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Title: Derivation and validation of pragmatic clinical models to predict hospital length of stay after cardiac surgery in Ontario, Canada
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Reviewer 1
General comments (author response in bold)

This is manuscript that describes the development of two predictive models for LOS for CVSx patients.

1. The authors do not clearly describe how it can be applied clinically.
The reviewer raises an important point. We have added the following to describe the clinical applications of these models.
Page 13 line 6: "Operative decision-making, performance benchmarking and postoperative resource planning may be enhanced by objective tools… The ability to predict continuous hospital LOS is advantageous to hospital administrators, patients and caregivers. Patients often ask about their projected LOS as it sets realistic expectations of the costs and benefits of surgery as a part of the informed consent and therapeutic decision-making process. For caregivers, an estimated LOS will more effectively facilitate personal and professional arrangements in order to care for loved ones after surgery. At the hospital level, the widening use of electronic medical records may lend itself to institution-based self quality assessments, and to rationally allocate telemonitoring and other post-discharge care and follow-up resources to reduce morbidity and readmissions. At the system level, these models could be used to generate risk-adjusted observed vs. expected LOS to systematically evaluate performance."
Page 14 line 6: "The ability to identify those at risk for extremely prolonged LOS allows for better decision-making from the perspectives of the healthcare system as well as the individual patient. As the system level, this ability, coupled with continuous LOS prediction, could facilitate data-driven clinical scheduling to increase throughput, facilitate targeted interventions such as prehabilitation, Enhanced Recovery After Surgery, and early referral to continuing care facilities. As prolonged LOS has also been implicated with increased healthcare cost(1) and disability after discharge,(2–6) our predictive models will inform effective provider-patient discussions and encourage patient-centered operative decision-making."
Page 15 line 4: "Importantly, our ability to predict continuous LOS enables precision-based hospital capacity planning, as well as … incentivized allocation of healthcare funding. Incorporation of the model into tools such as the province-wide CorHealth information system could also help individual providers to understand bed requirements at the time of intervention, allowing for more accurate resource planning."

2. The authors fail to adequately contextualize how their model compares to existing models (they only compare their model to another one...)
The majority of cardiac surgery literature on post-operative LOS centers on LOS in the CVICU and not of the entire hospital stay. There is in fact very sparse literature regarding total duration of hospital LOS in cardiac surgical patients, the

most robust and commonly used being the repurposing of STS and EuroScore for predicting hospital LOS as a binary variable. Accordingly, we had described these single center validation studies of the EuroScore to predict prolonged hospital LOS >12 days (7) and of the STS score to predict the probability of "short" and "long" LOS, with 14 days as the cutoff (8,9). We had described the potential uses (please refer to our response to your Comment #1) and advantages of our models over the STS and EuroScore, including their ability to identify top-tier resource users while also projecting continuous LOS with excellent accuracy.
We have made revisions in the manuscript to highlight this fact.
Page 6, line 11: "Nonetheless, while risk factors have been identified for prolonged postoperative hospital LOS, very few models are available to predict this important metric, and none are able to estimate actual post-operative LOS with accuracy. Further, though existing models include those from the Society of Thoracic Surgeons (STS) and the EuroSCORE datasets (1,7,9), they were developed to predict perioperative mortality and end organ morbidity and were only later validated in single center datasets for the purpose of predicting prolonged LOS in a binary fashion and are not used to estimate actual LOS."
Page 14, line 16: "Comparatively, the EuroScore had a c-statistic of 0.71 (0.69-0.72) for predicting prolonged hospital LOS (> 12 days) when validated in a monocentric setting(7), and the STS model had a c-statistic of 0.716-0.732 for predicting short hospital LOS of ≤ 5 days and 0.739-0.796 for predicting prolonged stay of > 5 days, depending on the type of surgery performed.(10)"

3. Not certain whether the readership of CMAJ would benefit from this study. Perhaps a more surgical-specific journal should be targeted.
The CMAJ showcases a variety of medical and surgical research, including many recent studies that specifically pertain to cardiac surgery (5,11–15). Given the potential impact of the present study at the level of patients, caregivers, hospitals and the healthcare system, we believe our findings will be of interest to readers of CMAJ.

