Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Defining and Assessing Surgical Efficiency in Addis Ababa's Tertiary Hospitals: A Cross- Sectional Study Using Data Envelopment Analysis (DEA)

Philisha Mesidor

pmesidor@mcw.edu

Medical College of Wisconsin

Zemenu Binalfewu

Global Partners In Improving Surgical Systems

Yemsrach Kedru

Addis Ababa University

Fitsum Kifle

Global Partners In Improving Surgical Systems

Ermiyas Belay

Network for Perioperative Critical Care

Tesfay Yohannes

Network for Perioperative Critical Care

Selam Daniel

Kidus Peteros Hospital

Fayrouz Abu-Hamdan

Medical College of Wisconsin

Christopher M. Dodgion

Medical College of Wisconsin

Andualem Beyene

Addis Ababa University

Katherine R. Iverson

Medical College of Wisconsin

Research Article

Keywords: Global Surgery, Technical Efficiency, Data Envelopment Analysis, Addis Ababa, Healthcare Optimization, Hospital Performance

Posted Date: November 12th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11108966/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Defining and Assessing Surgical Efficiency in Addis Ababa's Tertiary Hospitals: A Cross-Sectional Study Using Data Envelopment Analysis (DEA)

Philisha Mesidor, MSGH[1]; Zemenu Binalfewu, MD[2]; Yemsrach Kedru, MPH[3]; Fitsum Kifle, MD[2]; Ermiyas Belay, MSc[4]; Tesfay Yohannes, MSc[4]; Selam Daniel, MD[5]; Fayrouz Abu-Hamdan, MD[1]; Christopher M. Dodgion, MD[1]; Andualem Beyene, MD[3]; Katherine R. Iverson, MD, MPH[1]

Affiliations
[1] Medical College of Wisconsin, Milwaukee, United States
[2] Global Partners In Improving Surgical Systems, Addis Ababa, Ethiopia
[3] Addis Ababa University, Addis Ababa, Ethiopia
[4] Network for Perioperative Critical Care, Addis Ababa, Ethiopia
[5] Kidus Peteros Hospital, Addis Ababa, Ethiopia

Corresponding Author
Philisha Mesidor, MSGH
Medical College of Wisconsin
Milwaukee, United States
Email: pmesidor@mcw.edu

Zemenu Binalfewu, MD
Global Partners In Improving Surgical Systems
Addis Ababa, Ethiopia
Email: zemenubinalfewu1989@gmail.com

Yemsrach Kedru, MPH
Addis Ababa University
Addis Ababa, Ethiopia
Email: yemsrach192@gmail.com

Fitsum Kifle, MD
Global Partners In Improving Surgical Systems
Addis Ababa, Ethiopia
Email: fitsum@n4pcc.com

Ermiyas Belay, MSc
Network for Perioperative Critical Care
Addis Ababa, Ethiopia
Email: ermiyasbelay@n4pcc.com

Tesfay Yohannes, MSc
Network for Perioperative Critical Care
Addis Ababa, Ethiopia
Email: tesfay@n4pcc.com

Selam Daniel, MD
Kidus Peteros Hospital
Addis Ababa, Ethiopia
Email: selam28meshesha@gmail.com

Fayrouz Abu-Hamdan, MD

Medical College of Wisconsin
Milwaukee, United States
Email: fabuhamdan@mcw.edu

Christopher M. Dodgion, MD
Medical College of Wisconsin
Milwaukee, United States
Email: cdodgion@mcw.edu

Andualem Beyene, MD
Addis Ababa University
Addis Ababa, Ethiopia
Email: andualem94@gmail.com

Katherine R. Iverson, MD, MPH
Medical College of Wisconsin
Milwaukee, United States
Email: kiverson@mcw.edu

Abstract

Introduction

Efficient hospital resource utilization is essential for strengthening surgical systems in low resource settings. Guided by the World Health Organization technical efficiency framework, we applied Data Envelopment Analysis (DEA) to benchmark eight tertiary hospitals in Addis Ababa.

