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Authors: Aaron Conway, Jeffrey Gow, Nicholas Ralph, Jed Duff, Karen-Leigh Edward, Kim Alexander, Judy Munday, Anselm Bräuer



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## Implementing a thermal care bundle for inadvertent perioperative hypothermia: a cost-effectiveness analysis

Aaron CONWAY<sup>1,2</sup>, Jeffrey GOW<sup>3,4</sup>, Nicholas RALPH<sup>5,6,7, 14, 15</sup>, Jed DUFF<sup>7</sup>, Karen-Leigh EDWARD<sup>8,9</sup>, Kim ALEXANDER<sup>10,11</sup>, Judy MUNDAY<sup>12</sup> and Anselm BRÄUER<sup>13</sup>

1. RBC Chair in Cardiovascular Nursing Research, Peter Munk Cardiac Centre, Toronto General Hospital, University Health Network, Canada
2. Assistant Professor, Lawrence S. Bloomberg Faculty of Nursing, University of Toronto, Canada, E: aaron.conway@utoronto.ca , Tw:@aw\_conway
3. Professor of Economics, School of Commerce, University of Southern Queensland, Australia, jeffrey.gow@usq.edu.au
4. School of Accounting, Economics and Finance, University of KwaZulu-Natal, Durban, South Africa
5. Associate Professor, School of Nursing & Midwifery, University of Southern Queensland,
6. Institute for Resilient Regions, University of Southern Queensland, Australia, E: nicholas.ralph@usq.edu.au, Tw: @nicholas\_ralph
7. Associate Professor, School of Nursing & Midwifery, University of Newcastle, Newcastle, Australia, E: jed.duff@newcastle.edu.au Tw: @jed\_duff
8. Professor of Nursing and Practice Based Research, School of Nursing & Midwifery, Swinburne University, Melbourne, Australia, E: kedward@swin.edu.au ; Tw:@KarenLeigh10
9. Visiting Professor, St Vincent's Private Hospital, Melbourne, Australia
10. Associate Professor, School of Nursing, Queensland University of Technology, Brisbane, Australia E: k.alexander@qut.edu.au Tw:@kimealexander
11. Research Chair, Holy Spirit Northside Private Hospital, Brisbane, Australia
12. Lecturer, School of Nursing, Queensland University of Technology, Brisbane, Australia, E: judy.munday@qut.edu.au ; Tw: @judymunday2
13. Associate Professor, Department of Anaesthesiology, University Medical Center Goettingen, Germany, Email: abraeue@gwdg.de
14. Senior Manager (Health Systems and Psychooncology), Cancer Council Queensland, Brisbane, Australia
15. Senior Research Fellow, St Vincent's Private Hospital Toowoomba, Australia

### Corresponding to:

Aaron Conway, Lawrence S. Bloomberg Faculty of Nursing University of Toronto 155 College St Toronto, Ontario, M5T 1P8, Email: aaron.conway@utotonto.ca

### Abstract

#### *Background*

Active warming reduces risk of surgical complications. Implementation of a perioperative thermal care bundle increased use of active warming for surgical patients.

#### *Objective*

This study aimed to determine if implementing a thermal care bundle to prevent inadvertent perioperative hypothermia is cost-effective.

### *Design*

A model-based cost-effectiveness analysis was undertaken using Monte Carlo simulations from input distributions to estimate costs and effects.

### *Setting*

Hospitals undertaking between 5,000 and 40,000 surgeries per year, which either implemented or did not implement the thermal care bundle, were modelled.

### *Participants*

The decision tree guiding the structure of the model was populated with clinical outcomes (surgical site infection, blood transfusion requirement and morbid cardiac events) of a hypothetical cohort of surgical patients.

### *Interventions*

Implementation or non-implementation of the thermal care bundle.

### *Main outcome measures*

Net monetary benefit was calculated by multiplying the health benefits (quality-adjusted life years) by the willingness-to-pay threshold minus the cost. We tested a range of values for willingness to pay per quality-adjusted life year thresholds and plotted results for expected incremental benefits and probability of cost-effectiveness. The incremental cost-effectiveness ratio was also calculated.

### *Results*

Thermal care bundle implementation simultaneously reduced costs and increased quality-adjusted life years in the majority of simulations (88.1%). The average cost reduction was \$689,659 (95% credible intervals spanned from a \$2,718,364 decrease in costs to \$379,826 increase in costs) and average difference in quality-adjusted life years was 54 (95% CI=0.4 less to 176 more). This equated to an incremental cost-effectiveness ratio of \$12747 saved per quality-adjusted life year gained.

