TX). Geospatial analysis was performed using Arc-GIS 10 software (Esri, Redlands, CA). This study was approved by the University of California, San Francisco Committee on Human Research and the California Committee for the Protection of Human Subjects.

RESULTS

South Los Angeles County trauma volumes across hospitals

Between 1999 and 2009, a total of 37,131 trauma patients were admitted to the five major south Los Angeles trauma centers from the MLK service area. There was no significant change in total annual admissions at the five hospitals over the time period, with 3,236 admissions in 1999, to a peak of 3,546 in 2003, and down to 3,173 by 2009. By contrast, admissions at individual hospitals in the MLK service area experienced marked longitudinal trends. Despite trauma center catchment area downsizing and eventual de-designation between February and December of 2004, over 1000 trauma patients were seen at MLK in 2004, more than 500 in 2005, and over 450 in 2006. TCD, the busiest trauma center in the area, had a significant drop in admissions over the study period. However, the three other nearby centers experienced increases in trauma volumes after the MLK closure. TCC, which had not been a trauma center prior to

MLK's closure, but was given a Level II designation to increase local capacitance, saw a 10-fold increase in trauma admissions (Figure 1).

Demographic and injury severity redistribution across hospitals

Patient mechanisms of injury at the five area trauma centers were very different from each other during the study period (Table 1), with MLK seeing much higher numbers and percentages of penetrating trauma. Several centers saw significant changes after the closure of MLK. TCs A, B, and C experienced marked increases in the proportion of gunshot wound admissions after MLK closed; a 2-fold increase at TCs A & B (approximately 150 to 300 patients annually) and a 10-fold increase at TCC (from 10 to 300 patients annually), which were all statistically significant (p-values for all <0.001).

Over the entire time period, injury severity as measured by the proportion of patients with an ISS>16 also increased at TCA (9.1% to 14.8%, p <0.001) and TCC (3.1% to 11.1%, p <0.001). Gender mix and mean age of trauma patients only changed significantly at TCC, transitioning to an overall younger (mean age dropped from 54.1 to 39.9 years) and more male (from 38.7% to 68.3%) population (p-value for gender <0.001, p-value for change in mean age <0.001). Payer mix changed substantially at TCA and TCC, with an annual increase in uninsured patients (Figure 2). TCA originally began in 1999 with 24.1% of their trauma patients as uninsured, which increased to 44.6% by 2009. TCC saw an even more dramatic increase, with 12.9% of their trauma patients uninsured in 1999, and more than tripling to 44.6% in 2009.

Over 85% percent of trauma admissions in the MLK service area during the study period were African American or Latino. None of the five TCs in the study cared for a trauma patient population that was more than 15% Caucasian. TCA saw an increase of non-white patients from

84.9% to 95.4% during the study period ($p < 0.001$). TCB saw an increase of non-white patients from 91.9% to 97.0% ($p < 0.001$). TCC saw an increase from 97.5% to 98.5% ($p = 0.179$).

Injury mortality

Unadjusted mortality

Though total trauma admissions generally remained constant during the study period, overall injury mortality for individual centers experienced wide year-to-year variations in unadjusted mortality, particularly at TCs A, B, and C, beginning with the transition to MLK closure.

Adjusted mortality

We first created a model to predict injury mortality in the MLK service area by utilizing pre-closure admissions data from all hospitals that served the area, controlling for age, race, insurance status, ISS, SRR, injury mechanism, and time. Time was accounted for using a continuous variable indicating year of the study period starting with zero for 1999. The four models had pseudo-R^2 ranging from 0.085 for stabbings to 0.369 for motor vehicle collisions, and were used to predict mortality for each patient from 1999-2009. Observed and predicted mortality within each year of the study period were calculated by aggregating actual and predicted deaths annually. Predicted annual mortality was calculated with 99% confidence intervals. In all models, SRRs were the variables most strongly associated with mortality. We found a small but statistically significant improvement in observed compared to predicted mortality rates from 2004-2009 (3.0% vs. 2.8% and 2.8% vs. 2.4%) for the overall trauma population (Figure 3). However, there was a statistically significant increase in GSW mortality beginning in 2004. The observed mortality increased from 5.0% to nearly 7.5% ($p < 0.001$) in the years after the closure, and was nearly double the predicted mortality (Figure 4). As a sensitivity analysis, we also graphed observed versus predicted mortality rates for individual centers and found the same results.