4. The models also appear to add precious little in terms of novelty.
There are very few models that predict hospital LOS after cardiac surgery, and none that predict continuous LOS with accuracy. Therefore, the novelty of our study lies in its ability to address the need to accurately plan hospital and post-discharge resources via an efficient and data-driven approach to managing the mounting surgical backlog.

5. On a separate note, it would be easier to follow the manuscript if it was formatted properly and consistently. There are paragraphs where the between-line spacing is double (?) whereas the rest are not.
The manuscript has been reformatted.

Reviewer 2: Susan Brogly PhD MSc
Affiliation: Queen's Department of Surgery; Kingston Health Science Centre, Surgery
General comments (author response in bold)

The authors present findings on a model to predict hospital length of stay (LOS) after cardiac surgery in patients 18 and older in Ontario, Canada. It is stated that the models improve upon those previously published due to the population-based cohort in which

the model was developed. It is unclear who would use the models and for what purpose. These concerns and some additional suggestions are further described below.

Abstract

1. Perhaps type of resource intensity should be qualified; non-surgical personnel? surgeon? cost to health care provider? OR time?
We appreciate the comment and have amended the abstract to note the multidisciplinary care required to facilitate discharge. Certainly while the intraoperative course, operative time, and surgical personnel are an important component of cardiac surgical care, this manuscript aims to describe the postoperative length of stay and as such references the resources required for appropriate post-operative care).
Abstract, Page 4, line 2: "Cardiac surgery is resource intensive and often requires considerable length of stay (LOS) and multidisciplinary involvement to facilitate discharge."

2. The model fit predictors are not the key findings of interest here, rather it is the characteristics that predict longer length of stay. These should be added.
We thank the reviewer for this suggestion and have incorporated key characteristics predicting longer LOS in the abstract as suggested.
Abstract, Page 4, line 15: "Factors predicting prolonged LOS included age, female sex, procedure type and urgency, comorbidities including frailty, high-risk acute coronary syndrome, heart failure, reduced left ventricular ejection fraction, psychiatric and pulmonary circulatory disease."

3. How will the models benchmark quality, and quality of what? In addition, it is unclear how the model will inform the patient-centred decisions. Most patients will want cardiac surgery to prevent mortality regardless of LOS. If surgery allotments, OR time, cardiac surgeon availability, costs etc. are of concern to the hospital administration and Ministry of Health, then the models may be of use to them to determine which patients will undergo surgery. This should be clear in the objective and implications.
We appreciate this suggestion and have revised the abstract to reflect the idea of benchmarking clinical performance based on expected length of stay.
Abstract, Page 4, line 21: "Our models could be used to benchmark quality based on expected length of stay"

Methods

4. It would be clearer to start out that the cohort was identified using administrative health data held at ICES in the single-payer healthcare system in Ontario, Canada. And then go on to describe the privacy of ICES.
We have revised as suggested, by adding on page 7, line 7: "Ontario operates a publicly funded, universal health care system that reimbursed all covered services and clinicians.", as well as moving the description of privacy at ICES after this statement.

5. Need to specify that index procedure means "first cardiac surgery"; could just use the latter and avoid term index altogether.
We have revised as the reviewer suggested.

6. Was there some reason that surgeon characteristics: age, sex, years of practice, number of cardiac surgeries (and/or specific types per year) were not included? It seems these may be useful predictors.
The models were developed to predict hospital LOS at the time of surgical triaging, often before surgeons are assigned to the case. Thus, provider information is not always available at the time the models are applied.

7. Need to define how LOS was calculated: from date of cardiac surgery to discharge or from date of admission? The former would be more accurate given that there may be inter-hospital transfers etc.
Thank you for the opportunity to clarify our methodology. LOS is calculated from the date of surgery until the date of discharge from index hospital.
Page 9 line 7: "The primary outcome was postoperative hospital LOS, from the date of surgery until date of index hospital discharge."