## *Conclusions*

It is likely that increasing use of active warming by implementing the thermal care bundle would generate cost-savings and improve the quality of life for surgical patients. It would be good value for hospitals with similar characteristics to those included in our model to allocate the extra resources required for implementation.

**Keywords: Hypothermia: prevention; OR costs: labour vs materials; nurses; nursing; temperature; active warming**

## *Introduction*

Forced air warming is recommended for surgery performed with general and regional anaesthesia because it has been shown to reduce the risk of surgical site infections (1) and cardiac events as well as decrease surgical bleeding.(2) A British cost-effectiveness study identified that the use of active warming dominated standard care for patients undergoing surgery.(2) Despite the high quality evidence supporting the clinical and cost-effectiveness of active warming, as well as clinical guideline recommendations calling for its use, results from studies that have examined its application in real-world practice have revealed a considerable evidence-practice gap. For example, a multi-centre study in Australia identified that 45% of surgical patients did not receive active warming when indicated.(3) A Chinese study conducted across 28 hospitals revealed that active warming was rarely used, with less than 15% of a cohort of more than 3,000 surgical patients studied being warmed with electric heaters or blankets.(4) Moreover, in the largest observational study performed to date, 46% of all patients (n=50,689) admitted to an ICU after major elective surgery were hypothermic.(5) In response, we systematically developed and evaluated the Thermal Care Bundle and investigated whether it increased adherence to clinical guideline recommendations for the thermal care of patients undergoing surgery. Detailed descriptions of the bundle are provided elsewhere.(3, 6-8) In brief, a panel of clinicians (operating room nurses, anaesthetists and surgeons) and researchers

decided upon the central elements from the National Institute for Health and Clinical Excellence (NICE) guideline on the management of hypothermia during surgery using the electronic Guideline Implementability Appraisal (eGLIA) tool.(9) The central elements selected by the panel for the bundle were: 1) assessing risk for hypothermia and the complications associated with hypothermia during surgery; 2) Recording temperature at each phase of the perioperative journey (before, during and after surgery); and 3) Applying active warming with a forced air warming device intraoperatively to patients at-risk of hypothermia (using pre-determined criteria) or the complications of hypothermia, and at any time hypothermia was identified (defined as a temperature below 36°C). To implement the bundle, a collaborative model for implementation research based on the Institute of Healthcare Improvement's Breakthrough Series Model(10) and the John's Hopkins Translating Research into Practice model(11) was used. The model involved formation of a core team at each site who lead the implementation by: 1) accessing email and phone support from the research team when required; 2) attending workshops to learn about methods to utilise for local implementation; 3) using a structured local barrier identification and mitigation tool(12); 4) using Plan-Do-Study-Act cycles (which were taught at the workshops). Implementation of bundle elements in practice (i.e. assessing risk, measuring temperature and initiating active warming) was a multi-disciplinary responsibility, but heavily reliant on nursing. As such, the core teams leading implementation at each site were primarily comprised of nursing staff from the clinical areas and those in managerial/executive roles. The effects of the bundle were evaluated using a multi-site pre and post-implementation design.(7) The primary finding of this study was that implementing the bundle into practice resulted in increased use of active warming (difference 14.3%; 95% CI= 5.5% to 23.2%). Despite the improvement in adherence to this important guideline recommendation, it is unknown whether the extra costs required for implementation were good value. It has recently been highlighted that it is vital to conduct robust economic evaluations of strategies used to improve uptake of evidence into practice.(13) This is because the efforts required for implementation exerts an impact on costs and can be complex and time-consuming for clinicians. The changes in costs

mainly arise from the resources needed for the implementation strategy and also due to the changes in service delivery costs in response to the implementation.(13) As such, this study aimed to determine if the strategy used to implement the thermal care bundle was cost-effective.