DISCUSSION

Our findings show that after the MLK closure in 2007, trauma volumes rose significantly at all adjacent hospitals except for TCD, with a marked increase in patient volumes at TCs A and C in particular from 1999-2009. The substantial redistribution of the patient load was also accompanied by an increase in the severity of injured patients at hospitals that previously cared for less severely injured patients. In addition, certain hospitals experienced an extensive shift in the payer mix of their trauma populations, with one particular trauma center more than tripling its initial 1999 share of uninsured patients. In general, risk-adjusted mortality for trauma patients overall did not significantly change during the study period. However, we found a persistent and significant increase in mortality from GSWs after the closure. These findings may be explained by longer travel times and associated higher mortality for patients injured by GSWs,[27] random variation, or changes in weaponry though the latter is less likely, as our results were risk-adjusted by SRR and ISS. Finally, it may be that this increased mortality after the closure indicates particular expertise of the MLK trauma center in management of GSWs. However, given the relative lack of granularity of our risk stratification (the data set lacked ED blood pressure, transfusion data, base deficit, and other predictors of survival), we cannot make a definitive statement about this. Our conclusions cannot be necessarily extrapolated to other trauma center closures, since this particular closure was in the context of having overlapping and well-coordinated efforts by the county to provide adequate services. Our study does show that in these types of contexts, a trauma center closure may not necessarily lead to poorer outcomes.

Overall, violent crime rates decreased steadily during the study period, and homicide rates in LA County decreased from 9.1/100,000 to 6.7/100,000 by 2009. Given that the homicide rate overall was decreasing, it is also possible that the increased mortality for GSW victims in south Los Angeles could be linked to MLK closure.

Our findings have several implications for policymakers and health system planners. The MLK closure was not undertaken lightly and a transitional period of several years that included multiple efforts to improve quality outcomes was undertaken. These data demonstrate that the efforts of LA County to anticipate and forestall adverse events helped increase capacitance and decrease potentially negative impacts on trauma mortality despite dramatic increases in trauma volumes at nearby centers. An example of measures that were put in place included the creation of a new Level II Trauma Center in center of the MLK catchment area (TCC) to help safeguard this vulnerable population from excess injury mortality during and after the closure. Our findings are consistent with one previous study evaluating the effects of the MLK trauma center de-designation on Harbor-UCLA, which did not show an increase in mortality of the trauma admissions despite an increase in volume and injury severity.[28] A recent paper discussing trauma closures in California overall showed that trauma patients experiencing an increased distance to the nearest trauma center after a closure had higher inpatient mortality;[13] our findings within this local context showed that this was only true for a subset of patients with GSWs. Given that penetrating injury is particularly time-sensitive, this could provide some explanation of the nuances of our findings.

This study raises an important question of whether hospital quality measures, which are aimed to serve as proxies for patient care and outcomes, are effective for evaluating trauma outcomes across hospitals. The decision to close MLK was based on its failure to meet minimal federal standards on hospital quality measures. These quality measures include many aspects of inpatient and outpatient care, including cardiovascular disease, end-stage renal disease, and respiratory care.[29] Though deaths and injuries related to medical errors are included in the Centers for Medicare & Medicaid Services (CMS) appraisal, measurements of trauma care were not, and are still not included in these quality indicators. Other investigators have found that CMS quality indicators do not correlate with risk-adjusted mortality rates at trauma centers.[30] Of concern for our particular study is that GSW mortality steadily rose after redistribution of care to other hospitals, which was one of the objections voiced by opponents to the trauma center closure. Moreover, the increase in mortality from GSWs is counter to national trends in trauma mortality and raises concerns about unanticipated effects, particularly in areas disproportionately burdened by gun violence. In the future, metrics such as those included in the TQIP, in addition to CMS quality measures, might be beneficial to help guide decisions about trauma center closures.[26,31]

Finally, this study highlights the potential financial implications faced by neighboring hospitals after a closure. It has been well-documented that "safety-net hospitals"[32] such as MLK that provide disproportionate amounts of care to low-income and poorly insured patients are vulnerable to closure,[12,33] and that trauma centers are more likely to close in areas with higher proportions of non-white individuals and a poorer payer mix.[10,11] As seen in our study, the reallocation of thousands of poorly-insured patients to nearby hospitals inevitably requires that they absorb the financial implications of caring for this population as well. Further research into these financial consequences, and how a health system can help minimize the shock on the system, is crucial.