Methods

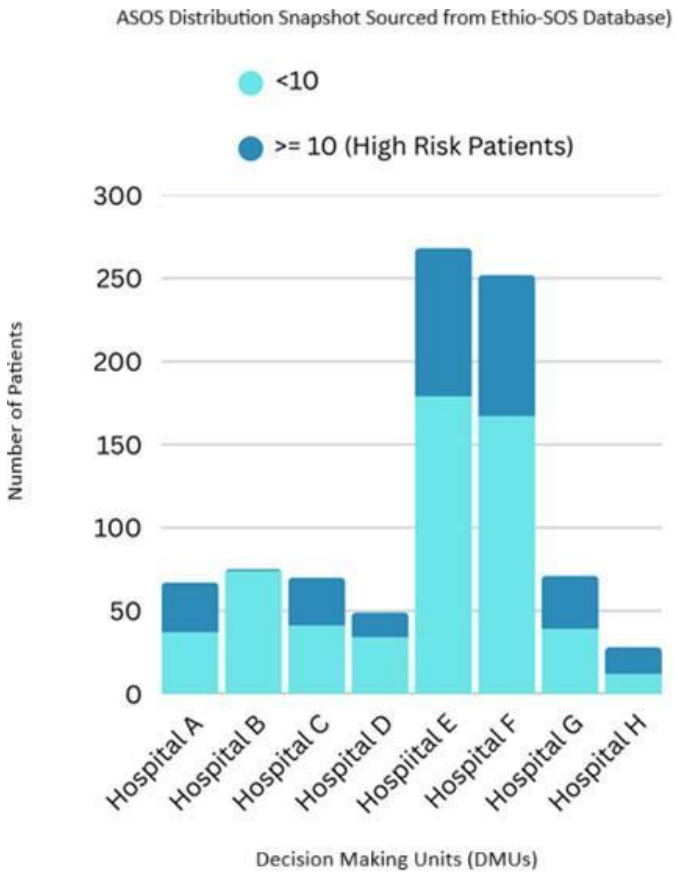
This study employed a two-stage approach, first applying DEA to assess technical efficiency, followed by regression analysis to explore the relationship between high-risk caseloads and efficiency. This cross-sectional study analyzed surgical technical efficiency in 8 hospitals using the variable returns to scale (VRS) approach. Efficiency inputs and outputs were extracted from the Ethiopian Surgical Outcome Study (Ethio-SOS), a nationwide seven-day prospective cohort study that enrolled 4,412 adult surgical patients at 46 public hospitals between January and April 2024. Technical efficiency was operationalized as the ratio of surgical beds (input) to completed surgeries (output). This input-output specification was selected by in-country partners to prioritized measure of surgical service productivity, defining efficiency as the conversion of surgical bed capacity into completed surgical procedures. Furthermore, an ordinary least squares (OLS) regression assessed the
relationship between high-risk caseloads and efficiency. High-risk caseloads were measured using the African Surgical Outcome Survey (ASOS) risk calculator to estimate complication risk.

Results

Efficiency scores ranged from 0.2 to 1.0 (median: 0.45), with one hospital achieving optimal overall technical efficiency as defined by a ratio of 1. Seven of the 8 hospitals had a variable return to scale, either increasing or decreasing. OLS regression analysis showed a non-significant relationship between high-risk cases and efficiency (coefficient: -0.762, p-value: 0.282).

Conclusion

This study provides a baseline for understanding the surgical efficiency of tertiary hospitals in Addis Ababa. Definitions of technical efficiency vary based on context, and this study contributes to broader knowledge of surgical efficiency assessments by illustrating one approach. Given the varied returns to scale across hospitals, further mixed methods research can contextualize the results produced by this study. Future investigations will build on these findings to uncover strategies for improving hospital performance and advancing collaborative studies in Ethiopia.



Graphical abstract: ASOS distribution snapshot sourced from Ethio-SOS database. ASOS surgical risk calculator distribution snapshot sourced from the Ethio-SOS database. ASOS scores estimate postoperative surgical risk, with scores ≥10 indicating high-risk patients. This independently distributed survey provides a cross-sectional snapshot of participating hospitals to identify the proportion of high-risk surgical populations at a single point in time.

Highlights

- Defines and evaluates surgical technical efficiency in tertiary hospitals in Addis Ababa using Data Envelopment Analysis (DEA).
- Uses WHO's technical efficiency framework to assess healthcare resource utilization.
- Identifies hospitals with optimal efficiency and those needing targeted interventions.
- Investigates the relationship between high-risk caseloads and hospital efficiency.
- Provides a foundation for further research on surgical system improvements in Ethiopia.

Keywords: Global Surgery, Technical Efficiency, Data Envelopment Analysis, Addis Ababa, Healthcare Optimization, Hospital Performance

Background

The Lancet Commission on Global Surgery (LCoGS) has set global aims to achieve universal access to safe surgery by 2030 and urged all countries to monitor key surgical indicators and establish national goals. The LCoGS prioritizes increasing quality surgical and anesthetic medicine worldwide, emphasizing the need for robust evaluations of existing surgical systems, especially in low- and middle-income countries (LMICs) [10]. Addressing surgical system inefficiencies is crucial; research has shown that resource limitations and variability in hospital efficiency significantly impacts the quality of maternal and surgical care [21]. Understanding these disparities can inform national policies aimed at optimizing resource use and improving healthcare outcomes.

Surgical care outcomes in LMICs remain a major concern, particularly in Africa, where postoperative mortality rates are significantly higher than in high-income countries[1]. The African Surgical Outcomes Study found that despite patients being younger and having fewer comorbidities compared to global averages, the risk of complications and mortality was disproportionately high due to gaps in perioperative care[1]. This highlights the need for efficiency assessments in surgical hospitals to improve perioperative management and reduce preventable deaths. Understanding how hospitals allocate resources and manage surgical risks is crucial for optimizing healthcare delivery in resource-constrained settings.

To evaluate healthcare system performance, the World Health Organization (WHO) adapted economic methods into a healthcare technical efficiency (TE) framework [19]. One widely used method within this framework is Data Envelopment Analysis (DEA), a quantitative tool for assessing efficiency across various sectors, including healthcare [3, 16]. In hospital efficiency studies, DEA can evaluate how well hospitals utilize their resources relative to patient outcomes [8]. Prior investigations that treat hospitals asdecision-making units (DMUs) reinforce its applicability for comparative efficiency analysis [11]. In Ethiopia, research applying DEA on hospitals in Oromia has identified inefficiencies in maternal and reproductive health services, further demonstrating the method's applicability in assessing resource utilization in the country [21].