## **Methods**

### *Research design*

A cost-effectiveness analysis was undertaken from the perspective of the Australian health care system funder. A probabilistic model was used for the primary analysis with model uncertainty quantified by drawing 1000 Monte-Carlo samples from probability distributions specified for model parameters.(14) Beta distributions were used for probabilities and utilities, gamma distributions were used for costs and lognormal distributions for relative risks. It was assumed that the parameters in the model were not correlated. Health benefits were measured using quality-adjusted life years (QALY) gained. Quality-adjusted life years represent both the additional duration and quality of life gained from an intervention. Quality of life is incorporated into the quality-adjusted life year measure by calculating utility scores, which provide a single index to describe health states ranging from 0 (worst health state) to 1 (perfect health). To illustrate, a person living for 10 years with a quality of life utility score of 0.8 is equivalent to 8 quality-adjusted life years. As such, the particular type of cost-effectiveness analysis we performed could be described as a 'cost-utility' analysis. Net monetary benefit was calculated by multiplying the health benefits associated with an intervention by the willingness-to-pay threshold minus the cost.(15) We tested a range of values for willingness to pay per quality-adjusted life year thresholds and plotted results for expected incremental benefits with 95% credible intervals as well as on a cost-effectiveness acceptability curve. All analyses were conducted in the statistical program R (16). The R code and calculations can be accessed via <https://doi.org/10.6084/m9.figshare.6934325.v2> .

Ethics approval for this modelling study was not sought because we used previously published material as input for the model. The evaluation study was obtained from the site institutional Human Research Ethics Committee (LNR/14/SVH/403).

### *The decision model*

The clinical problem is summarised in the decision tree presented in Figure 1. The decision tree displays the clinical outcomes of a hypothetical cohorts of surgical patients undergoing surgery at tertiary care hospitals undertaking between 5,000 and 40,000 surgeries per year, which either implemented or did not implement the thermal care bundle. The primary assumption for this cost-effectiveness analysis was that patients included in the model would develop complications, including surgical site infection, bleeding and morbid cardiac events, at the same rate as those included in the active warming and standard care arms from previous randomised controlled trials. The rates of active warming use for the model were taken from the pre (38%) and post (53%) thermal care bundle implementation periods from our previous study.<sup>(7)</sup> The following explanation is provided to illustrate how these estimates of the effectiveness of the bundle in increasing the number of patients who receive active warming were translated to the cost-effectiveness model. On average in the model, 53% of patients undergoing surgery at a hospital who implemented the thermal care bundle would receive active warming and then develop surgical complications at the same rate as those who were randomised to receive active warming in previous randomised controlled trials. The remaining 47% of patients who would not have received active warming despite implementation of the thermal care bundle were modelled to develop surgical complications at the same rate as patients randomised to standard care (i.e. no active warming) arms in the prior randomised controlled trials. In contrast, 38% of patients undergoing surgery at a hospital in our model that did not implement the thermal care bundle would receive active warming and then develop surgical complications at the same rate as those who received active warming in the prior

randomised controlled trials. The remaining 62% of patients who would not have received active warming would be modelled to develop surgical complications at the same rate as patients randomised to the standard care (i.e. no active warming) arms of the prior randomised controlled trials. We did not include the potential risk for death arising from the more severe surgical complications such as deep surgical site infection and perioperative myocardial infarction in the model.

#### *Parameters for use in the model*

As our evaluation of the thermal care bundle(7) was not powered for cost-effectiveness, quality of life and costs associated with hypothermia-associated complications were derived from literature and then modelled using this information (2, 17). Table 1 presents the parameters and distributions for the probabilistic model.

#### Probabilities

The probabilities for the effect of active warming on surgical site infections after minor and major surgery were taken from two separate trials. For minor surgery, we used the estimate from a trial that randomised 421 patients having clean, minor surgery to no warming, pre-operative local warming (radiant heat over the surgical site) or pre-operative forced air warming (1). Fewer surgical site infections occurred in the warming group (8/139 versus 19/138; RR=0.42, 95% CI= 0.19 to 0.92)(18). For major surgery, we used the estimate from a trial that randomised 200 patients undergoing colorectal surgery to receive passive insulation or intra-operative forced air warming.(19) There were fewer infections in the forced air warming group (18% versus 6%). However, classifications for superficial or deep infections were not reported in either of the trials. For this reason, we conservatively assumed that all infections after minor surgery were superficial, and used results from a more recent study, which identified that 30% of infections after midline



abdominal laparotomy were deep, for our estimate for major surgery.(20) The probabilities for the effect of active warming on cardiac events was taken from a randomised controlled trial of forced air warming for patients at high-risk of cardiovascular complications undergoing major surgery.(21) Active warming reduced the risk of a morbid cardiac event (defined as a cardiac arrest, unstable angina, or myocardial infarction).(22) High risk was defined in the trial as having previous coronary artery disease, undergoing a procedure to treat peripheral vascular disease or 2 or more risk factors including, diabetes, hypertension, smoking, hyperlipidaemia or age over 65.(21) Due to the strict inclusion criteria for this study, in our probabilistic model we assumed that 20% of patients undergoing major surgery would meet this criteria and hence be classified as 'at-risk' of cardiac events. The probabilities for both baseline rate and the effect of active warming on blood transfusion requirement were drawn from the Cochrane review.(18)