This study has several limitations. It is a retrospective, observational study that includes only basic patient demographics and a calculated measurement of ISS. It also does not include pre-hospital data, such as measurements of systolic blood pressure and transport times, nor data about procedures performed, blood transfusions given, or other patient- and hospital-level data. However, it would be very difficult to undertake this type of study prospectively across multiple hospitals and a complicated EMS system in a large, urban setting. Also, we deliberately did not limit our study population to adults, in the hopes of providing the most accurate representation of the MLK patient population. However, this inclusion may have actually biased our results to the null if most injured children were being taken to other local pediatric trauma centers, which would make any volume or outcome-related changes after the closure appear smaller overall.

In addition, our findings that mortality was not impacted after the MLK closure does not take into account fatalities that did not present to a trauma center, such as individuals pronounced dead at the scene. Furthermore, our dataset does not capture deaths occurring in the ED. Because the state began collecting ED data in 2005, we are unable to include ED deaths in our study. Our findings may actually be conservative in the sense that there may be a survival bias in patients who survived the transport to hospitals that were located farther away than MLK. Lastly, it also may be that these findings are unique to this particular trauma system in this local context. Contextual factors likely play an important role in the impact of these closures on the surrounding communities and our findings cannot be extrapolated to all areas of the country that have experienced trauma center closures.

CONCLUSIONS

Our study showed there was a significant redistribution of trauma patients to nearby hospitals after the MLK closure, with a marked increase of uninsured patients at certain hospitals. Overall, injury mortality did not change for trauma patients in south central Los Angeles, though concerns remain about the post-closure outcomes for GSW victims. Our findings shed hope on how careful planning, including using available technology such as geocoding methodology to map road traffic patterns and ambulance diversions to nearby hospitals, might anticipate potential pitfalls and inform decision-making with respect to resource allocation, ultimately to provide optimal patient care.

CONTRIBUTORSHIP

Study concept and design: Crandall, Sharp, Hsia, Nathens, Wei

Acquisition of data: Hsia

Analysis and interpretation of data: Crandall, Sharp, Hsia

Drafting of manuscript: Crandall

Critical revision of manuscript for important intellectual content: Crandall, Sharp, Hsia, Nathens, Wei

Statistical analysis: Sharp

Obtained funding: Crandall

Administrative, technical, or material support: Crandall, Sharp, Hsia, Nathens, Wei

Study supervision: Crandall

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REFERENCES

1. Injury Center: Overview. 2010; 2011. Available from: http://www.cdc.gov/injury/overview/.

2. Rutledge R, Fakhry SM, Meyer A, et al. An analysis of the association of trauma centers with per capita hospitalizations and death rates from injury. *Ann Surg* 1993;218:512-21.

3. Nathens AB, Jurkovich GJ, Cummings P, et al. The effect of organized systems of trauma care on motor vehicle crash mortality. *JAMA* 2000;283:1990-4.

4. Nathens AB, Jurkovich GJ, Rivara FP, et al. Effectiveness of state trauma systems in reducing injury-related mortality: a national evaluation. *J Trauma* 2000;48:25-30.

5. Buchmueller TC, Jacobson M, Wold C. How far to the hospital?: the effect of hospital closures on access to care. *J Health Econ* 2006;25:740-61.

6. Joynt KE, Chatterjee P, Orav EJ, et al. Hospital closures had no measurable impact on local hospitalization rates or mortality rates, 2003–11. *Health Aff (Millwood)* 2015;34:765-72.

7. Liu C, Srebotnjak T, Hsia RY. California emergency department closures are associated with increased inpatient mortality at nearby hospitals. *Health Aff (Millwood)* 2014;33:1323-9.

8. Shen YC, Hsia RY. Does decreased access to emergency departments affect patient outcomes? analysis of acute myocardial infarction population 1996–2005. *Health Serv Res* 2012;47:188-210.

9. Hsia RY, Kanzaria HK, Srebotnjak T, et al. Is emergency department closure resulting in increased distance to the nearest emergency department associated with increased inpatient mortality? *Ann Emerg Med* 2012;60:707-15.e4.

10. Hsia RY, Kellermann AL, Shen YC. Factors associated with closures of emergency departments in the United States. *JAMA* 2011;305:1978-85.

11. Shen YC, Hsia RY, Kuzma K. Understanding the risk factors of trauma center closures: do financial pressure and community characteristics matter? *Med Care* 2009;47:968-78.

12. Dailey JT, Teter H, Cowley RA. Trauma center closures: a national assessment. *J Trauma.*1992;33:539-46.

13. Hsia RY, Srebotnjak T, Maselli J, et al. The association of trauma center closures with increased inpatient mortality for injured patients. *J Trauma Acute Care Surg* 2014;76:1048-54.