Risk adjustment is essential in efficiency analysis to account for patient complexity variations across hospitals. The African Surgical Outcomes Study (ASOS) provides a validated framework tailored for African surgical settings, incorporating the American Society of Anesthesiologists (ASA) classification and comorbidity scores to enable fair comparisons between hospitals with different case-mix complexities [1].

Using this framework, this study employs DEA to compare the defined surgical technical efficiency of tertiary hospitals in Addis Ababa, Ethiopia. By applying DEA, efficiency levels of tertiary hospitals in Addis Ababa can be defined and assessed in a standardized manner. This

allows the decision-making units (DMUs) i.e. hospitals, a context-dependent assessment. Instead of being compared to hospitals outside of the Ethiopian healthcare system, each hospital is being assessed relative to one another, comparing resources (input) and outcomes (output). These analytical insights of efficiencies ultimately contribute to the broader goal of optimizing surgical care, particularly in LMICs where resources are often scarce. Investing in surgical system efficiency aligns with global health priorities to ensure equitable access to quality surgical care [10].
To ground our efficiency estimates in contemporary Ethiopian practice we used the Ethiopian Surgical Outcome Study (Ethio-SOS), the largest prospective perioperative dataset yet collected in the country [2]. Ethio-SOS consecutively enrolled every adult inpatient surgical case during a single seven-day study week in early 2024 and followed each patient for seven postoperative days, capturing complications, re-operations, critical-care use and mortality across forty-six public hospitals located in all twelve regions.

Project Aim/Purpose

The purpose of this study is to evaluate the surgical technical efficiency across tertiary hospitals in Addis Ababa, Ethiopia with integration of case complexity into this metric to identify areas for resource optimization.

Methods

This study employs a cross-sectional design, treating hospitals as Decision-Making Units (DMUs), consistent with previous efficiency assessments in healthcare settings [6, 11]. For this study, each DMU met three criteria: 1) it is located in Addis Ababa, 2) it is officially recognized by the Ethiopian Ministry of Health as either a primary, general or specialized hospital, and 3) the institution has a complete relevant dataset.
This study is set in Addis Ababa, Ethiopia's capital and the country's primary healthcare center. The city serves as a major hub, leading Ethiopia's efforts to strengthen health services. Ethiopia's health system has faced multiple unforeseen events, such as COVID-19 and in-country conflicts. These major disruptions affected healthcare delivery and access; one way to assess their impact is by surveying institutions and generating metrics that can guide quality improvement and optimize care. Ethiopia's healthcare system is organized into a tiered structure that includes primary, general, and specialized hospitals. Specialized hospitals manage the most severe and complex medical cases in the country and are also considered tertiary referral hospitals.
Data Envelopment Analysis (DEA) was applied using the Banker, Charnes, and Cooper (BCC) model under a Variable Returns to Scale (VRS) framework, which accounts for differences in hospital size and resource availability [3, 12].
The research team performed an ordinary least squares (OLS) regression analysis assessing whether high-risk caseloads influence efficiency, with high-risk patients identified using the African Surgical Outcome Survey (ASOS) risk calculator. This analysis is relevant in the context of the Ethiopian hospital system, where patients do not access hospitals through a consistent/stepwise referral pathway that is uniform in burden or capacity. Instead, they may seek care at specific higher-level facilities, such as tertiary hospitals in Addis Ababa, while others may opt to receive care at lower-level hospitals. As a result, hospitals treat very different mixes of patient severity, and facilities with more high-risk surgical patients may appear less efficient due to these cases requiring more resources. Therefore, we adjusted for high-risk case volume using the ASOS risk calculator to reduce case-mix confounding in our efficiency comparisons.
A review of efficiency models in healthcare compiled key "rules of thumb" for defining DMUs, inputs, and outputs, which inform the methodology of this study [4, 6]. For post-DEA analysis, the study team used the African Surgical Outcomes Study (ASOS) risk calculator to identify high-risk patients. The risk calculator aligned with the aims of this research study, as it identified key perioperative variables, including the American Society of Anesthesiologists (ASA) physical status classification and comorbidity scores, which are essential for surgical risk stratification [1]. Following the same approach, this team incorporated these variables into the Ethio- SOS tool to

adjust for patient risk profiles and ensure fair efficiency comparisons across hospitals. All data was derived from the Ethio-SOS database. The information was collected from the hospital level, bypassing the need to obtain and store personal patient information.
This study was approved by IRBs at both the Medical College of Wisconsin andEthiopian Public Health Institute (EPHI).

Theory/Calculation

DEA measures efficiency by comparing multiple input-output ratios across hospitals. Accordingly, this analysis defines surgical technical efficiency as relative surgical throughput efficiency with respect to bed capacity among the included hospitals. This operational definition is policy-relevant for hospital benchmarking in Ethiopia and is not intended to represent all dimensions of hospital-wide performance. All DEA calculations and post-DEA regression analyses were performed using Python. Python was also used to generate descriptive statistics, calculate efficiency scores, assess returns to scale, conduct the OLS regression evaluating the association between high-risk ASOS caseload and efficiency, and produce the study figures. The VRS model ensures that hospitals are not unfairly evaluated based on size differences. Efficiency scores derived from DEA include:

- Pure Technical Efficiency (PTE): Measures efficiency based solely on input-output relationships.
- Scale Efficiency (SE): Accounts for the impact of hospital size on efficiency.
- Overall Technical Efficiency (OTE): A combined measure of PTE and SE.
- Return to Scale (RTS): Determines whether efficiency is influenced by input size or operational processes.