#### Costs

Costs were calculated in Australian dollars (\$AUD) in 2018. There was no discounting of costs because the model horizon was only one year. Costs associated with implementation of the thermal care bundle were calculated using estimations of resource consumption of staff time and thermal care bundle (Supplementary File Table 1).

Although there are many different active warming interventions available and utilisation of particular devices differs between institutions, the thermal care bundle emphasised use of forced air warming. The cost of forced air warming was estimated to vary between \$10-30. An additional cost for purchasing forced air warming units was not included because it was assumed that all surgical facilities would have these available.

The distributions from a recent cost-effectiveness analysis that included costs for surgical site infection in the Australian context were used to inform our model.(23) These distributions were

based on the cost of treatment for a superficial surgical site infection (comprising a primary care practitioner visit, course of oral antibiotics and a pathology test) equating to \$250(24) and the cost of treatment for deep surgical site infection (comprising hospitalisation, pathology tests, and intravenous antibiotics for 1-2 weeks) equating to \$10,000.(25) The estimate for costs of a cardiac event were taken from a recent cost-effectiveness analysis.(26) The costs for a suspected myocardial infarction including emergency coronary angiography, transthoracic echocardiography and serial pathology tests and electrocardiograms were converted from UK currency to Australian dollars (\$20,000). The average price per unit of blood product was estimated to be \$400. This figure was sourced from the Australian Red Cross (2017)(33).

#### Utilities

The distributions for utilities were mostly drawn from a recent cost-effectiveness analysis undertaken in the Australian health care context.(26) These distributions were based on a utility score of 0.9 where no surgical complications occurred(27) and a disutility of 0.2 and 0.4 for superficial and deep surgical site infection, respectively(28). Utilities were based on EuroQoL 5D scores with 0 representing death and 1 a state of perfect health. We assumed the disutility of superficial surgical site infection would be present for two weeks and the disutility of deep surgical site infection for one month. The utility score for patients who have sustained a perioperative cardiac event (0.84) was drawn from a different cost-effectiveness analysis.(29) We did not include a disutility for blood transfusion requirement for consistency with previous economic analyses.(2)

#### *Sensitivity analyses*

The impact of assumptions made about specific model parameters was explored separately using univariate sensitivity analysis. Minimum and maximum values for parameters were substituted one

at a time into separate models populated only by base-case values. Base-case values were the averages of all the parameters included in the full probabilistic model (Table 1). Results of sensitivity analyses were plotted in a tornado diagram of the difference between the base-case estimates of the incremental net benefit associated with implementing the thermal care bundle at a willingness to pay threshold of \$25,000 per quality-adjusted life year. We used the incremental net benefit in a tornado diagram to avoid plotting negative incremental cost-effectiveness ratio values, which are meaningless.(30)

### **Results**

On average, implementation of the thermal care bundle resulted in a \$689,659 decrease in costs. There was some uncertainty surrounding this estimate with lower and upper 95% credible intervals spanning from a \$379,826 increase in costs to \$2,718,364 decrease in costs. Quality-adjusted life years were higher for the thermal care bundle across nearly all simulations (97% probability of higher number of quality-adjusted life years; mean difference was 54 more quality-adjusted life years; 95% credible intervals 0.4 less to 176 more quality-adjusted life years). The cost-effectiveness plane is presented in Figure 2. Implementation of the thermal care bundle resulted in a reduction in both costs and quality-adjusted life years in the majority of simulations (88.1%). This equated to an incremental cost-effectiveness ratio of \$12747 saved per quality-adjusted life year gained. Supplementary file figure 1 shows the probability that implementing the thermal care bundle would be cost-effective and Supplementary file Figure 2 displays the incremental net benefit (with 95% credible intervals) across a range of willingness to pay thresholds.