8. Unclear why 98th percentile (35 days) was selected for the outliers. Is there a clinical reason? A statistical one? Why not the 90th?
Thank you for the opportunity to clarify our methodology. We have added the following to explain the rationale for choosing the 98th percentile as cut-off for the binary prediction model.
Abstract: "To address the rightward skew in LOS data and to identify top-tier resource users, we used logistic regression to derive a model to predict the likelihood of LOS being >98th percentile (≥35 days)."
Methods, page 9 line 8: "We derived two separate models: the first (binary outcome model) to identify the top-tier resource users (i.e., LOS exceeding the 98th percentile value of ≥ 35 days), and the other (continuous outcome model) to predict the actual LOS in days in the remainder of the cohort. The rationale for our modeling approach was two-fold. First, as LOS data is invariably right-skewed with extreme values in those with prolonged stay, (16,17) the choice of 98th percentile (LOS ≥ 35 days) as cut-off eliminates extreme values and increases the precision of continuous LOS prediction. Second, those with LOS ≥ 35 days are amongst the highest resource users and are most likely to acquire a new disability that would impair their quality of life after eventual discharge. (2–6) The ability to predict extremely prolonged LOS will allow patients to be informed partners in the therapeutic decision-making process"
Interpretation, Page 14 line 6: "The ability to identify those at risk for extremely prolonged LOS allows for better decision-making from the perspectives of the healthcare system as well as the individual patient. As the system level, this ability, coupled with continuous LOS prediction, could facilitate data-driven clinical scheduling to increase throughput, facilitate targeted interventions such as prehabilitation, Enhanced Recovery After Surgery, and early referral to continuing care facilities. As prolonged LOS has also been implicated with increased healthcare cost(1) and disability after discharge,(2–6) our predictive models will inform effective provider-patient discussions and encourage patient-centered operative decision-making."

9. Terminology should be consistent throughout the manuscript: sometimes actual is used for the model of all patients and sometimes continuous. It would be easier to follow with consistent terminology.

Thank you for pointing this out. We have replaced "actual" with "continuous" throughout, for consistency and clarity.

10. Why were variables modeled as continuous? Is this clinically relevant?
We have added the following to clarify.
Page 13 line 6: "Operative decision-making, performance benchmarking and postoperative resource planning may be enhanced by objective tools… The ability to predict continuous hospital LOS is advantageous to hospital administrators, patients and caregivers. Patients often ask about their projected LOS as it sets realistic expectations of the costs and benefits of surgery as a part of the informed consent and therapeutic decision-making process. For caregivers, an estimated LOS will more effectively facilitate personal and professional arrangements in order to care for loved ones after surgery. At the hospital level, the widening use of electronic medical records may lend itself to institution-based self quality assessments, and to rationally allocate telemonitoring and other post-discharge care and follow-up resources to reduce morbidity and readmissions. At the system level, these models could be used to generate risk-adjusted observed vs. expected LOS to systematically evaluate performance."
Page 15 line 4: "Importantly, our ability to predict continuous LOS enables precision-based hospital capacity planning, as well as … incentivized allocation of healthcare funding. Incorporation of the model into tools such as the province-wide CorHealth information system could also help individual providers to understand bed requirements at the time of intervention, allowing for more accurate resource planning."

Results

11. While it is appreciated that the authors highlight differences in patients in Table 1, some key features are missed. For instance, a minority of the population is female, and the age difference in groups is 6 years etc.
Thank you for the comment. Amendments to the manuscript have been made to better reflect the demographic differences between the two populations described in Table 1.
Page 11, line 13: "A minority of the patients in either group were female, though females more likely than males to have prolonged hospital LOS. Those with prolonged hospital LOS were more likely to be older, with a 6 year median age difference noted, of lower income levels, and were more likely to present urgently and emergently for complex procedures (redo sternotomy, CABG + valve(s), multiple valves and thoracic aorta surgery) of longer surgical duration and at teaching hospitals. They are also more likely to have a higher multimorbidity burden including frailty, in addition to cardiovascular comorbidities such as recent myocardial infarction, reduced LVEF, and higher NYHA classification."