This research focused on the OTE and RTS because they are the most applicable to healthcare models, according to the Banker, Charnes, and Cooper (BCC) model [3, 16].

One of the key methodological considerations in DEA is the relationship between the number of DMUs and the number of inputs and outputs known as "the curse of dimensionality" in which too many inputs and outputs lead to low discrimination in efficiency scores. To circumvent this, this study adheres to established guidelines for DMU-to-variable ratios [7]. DEA researchers suggest that the number of DMUs should be at least twice the total number of inputs and outputs [5], and the more conservative standard is a ratio of three times the number of variables [13, 15] . Our ratio satisfies all of these recommendations. This study enhances the discriminatory power of the DEA model and improves the reliability of efficiency estimates by ensuring sufficient DMUs (8) relative to variables (2) [4].

The African Surgical Outcomes Study (ASOS) provides a validated framework for risk adjustment, including the American Society of Anesthesiologists (ASA) classification and comorbidity scores, which were used to control for patient-level risk factors in this study [1]. While data on surgical urgency was unavailable to the study team, previous research justifies the use of an ASOS-based risk calculator even in the absence of urgency data, as it remains an objective, unbiased construct with minimal subjectivity [12].

For post-DEA analysis, the research team ultimately selected ordinary least squares (OLS) regression. Previous studies have employed non-parametric tests such as the Mann-Whitney U test and chi-square test to assess differences in efficiency across facility types or regions [11]. However, OLS allows for a more comprehensive assessment by modeling linear relationships between variables and adjusting for potential confounders. Unlike non-parametric methods, it provides more interpretive power regarding analysis of associations and ultimately the regression analysis aligned better with the research question.

Results

Technical efficiency scores ranged from 0.20 to 1.00, with a median score of 0.45 (Table 1). Hospital G achieved an efficiency score of 1.0, indicating optimal utilization of resources. Comparatively, the other hospitals had varied scores. Hospital E and Hospital B followed with scores of 0.78 and 0.61. Hospital F, Hospital A, and Hospital D exhibited intermediate efficiency levels, with scores ranging from 0.40 to 0.49. By contrast, Hospital C and Hospital H were the least efficient performers, with scores of 0.23 and 0.20, respectively. Regarding output performance, Hospital E had the highest annual surgical volume (16,800 procedures), followed by Hospital A (15,298) and Hospital G (12,600). Overall, the results suggest considerable variation in hospitals' ability to transform available surgical resources into annual surgical procedures.

When incorporating high-complexity patients in context, the results are also varied (Table 2). Of the total 880 patients included in the Ethio-SOS sample, 583 had an ASOS score of <10, whereas 297 were classified as high-risk with an ASOS score of ≥10. Hospital E contributed the largest number of patients overall (268), followed by Hospital F (252), while Hospital H contributed the fewest (28). In terms of high-risk patients, Hospital E recorded the highest number (89), closely followed by Hospital F (85). Hospital G, Hospital A, and Hospital C reported 32, 30, and 29 high-risk patients, respectively. On the other hand, Hospital B recorded the lowest number of high-risk patients (1). Overall, the findings show that although most patients had ASOS scores of <10, the burden of high-risk patients was concentrated in a smaller number of hospitals, particularly Hospitals E and F.

Hospitals B, C, D, F, and H operated under increasing returns to scale (IRS) (Table 3). This suggests that these hospitals were functioning below their most productive scale size and could potentially improve output proportionately through expansion of activity. In contrast, Hospitals A and E showed decreasing returns to scale (DRS), indicating scale inefficiency consistent with operating beyond the optimal scale. Hospital G, as the fully efficient unit, served as the reference hospital against which the performance of the other hospitals can be compared.

Figure 1 presents the OLS regression of the proportion of high-risk ASOS patients against hospital technical efficiency. The fitted regression line showcases a slight negative coefficient, suggesting that hospitals with a greater proportion of high-risk patients tended to report lower technical efficiency scores, although not statistically significant. Additionally, there is visible variation in efficiency across hospitals at similar levels of high-risk case burden.

Among the eight hospitals, five demonstrated increasing returns to scale, suggesting that increasing input (surgical beds) could lead to proportionally greater output (completed surgeries). Two of the hospitals showed decreasing returns to scale, meaning increasing input did not proportionally improve output, potentially reducing efficiency. One hospital maintained an efficiency score of 1.0 without any return to scale effects, indicating that scale changes do not influence efficiency.

The OLS regression analysis revealed a weak, non-significant relationship between high-risk cases and technical efficiency (coefficient: -0.762, p-value: 0.282, R-squared: 0.189) (Figure 1). With an 18.9% variance, which indicates a modest coefficient. While a non-significant inverse coefficient was observed, 18.9% of the variation in efficiency could be explained by high-risk caseloads, indicating that other factors influence hospital performance.