### *Sensitivity analyses*

Univariate sensitivity analyses were undertaken to further explore parameter uncertainty. The tornado diagram in Figure 3 shows that cost-effectiveness estimates differed considerably from the base-case result when extreme minimum and maximum values were substituted into the model for several of the parameters. These parameters included the effect of implementing the thermal care bundle on use of active warming, the percentage of minor operations performed at a hospital, the number of surgeries performed per year, the cost of treating a deep surgical site infection, and the percentage of surgical site infections after major surgery that are classified as deep.

## DISCUSSION

The aim of this study was to determine if the strategies used to implement a bundle of evidence-based interventions for perioperative thermal care was cost-effective. Results from the probabilistic cost-effectiveness model indicate that it is highly likely (about 80%) implementing the thermal care bundle would generate cost-savings for the health care system and improve quality of life for patients undergoing surgery. Therefore, it would be good value for hospitals to allocate the extra resources required to implement the thermal care bundle.

Univariate sensitivity analyses revealed that substituting in extreme minimum and maximum values for several of the parameters resulted in cost-effectiveness estimates that were considerably different from the base-case result. These analyses provide important insights into the generalisability of the model. For example, implementation of the thermal care bundle at hospitals that perform none or small amounts of major surgery is unlikely to be cost-effective. Also, the number of surgeries performed at a hospital is central to determining whether implementation will be cost-effective or not. This finding is important because hospitals that perform a lower number of surgeries would still need to undertake a similar amount of work to properly implement the bundle as a larger hospital and therefore require a similar amount of resources. As such, this would increase

the cost of implementation per patient, which our sensitivity analyses indicate would impact cost-effectiveness estimates considerably. In contrast, it should be noted that increasing the cost of active warming per patient did not have a considerable impact on the expected net benefit of implementing the thermal care bundle. Consequently, hospitals that employ more expensive methods of active warming should still expect that implementing the thermal care bundle to increase the use of active warming would be a cost-effective strategy.

Although we were able to estimate the cost-effectiveness of a decision to adopt implementation of the thermal care bundle across a range of values as per the standard approach, inputting values for parameters that are specific to a hospital into our model would be more informative for decision makers. To assist, we have developed an interactive webpage (<https://sedationapps.shinyapps.io/thermalbundleCEA>), so that decision-makers can estimate the probability that implementing the thermal care bundle would be cost-effective at their hospital. On the webpage, decision-makers first input the number of surgical procedures performed per year, the proportion of procedures classified as minor, the specific amounts they are required to pay for active warming per patient, as well as their currency code to allow for conversion. In response, individualised output including a cost-effectiveness plane, incremental net benefit and probability of cost-effectiveness across a range of Willingness-To-Pay thresholds and estimates of the differences in costs and quality-adjusted life years between decisions to either adopt or not adopt the thermal care bundle is produced to assist their decision making.

As with all probabilistic cost-effectiveness models that draw evidence from the literature as input, study quality should be considered. In this regard, it should be noted that the evidence for a reduction in risk of cardiac events was rated as low quality by the authors of a recent Cochrane review(18), due to concerns about imprecision considering that there was only one myocardial infarction event and no mortality observed in the one trial that reported on this outcome.(22)

Similarly, the Cochrane review rated the quality of evidence for the effect of active warming on surgical site infection as low quality, again due to concerns about imprecision.<sup>(18)</sup> The quality of evidence for the effect of active warming on the requirement for blood transfusion was rated as moderate quality due to concerns about risk of bias.<sup>(18)</sup> However, the quality of all warming intervention studies is said to be of low quality because the intervention is difficult or impossible to blind. Still it was noted by the Cochrane review authors that further studies were unlikely to exert a substantial change to the effect estimate. Therefore, despite there being only low to moderate quality evidence available about the effect of active warming on surgical complications, this was mostly driven by downgrading for imprecision. As such, by utilising a probabilistic cost-effectiveness model, the uncertainty arising from the inclusion of these imprecise estimates in the model has been quantified by drawing simulations from probability distributions.