14. Martin Luther King, Jr. Multi-service ambulatory care center. Los Angeles County Health Services;2011. Accessed on September 9, 2011. Available from: http://www.ladhs.org/wps/portal/KingHomepage.

15. McCone J. Report of the Governor's Commission on the Los Angeles Riots. Los Angeles;1965.

16. Designated Trauma Centers;2007. Accessed on September 9, 2011. Available from: http://www.emsa.ca.gov/systems/files/trauma/trma_ctr.pdf.

17. Critical Condition: Examining the scope of medical services in South Los Angeles. Los Angeles: The California Endowment;2007.

18. HASC Report: King-Harbor closure hospital inpatient impact analysis. Fact Sheet. Los Angeles: Hospital Association of Southern California;2008. Available from: http://www.lahealthaction.org/library/LADHS_Board_Report_and_HASCReportFactSheet032708.pdf

19. Achieving the vision: healthcare options for Los Angeles County. Los Angeles;2009.

20. Lott J. King-Harbor closure hospital inpatient impact analysis. Communication to Hospital Executives, Los Angeles County Region. Los Angeles: Hospital Association of Southern California;2008. Available from: http://www.hasc.org/.

21. Chernof B. Status of the implementation of the contingency services plan and Martin Luther King, Jr.--harbor hospital. Communication to the Los Angeles County Board of Supervisors. Los Angeles: Department of Health Services Los Angeles County;2008.

22. CDC. External cause-of-injury mortality matrix based on ICD-9 cause of injury codes. Atlanta, GA: Center for Disease Control;1997.

23. ICDPIC v3.0 for Stata. 2008;2011. Available from: http://ideas.repec.org/c/boc/bocode/s457028.html.

24. Ashkenazi I, Kessel B, Khashan T, et al. Precision of in-hospital triage in mass-casualty incidencts after terror attacks. *Prehosp Disaster Med* 2006;21:20-3.

25. Geiger AA, deRoon-Cassini T, Brasel KJ. Considering the patient's perspective in the injury severity score. *J Surg Res* 2011;170:133-8.

26. Shafi S, Nathens AB, Parks J, et al. Trauma quality improvement using risk-adjusted outcomes. *J Trauma* 2008;64:599-604.

27. Crandall M, Sharp D, Unger E, et al. Trauma deserts: distance from a trauma center, transport times, and mortality from gunshot wounds in Chicago. *Am J Public Health* 2013;103:1103-9.

28. Yaghoubian A, Lewis RJ, Putnam BA, et al. Impact on patient outcomes after closure of an adjacent trauma center. *Am Surg* 2008;74:930-4.

29. Roadmap for Quality Measurement in the Traditional Medicare Fee-for Service Program. In: Centers for Medicaire & Medicaid Services. Washington, D.C.;2008.

30. Shafi S, Parks J, Ahn C, et al. Centers for Medicare and Medicaid services quality indicators do not correlate with risk-adjusted mortality at trauma centers. *J Trauma* 2010;68:771-7.

31. Shafi S, Nathens AB, Cryer HG, et al. The trauma quality improvement program of the American College of Surgeons Committee on Trauma. *J Am Coll Surg* 2009;209:521-30 e1.

32. Baxter RJ, Mechanic RE. The status of local health care safety nets. *Health Aff (Millwood)* 1997;16:7-23.

33. Mansuri O, Hoonpongsimanont W, Vaca F, et al. The crisis in emergency and trauma care in california and the United States. *Cal J Emerg Med* 2006;7:81-6.

Table 1: Trauma volumes by hospital and most common mechanisms, 1999-2009

	TCA N (%)	TCB N (%)	TCC N (%)	TCD N (%)	MLK N (%)
GSW*	987 (22)	1841 (22)	1522 (18)	1296 (17)	2752 (33)
SW#	322 (7)	487 (6)	315 (4)	496 (7)	499 (5)
MVC^	1443 (32)	2121 (26)	3272 (39)	2553 (33)	2229 (27)
Falls	1753 (39)	3855 (46)	3346 (40)	3280 (43)	2762 (34)