Discussion

This study assessed the surgical technical efficiency of eight tertiary hospitals in Addis Ababa, Ethiopia to identify areas for optimization of performance. These findings should be interpreted within the study's predefined operational framework: surgical technical efficiency was defined and measured as the relative conversion of surgical bed capacity into completed surgical procedures. This context resulted in a focused benchmark for surgical service productivity across Addis Ababa tertiary hospitals. The study team recognizes that other dimensions of performance (including but not limited to staffing, operating room availability, supply chains, cost, and postoperative outcomes) require complementary analyses.

An efficiency score of 1.0 in DEA does not imply perfect or ideal performance in an absolute sense but rather indicates that a hospital is operating efficiently relative to its peers within the sample, based on the selected inputs and outputs. This does not rule out the possibility of further improvement for these hospitals, especially when compared to institutions outside the sample or under different DEA specifications.

The increasing returns to scale observed in some hospitals indicate potential benefits from expanding capacity. This finding should be interpreted cautiously. Although IRS may indicate that these hospitals are operating below their most productive scale size, this does not necessarily mean that increasing surgical beds alone would proportionately increase operative throughput. Surgical output may also be constrained by factors not captured in the model, including operating room availability, anesthesia provider capacity, staffing limitations, scheduling efficiency, and supply chain constraints. Conversely, hospitals with decreasing returns may need process-specific improvements rather than increased input. The lack of a significant relationship between high-risk caseloads and efficiency may be due to the study being underpowered to detect or exclude this relationship.

Future studies should investigate qualitative aspects of hospital management and operational strategies, providing deeper insight into the practices and challenges faced by tertiary hospitals in Addis Ababa.

DEA is widely used for measuring technical efficiency in hospitals, providing a data-driven approach to identifying performance gaps and opportunities for improvement [17]. Beyond general hospital efficiency assessments, recent applications of DEA extend to specialized services, such as ambulance operations. A study evaluating ambulance services under the Ministry of Health in Malaysia utilized DEA to measure overall technical efficiency (OTE), pure technical efficiency (PTE), scale efficiency (SE), and returns to scale [11]. Similar methodological approaches can be applied in hospital-based efficiency studies to provide a granular understanding of performance across different hospital functions. Given that this research also treats hospitals as Decision-Making Units (DMUs), the literature findings reinforce the suitability of DEA for comparative efficiency analysis [11].

However, several methodological challenges must be considered, including issues related to input-output selection, data variability, and contextual factors that influence efficiency scores [8]. A recent review highlights potential pitfalls in applying DEA to healthcare settings and provides recommendations for mitigating biases in efficiency assessments [8]. This study addressed these concerns by conducting a post-DEA analysis, to explore whether the number of high-risk patients may be a confounding factor.

Moreover, DEA is a non-parametric linear programming model that assumes no random errors in efficiency measurements, making it sensitive to data variability and potential biases [9]. A systematic review of DEA applications in acute care hospitals highlights common methodological pitfalls, such as the challenge of selecting appropriate inputs and outputs and the risk of overfitting models when too many variables are included [14]. To mitigate these issues, this study limited the number of inputs and outputs relative to the number of Decision-Making Units (DMUs), ensuring that efficiency scores remain meaningful and discriminatory [16]. Previously described above, the selected DEA specification was designed to evaluate a focused, policy-relevant dimension of surgical service productivity rather than all domains of hospital performance.

This study employs an input-oriented DEA model, focusing on optimizing resource utilization in Ethiopian hospitals. Input-oriented DEA is particularly relevant in settings where resource constraints are a primary concern, allowing for an assessment of how hospitals can improve efficiency by reducing unnecessary input consumption [21]. Similar studies have successfully applied input-oriented DEA to measure healthcare efficiency, reinforcing the validity of this approach [7].

This study's findings are relevant to other comparable low-resource settings, including locations such as Sub-Saharan Africa. These settings operate under constraints that ultimately have downstream effects on staffing, infrastructure, equipment costs/budgeting, and the capacity to adequately care for patients. DEA has been applied in multiple African health systems [14]. Additionally, studies analyzing efficiency and productivity have been completed with DEA, varying in implementation of the same methodology [22]. These studies comprehensively show that inefficiency in a health system cannot always be explained through resource limitations, as scale of operation, case mix, and other aspects of efficiency can significantly influence the system. Our study aligns with this consensus. Therefore, we can use DEA to help identify and target inefficiencies linked to excess and/or limited input use, suboptimal scale, and operational bottlenecks that may occur. On the other hand, results need to be considered within the context of DEA, specifically whether efficiency scores are accurate because of their relative context, including the chosen inputs and outputs being analyzed. To further develop this context, subsequent studies are encouraged to add a qualitative component to further flesh out the differences in the scores and what may be contributing.