Results from this cost-effectiveness analysis should be considered applicable only to the demographic and setting of the evaluation study we conducted to estimate the success of the thermal care bundle on increasing use of active warming for patients at-risk of perioperative hypothermia.<sup>(7)</sup> Therefore, results of this cost-effectiveness analysis may not generalise to other populations where considerably more resources would be required to exert a similar impact on increasing use of active warming. For example, in some countries, such as China, it is rare for active warming to be utilised during surgery.<sup>(31)</sup> Likewise, there are some institutions where active warming is almost universally applied, so implementation of the thermal care bundle would not be a good investment in such circumstances.<sup>(32)</sup> Finally, it should also be noted that our estimate of the effect of the thermal care bundle on increasing use of active warming was based on a non-randomised, pre-test post-test comparison. More confidence in the effect of the bundle on use of application of active warming for patients at-risk of hypothermia could be drawn if the study was replicated using a randomised controlled trial design. It is likely that due to the nature of the intervention that a cluster approach to randomisation would be required for such an approach.

However, delaying implementation of the bundle to wait for more definitive evidence from a randomised controlled trial means the health system may be missing out on the cost-savings and health benefits projected by our model.

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### *Conflicts of interest*

The funders of this study had no role in study design, data collection, management, analysis, and interpretation of data; writing of the report; and the decision to submit the report for publication. Prof. Dr. Anselm Bräuer has consulted for 3M and The 37°C Company and has received expenses and an honorarium for presentations and sitting on the advisory board for 3M. Associate Professor Nicholas Ralph and Professor Jeff Gow have received expenses and an honorarium for presentations from 3M to provide education to clinicians.

## Contribution of the paper

### *What is already known about the topic?*

- Clinical guidelines recommend that active warming should be used peri-operatively to prevent surgical complications that are associated with high costs and reduced quality of life such as surgical site infections and bleeding.
- A multi-site pre-post implementation study showed that a Thermal Care Bundle, mostly led by nurses, increased adherence to clinical guideline recommendations, with active warming



being applied to 15% more patients at-risk of perioperative hypothermia in the post-implementation phase.

*What this paper adds*

- It would be a good decision for hospitals with similar profiles to those included in our probabilistic cost-effectiveness model to allocate the extra resources required to implement the thermal care bundle as it is highly likely to result in reduced costs and improved quality of life.
- We have developed an interactive webpage (<https://sedationapps.shinyapps.io/thermalbundleCEA>), so that decision-makers can estimate the probability that implementing the thermal care bundle would be cost-effective at their hospital.
- Delaying implementation of the bundle to wait for more definitive evidence from a randomised controlled trial means the health system may be missing out on the large amount of cost-savings and health benefits projected by our model.

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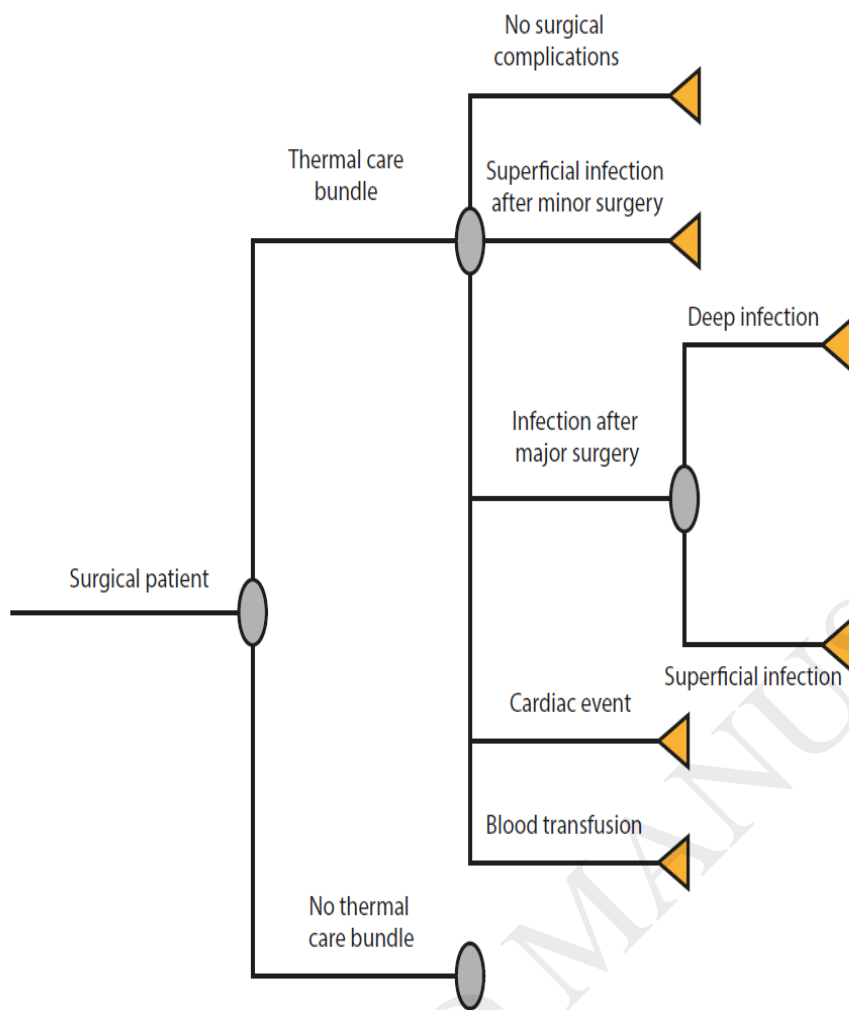