*=gunshot wound, #=stab wound, ^=motor vehicle collision and auto vs. pedestrian

Figure 1: Annual Admissions, Trauma Centers Serving MLK Catchment Area

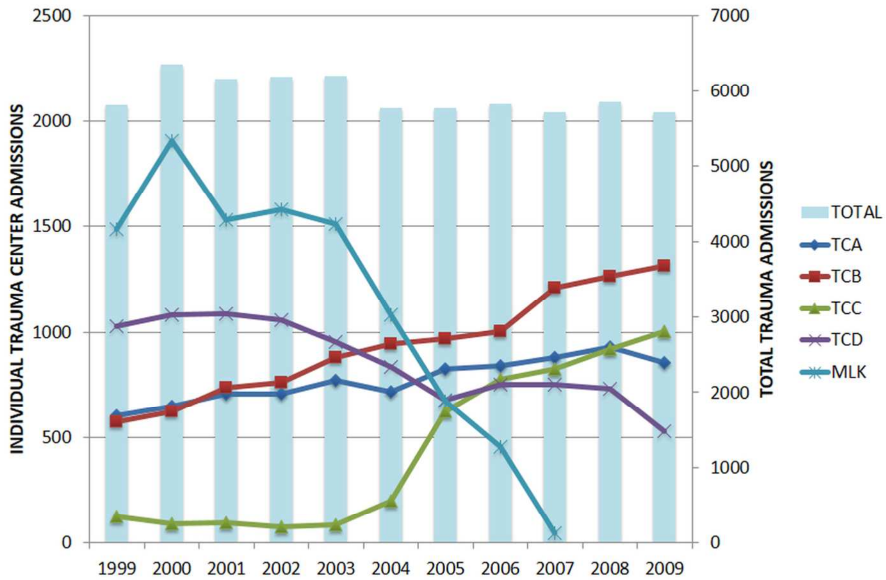

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Figure 2: MLK Area Trauma Centers, Percent Uninsured Patients

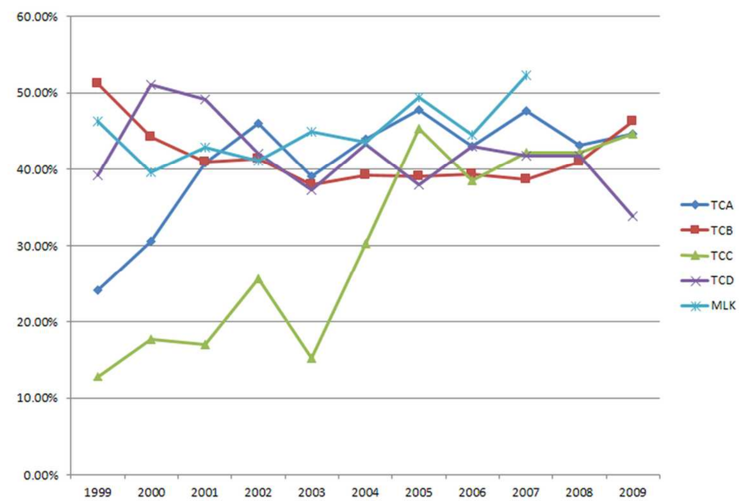

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Figure 3: Overall Trauma Mortality Rates, 1999-2009