Limitations

This study has several limitations. It is based on data from eight large public hospitals in Addis Ababa, so the findings may not apply to smaller regional hospitals or rural facilities elsewhere in Ethiopia. The efficiency model uses only one resource, the number of surgical beds, and one

service output, the number of completed operations. This streamlined approach omits other important inputs such as operating room time, staffing and supplies, and it does not capture outcomes that occur after discharge. All variables were aggregated at hospital level from the Ethio-SOS (Ethiopia's surgical outcomes study); because patient level details such as procedure urgency were unavailable, risk adjustment relied solely on the ASOS calculator, which may not fully reflect differences in case mix. DEA treats every unexplained difference between hospitals as inefficiency, so its scores are sensitive to measurement error, extreme values and the small cross-sectional sample size used here. Ethio-SOS followed patients for seven days after surgery and included few highly complex procedures, so late complications and performance in specialized services are probably underestimated. In addition, hospital setting variance between patient totals and daily averages highlights that collected data may affect the reliability of the efficiency estimates. Differences between daily averages and total surgeries per year are due to the variability of case volume day to day. For example, interruptions due to weekends, public holidays, cleaning, maintenance, or supply shortages are normal and expected in real hospital operations. Although we anticipated this variation in the hospital setting, the research team acknowledges that these estimations may influence how efficiency is measured and interpreted. Finally, the regression model that linked the share of high-risk patients to efficiency explained less than one fifth of the observed variation, suggesting that unmeasured managerial and contextual factors also influence hospital performance.

Conclusions

Both the Lancet Commission on Global Surgery (LCoGS) and the World Health Organization (WHO) call for standardized efficiency assessments to guide financing and system reform [10, 20]. This study provides an initial exploratory baseline for understanding surgical technical efficiency in Addis Ababa's tertiary hospitals and directly supports LCoGS priorities by generating exploratory data for Ethiopia's health system. By applying DEA within Ethiopia's hospital context, this study advances the broader discourse on health system performance and offers insight for targeted national and regional reforms [3, 18]. Future research should rigorously test alternative input–output models and integrate qualitative methods to uncover the operational drivers of high-performing hospitals. Strengthening data infrastructure is essential for enabling robust evaluations and shaping evidence-informed policy to improve surgical care delivery.

Appendix

ASOS-defined high risk cases varied widely between hospitals

Table 1: Surgical Capacity of Hospitals in Addis Ababa (From Ethio-SOS Structural Survey)

S.N	Name of the Hospital	Level of the Hospital	Number of Surgical Beds in the Hospital	Surgeries Done per Day in the Surgical Unit (on Average)	Total Annual Surgical Procedures	Calculated Technical Efficiency
1	Hospital A	Specialized	190	52	15298	0.41
2	Hospital B	General	35	14	5000	0.61
3	Hospital C	Specialized	176	36	9540	0.23
4	Hospital D	Specialized	54	12	5084	0.40
5	Hospital E	Specialized	92	50	16800	0.78
6	Hospital F	Specialized	95	30	11000	0.49

7	Hospital G	General	54	35	12600	1.0
8	Hospital H	General	57	8	2688	0.20

The technical efficiency scores ranged from 0.20 to 1.0 (median: 0.45), with 1 hospital achieving a score of 1.0.

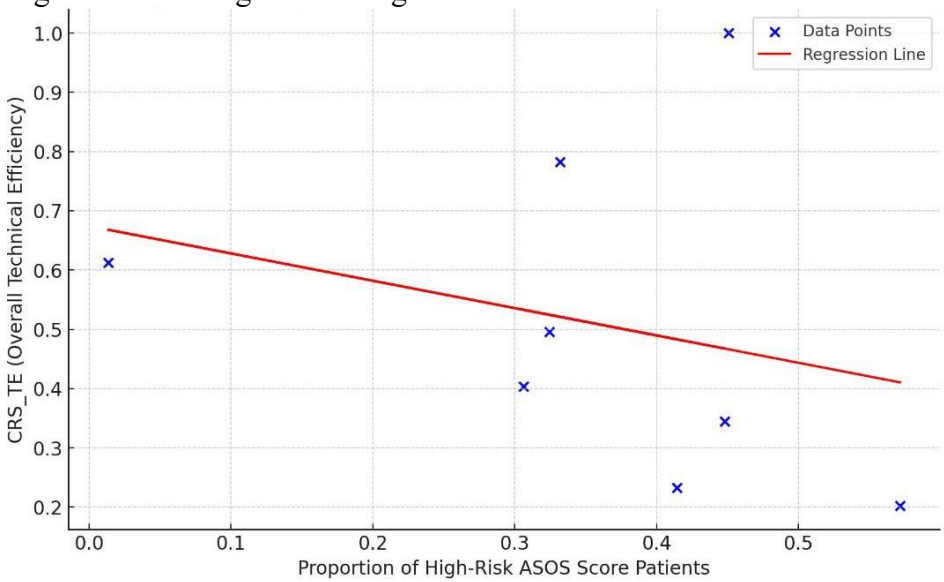
Table 2: Hospitals with number of high-risk patients in Addis Ababa which participated in Ethio-SOS

S.N.	Name of the hospital	ASOS Score		Total
		<10	>=10 (High-Risk Patients)	
1	Hospital A	37 (55.2%)	30 (44.8)	67
2	Hospital B	74 (98.7%)	1 (1.3%)	75
3	Hospital C	41 (58.6%)	29 (41.4%)	70
4	Hospital D	34 (69.4%)	15 (30.6%)	49
5	Hospital E	179 (66.8%)	89 (33.2%)	268
6	Hospital F	167 (66.3%)	85 (33.7%)	252
7	Hospital G	39 (54.9%)	32 (45.1%)	71
8	Hospital H	12 (42.9%)	16 (57.1%)	28
	Total	**583 (66.2%)**	**297 (33.8%)**	**880**