12. Since study size is large—and the p-value is a reflection of the difference and the study size—suggest replacing the p-values in Table 1 with standardized differences.
Thank you for this suggestion. We have updated Table 1 accordingly.

Discussion

13. Unclear to this reader how this model would be used. There did not appear to be an equation in the manuscript—nor a link to an on-line calculator—to allow the cardiac surgeon (or hospital administration) to calculate predicted LOS. Who is the model for?
Thank you for this suggestion. We are currently working on digital risk calculators and will have them ready prior to publication.

14. Likely irrelevant to the cardiac surgeon (though he/she will monitor patient while in recovery) and more relevant to hospital administration who will manage beds, costs, and support staff. Related to this is "The ability to identify those at risk for prolonged LOS allows for better decision-making from the healthcare system as well as the individual patient" is not transparent. What aspect of the healthcare system?
Thank you for the opportunity to expand on our discussion. We have provided clarification below:
Page 13, line 19: "At the system level, these models could be used to generate risk-adjusted observed vs. expected LOS to systematically evaluate performance."
Page 14, line 10: "As prolonged LOS has also been implicated with increased healthcare cost(1) and disability after discharge,(2–6) our predictive models will inform effective provider-patient discussions and encourage patient-centered operative decision-making.
Page 16, line 10: "Care, outcomes, and patient satisfaction may be substantially improved if clinical judgment is supported by objective quantification in the planning of care. Shared decision-making through a thorough discussion of evidence-based estimates of risk and benefits of treatment options with patients and caregivers, is vital to patient-centered care. Our research fills an important knowledge gap by providing scientific evidence to inform shared clinical decision-making."

15. Also, as mentioned, LOS is less important to the patient than undergoing needed cardiac surgery.
We have added the following to clarify our point about the importance of LOS prediction for patients, caregivers and administrators:
Page 13 line 11: "The ability to predict continuous hospital LOS is advantageous to hospital administrators, patients and caregivers. Patients often ask about their projected LOS as it sets realistic expectations of the costs and benefits of surgery as a part of the informed consent and therapeutic decision-making process. For caregivers, an estimated LOS will more effectively facilitate personal and professional arrangements in order to care for loved ones after surgery. At the hospital level, the widening use of electronic medical records may lend itself to institution-based self quality assessments, and to rationally allocate telemonitoring and other post-discharge care and follow-up resources to reduce morbidity and readmissions. At the system level, these models could be used to generate risk-adjusted observed vs. expected LOS to systematically evaluate performance."

16. Unclear which models relied on designated staff for the variables needed; prior papers? present manuscript? It seems that the current model also would require staff to identify the variables. Later it is stated that the variables included in the model are routinely collected; perhaps in ICES but the ICES data are unavailable to hospital

administrators and certainly the surgeons do not have time to collate these data from their patient charts.

The models reported in the present study are based on routinely collected, data from a standardized, province-wide surgery referral form that is completed by the referring physician. Information from this referral form is directly available to the triaging team at each Ontario cardiac centre. In comparison, the STS models make predictions with 50 covariates. The collection of STS data requires additional infrastructure to be in place, which is not practical for the Canadian healthcare system.(13)

17. Unclear that a model for all cardiac surgeries is an advantage over models developed in homogenous groups of cardiac surgery patients.

We agree that modeling could be performed either in an omnibus fashion across all procedure types, or within a subgroup of patients who underwent a particular type of surgical procedure. The advantage of omnibus models is that they are very practical and are widely applicable across all types of cardiac surgeries, and that predictions could still be tailored to the complexity of the procedure. On the other hand, as there are many potential combinations of complex cardiac procedures, models that are specific to a single procedure type are not readily applicable to patients who undergo a variant of that procedure (i.e., an AVR-only or AVR+CABG model is not applicable to patients who undergo AVR + MAZE). It is likely for these reasons that the widely used models in cardiac surgery are omnibus.

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