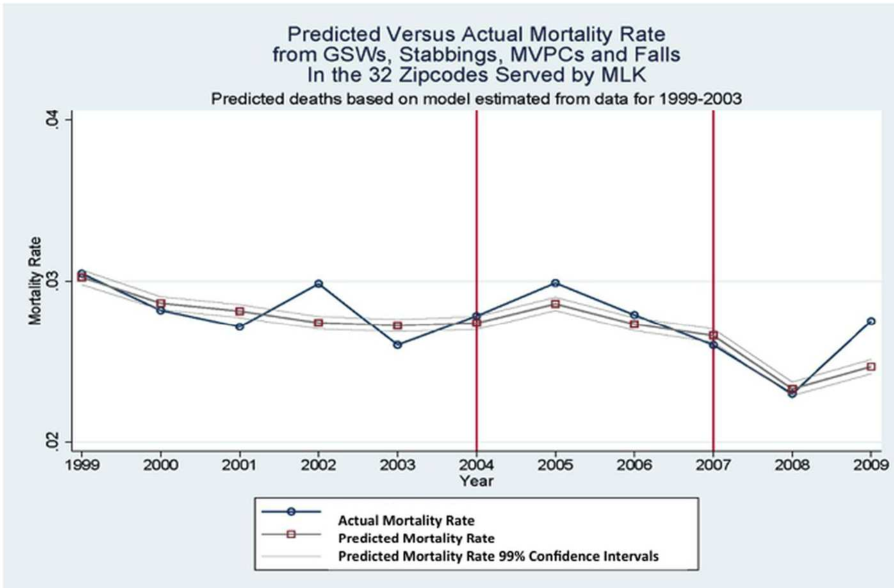

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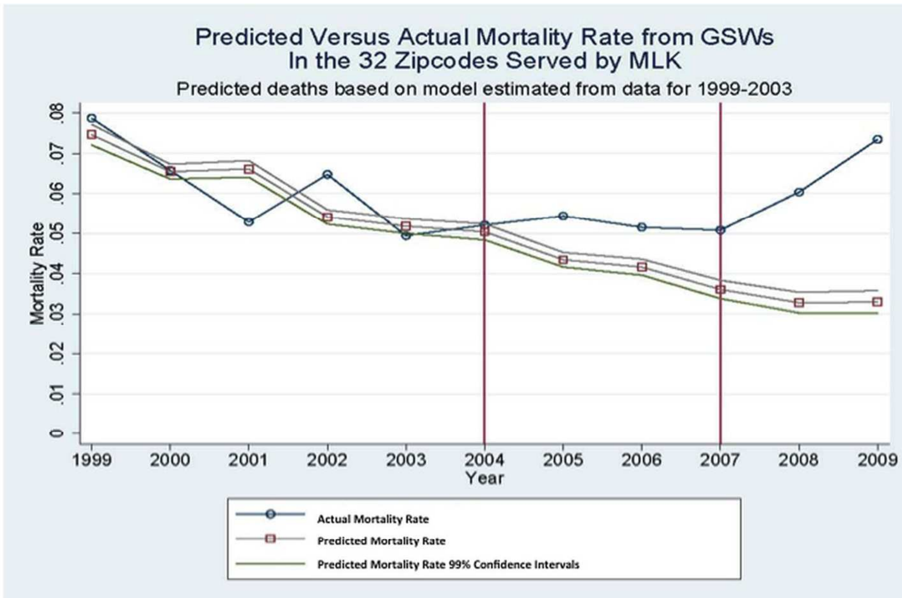
Figure 4: Trauma Mortality for Gunshot Wounds, 1999-2009



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Appendix Table 1: ICD-9-CM Codes of Visits Excluded from the Study

ICD-9-CM	Description
840–848	Sprains and strains of joints and adjacent muscles
905–909	Late effects of injuries, poisonings, toxic effects, and other external causes
919.0	Abrasion or friction burn of other multiple and unspecified sites without infection
919.1	Abrasion or friction burn of other multiple and unspecified sites infected
919.4	Insect bite nonvenomous of other multiple and unspecified sites without infection
919.5	Insect bite nonvenomous of other multiple and unspecified sites infected
919.6	Superficial foreign body (splinter) of other multiple and unspecified sites without major open wound and without infection
919.7	Superficial foreign body (splinters) of other multiple and unspecified sites without major open wound infected
920–924	Contusion with intact skin surface
930–939	Effects of foreign body entering through body orifice
940–949	Burns
960–979	Poisoning by drugs, medicinal and biological substances
986	Poisoning, carbon monoxide
989.5	Venom (bites of venomous snakes, lizards, and spiders; tick paralysis)
994.1	Drowning and nonfatal submersion
994.5	Exhaustion due to excessive exertion

STROBE 2007 (v4) checklist of items to be included in reports of observational studies in epidemiology*
Checklist for cohort, case-control, and cross-sectional studies (combined)

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4
Objectives	3	State specific objectives, including any pre-specified hypotheses	5
Methods			
Study design	4	Present key elements of study design early in the paper	6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6-7
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	6-7
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6
Bias	9	Describe any efforts to address potential sources of bias	7-9
Study size	10	Explain how the study size was arrived at	6-7
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7-8
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	7-9
		(*b*) Describe any methods used to examine subgroups and interactions	N/A
		(*c*) Explain how missing data were addressed	6-7
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed	6-7

		Cross-sectional study—If applicable, describe analytical methods taking account of sampling strategy	
		(*e*) Describe any sensitivity analyses	11
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	9
		(b) Give reasons for non-participation at each stage	N/A
		(c) Consider use of a flow diagram	N/A
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	9-11
		(b) Indicate number of participants with missing data for each variable of interest	N/A
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	
		Cross-sectional study—Report numbers of outcome events or summary measures	9-12
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	9-12
		(*b*) Report category boundaries when continuous variables were categorized	9-12
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	11
Discussion			
Key results	18	Summarise key results with reference to study objectives	12-13
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	15-16
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	16
Generalisability	21	Discuss the generalisability (external validity) of the study results	15-16
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	17

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.