Table 3: High Risk ASOS Score Patients vs Technical Efficiency

	Name of the Hospital	Number of Surgical Beds in the Hospital	Annual Surgical Procedures	High Risk Percentage	Technical Efficiency	Return to Scale
1	Hospital A	190	15298	44.78%	0.41	DRS
2	Hospital B	35	5000	1.33%	0.61	IRS
3	Hospital C	176	9540	41.42%	0.23	IRS
4	Hospital D	54	5084	30.61%	0.40	IRS
5	Hospital E	92	16800	33.21%	0.78	DRS
6	Hospital F	95	11000	33.73%	0.49	IRS
7	Hospital G	54	12600	45.07%	1.0	—
8	Hospital H	57	2688	57.14%	0.20	IRS

Figure 1: OLS Regression: High-Risk ASOS Score Patient vs Technical Efficiency



Regression revealed high ASOS risk cases were slightly associated with a decreasing technical efficiency (TE) score of hospitals

Acknowledgements

Thank you to all contributing authors: Zemenu Binalfewu, MD; Yemsrach Kedru, MPH; Fitsum Kifle, MD; Ermiyas Belay, MSc; Tesfay Yohannes, MSc; Selam Daniel, MD; Fayrouz Abu-Hamdan, MD; Christopher M. Dodgion, MD; Andualem Beyene, MD; Katherine R. Iverson, MD, MPH.

In Partnership with Ethio-USA Global Surgery Fellows, Global Partners In Improving Surgical Systems (GPISS), Addis Ababa University, Network for Perioperative Critical Care (N4PCC), Kidus Peteros Hospital. Thank you to the St. Joseph's PES Fund for funding the Dr. Elaine Kohler Summer Academy of Global Health Research Scholar.

List of Abbreviations:

Abbreviation	Definition
AHRI	Armauer Hansen Research Institute
ASA	American Society of Anesthesiologists
ASOS	African Surgical Outcomes Study
BCC	Banker, Charnes, and Cooper Model
DEA	Data Envelopment Analysis
DMU	Decision-Making Unit

DRS	Decreasing Returns to Scale
Ethio-SOS	Ethiopian Surgical Outcome Study
GPISS	Global Partners In Improving Surgical Systems
IRS	Increasing Returns to Scale
LCoGS	Lancet Commission on Global Surgery
LMIC	Low- and Middle-Income Country
N4PCC	Network for Perioperative Critical Care
OLS	Ordinary Least Squares
OTE	Overall Technical Efficiency
PTE	Pure Technical Efficiency
RTS	Returns to Scale
SE	Scale Efficiency
TE	Technical Efficiency
VRS	Variable Returns to Scale
WHO	World Health Organization

Ethics Declarations: Ethics Approval

This study was approved by the Medical College of Wisconsin Institutional Review Board (Protocol No. PRO00043474), titled Surgical Data in Ethiopia, with approval granted through October 18, 2029. The study was also approved by the Ethiopian Public Health Institute Institutional Review Board (Protocol No. 454-2022; Assigned No. EPHI-IRB 454-2022) for the protocol entitled Assessment of Current Surgical Data Practices in Ethiopia.

Consent to Participate

Hospitals were enrolled as part of the larger Ethiopian Surgical Outcomes Study to track and compare surgical outcomes longitudinally, and consented to participate via this study.[2]

Consent for Publication
N/A

Funding
This work was supported by the St. Joseph's PES Fund through the Dr. Elaine Kohler Summer Academy of Global Health Research Scholar program. This funder had no role in the study design, data collection nor analysis/interpretation, preparation of the manuscript, or decision to submit the manuscript for publication.

Author Contributions
Philisha Mesidor: Conceptualization, Investigation, Methodology, Software, Project Administration, Writing – Original Draft Preparation, Writing – Review & Editing.
Zemenu Binalfewu: Conceptualization, Investigation, Methodology, Software, Project Administration, Writing – Original Draft Preparation.
Yemsrach Kedru: Conceptualization, Methodology, Software, Writing – Original Draft Preparation, Writing – Review & Editing.
Fitsum Kifle: Conceptualization, Funding Acquisition, Project Administration, Resources, Supervision, Validation, Writing – Review & Editing.
Ermiyas Belay: Methodology, Formal Analysis, Validation, Visualization.
Tesfay Yohannes: Methodology, Formal Analysis, Validation, Visualization.
Selam Daniel: Methodology, Formal Analysis, Validation, Visualization.
Fayrouz Abu-Hamdan: Resources, Validation, Writing – Review & Editing.
Christopher M. Dodgion: Funding Acquisition, Resources, Supervision, Validation, Writing – Review & Editing.
Andualem Beyene: Conceptualization, Funding Acquisition, Resources, Supervision, Validation, Writing – Review & Editing.
Katherine R. Iverson: Conceptualization, Funding Acquisition, Project Administration, Resources, Supervision, Validation, Writing – Review & Editing.

Competing Interests
The authors declare no competing interests.

References

1. Biccard BM, Madiba TE, Kluyts HL, Munlemvo DM, Madzimbamuto FD, Basenero A, et al. Perioperative patient outcomes in the African Surgical Outcomes Study: a 7-day prospective observational cohort study. Lancet. 2018;391(10130):1589-98. doi:10.1016/S0140-6736(18)30001-1.
2. Awedew AF, Belachew FK, Iverson KR, Ambese TY, Belihu KD, Tantu AD, Gebreslase LG, Teklehaimanot MG, Kifle K, Addis NA, et al. The Ethiopian Surgical Outcome Study (Ethio-SOS): a 7-day multicentre national prospective observational cohort study. BMJ Glob Health. 2025;10(9):e020147. doi:10.1136/bmjgh-2025-020147.
3. Cooper WW, Seiford LM, Zhu J. Handbook on data envelopment analysis. 2nd ed. New York (NY): Springer; 2011. doi:10.1007/978-1-4419-6151-8.
4. Dyson RG, Allen R, Camanho AS, Podinovski VV, Sarrico CS, Shale EA. Pitfalls and protocols in DEA. Eur J Oper Res. 2001;132(2):245-59. doi:10.1016/S0377-2217(00)00149-1.

5. Golany B, Roll Y. An application procedure for DEA. Omega. 1989;17(3):237-50. doi:10.1016/0305-0483(89)90029-7.
6. Jaafaripooyan E, Emamgholipour S, Raei B. Efficiency measurement of health care organizations: what models are used? Med J Islam Repub Iran. 2017;31:86. doi:10.14196/mjiri.31.86.
7. Kapelko M. Evaluating input- and output-specific inefficiency in courts of justice: an empirical study of Polish district courts. Int Trans Oper Res. 2024. doi:10.1111/itor.13503.
8. Kohl S, Schoenfelder J, Fügener A, Brunner JO. The use of data envelopment analysis (DEA) in healthcare with a focus on hospitals. Health Care Manag Sci. 2019;22(2):245-86. doi:10.1007/s10729-018-9436-8.
9. Kočišová K. Using DEA models to measure efficiency. In: Proceedings of the XIII International Conference: Theoretical and Practical Aspects of Public Finance. Košice (Slovakia): Technical University of Košice; 2005. p. 24-28.
10. Meara JG, Leather AJM, Hagander L, Alkire BC, Alonso N, Ameh EA, et al. Global surgery 2030: evidence and solutions for achieving health, welfare, and economic development. Lancet. 2015;386(9993):569-624. doi:10.1016/S0140-6736(15)60160-X.
11. Mohd Hassan NZA, Bahari MS, Aminuddin F, Mohd Nor Sham Kunusagaran MSJ, Zaimi NA, Mohd Hanafiah AN, et al. Data envelopment analysis for ambulance services of different service providers in urban and rural areas in Ministry of Health Malaysia. Front Public Health. 2023;10:959812. doi:10.3389/fpubh.2022.959812.
12. Newman DA. Missing data: five practical guidelines. Organ Res Methods. 2014;17(4):372-411. doi:10.1177/1094428114548590.
13. Nunamaker TR. Using data envelopment analysis to measure the efficiency of non-profit organizations: a critical evaluation. Manag Decis Econ. 1985;6(1):50-58. doi:10.1002/mde.4090060106.
14. Pai DR, Pakdil F, Azadeh-Fard N. Applications of data envelopment analysis in acute care hospitals: a systematic literature review, 1984-2022. Health Care Manag Sci. 2024. doi:10.1007/s10729-024-09669-4.
15. Raab RL, Lichty RW. Identifying subareas that comprise a greater metropolitan area: the criterion of county relative efficiency. J Reg Sci. 2002;42(3):579-94. doi:10.1111/1467-9787.00272.
16. Ramanathan R. An introduction to data envelopment analysis: a tool for performance measurement. Thousand Oaks (CA): Sage Publications; 2003.
17. Thanassoulis E, Silva MCA. Measuring efficiency through data envelopment analysis. Impact. 2018;2018(1):37-41. doi:10.1080/2058802X.2018.1440814.
18. World Health Organization Regional Office for Africa. Strengthening health information systems in the WHO African Region: a strategic and governance framework. Brazzaville (Republic of the Congo): World Health Organization Regional Office for Africa; 2015.
19. World Health Organization. How to make sense of health system efficiency comparisons. Geneva (Switzerland): World Health Organization; 2022.
20. World Health Organization. Why and how to assess health system efficiency: a policy brief. Geneva (Switzerland): World Health Organization; 2022.
21. Yitbarek K, Adamu A, Tsega G, Siraneh Y, Erchafo B, Yewhalaw D, et al. Technical efficiency of maternal and reproductive health services in public hospitals of Oromia Regional State, Ethiopia. Health Serv Insights. 2019;12:1178632919837630. doi:10.1177/1178632919837630.
22. Zhang M, Gajewski J, Pittalis C, Shrime M, Broekhuizen H, Ifeanyichi M, et al. Surgical capacity, productivity and efficiency at the district level in Sub-Saharan Africa: a three-country study. PLoS One. 2022;17(11):e0278212. doi:10.1371/journal.pone.0278212.