Figure 1. Economic model structure

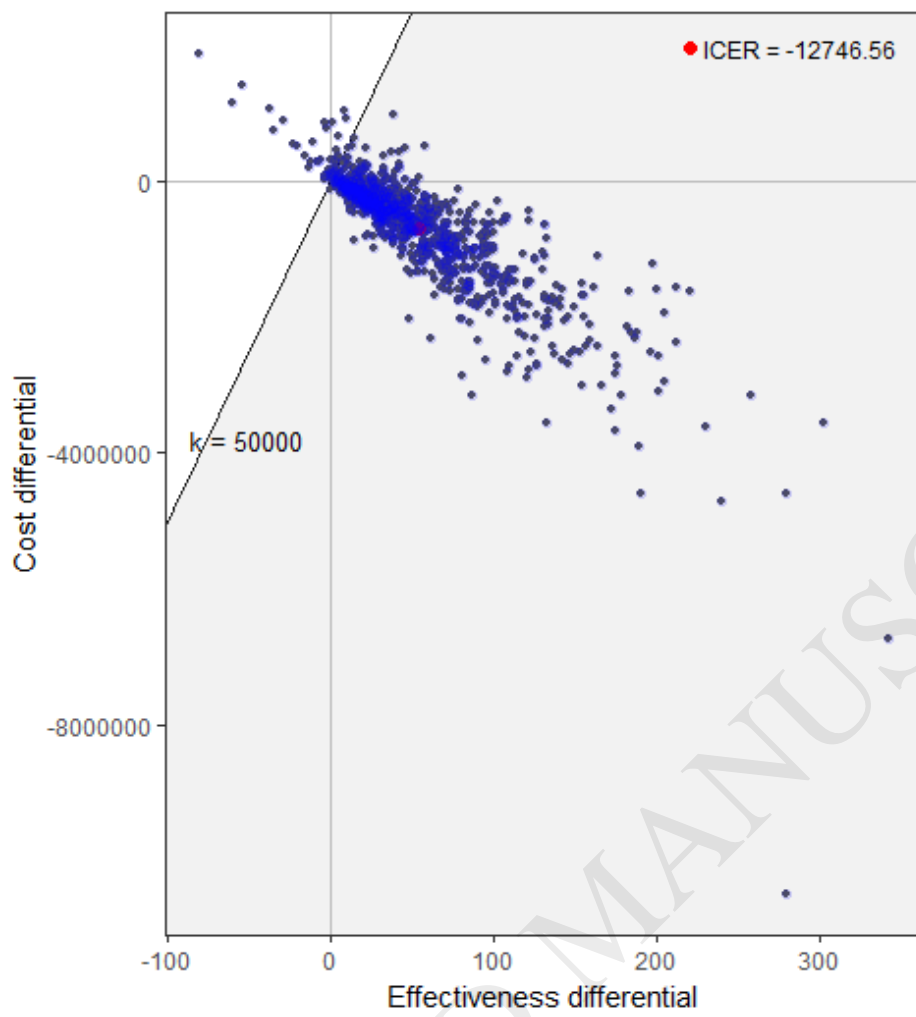


Figure 2. Cost-effectiveness plane

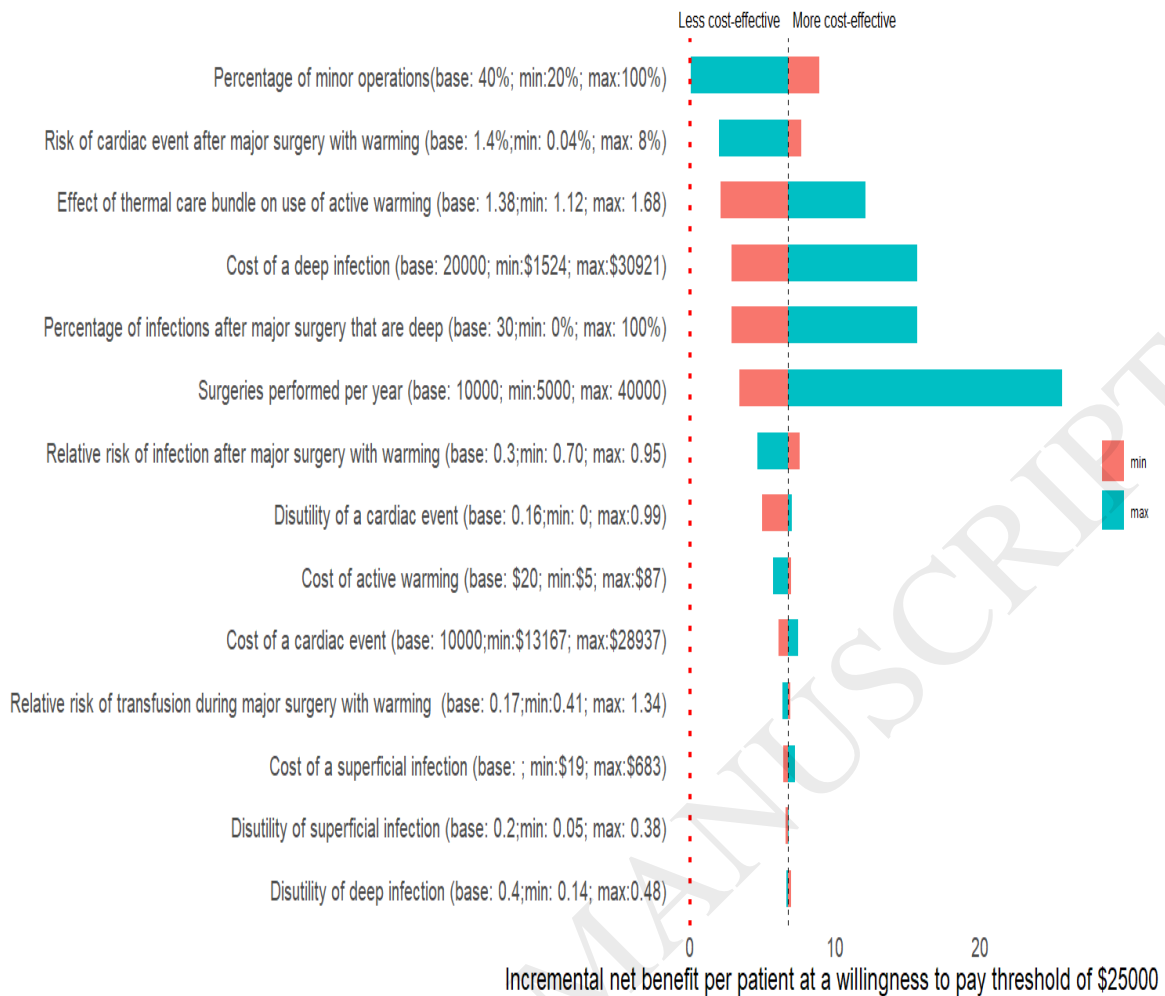


Figure 3. Tornado diagram for sensitivity analyses

**Table 1. Cost-effectiveness model input parameters**

Parameter	Average value	Distribution	Source
Population	10000	Uniform (min=5000, max=40000)	Estimated from number of surgeries performed at each site from prior study(7)
Increase in active warming with implementation of the thermal care bundle	1.38	Log-normal (0.32, 0.12)	Duff et al., (2018)(7)
Percentage of surgeries that are minor	40%	Beta ( $\alpha=60$ , $\beta=40$ )	Estimate
Baseline risk of superficial surgical site infection after minor surgery	13%	Beta ( $\alpha=19$ , $\beta=120$ )	Melling et al., (2001)(1)
Relative risk of superficial surgical site infection after minor surgery with active warming	0.42	Log-normal (0.19-0.92)	Melling et al., (2001)(1)
Risk of surgical site infection after major surgery without active warming	19%	Beta ( $\alpha=18$ , $\beta=78$ )	Kurz et al., (1996)(19)
Relative risk of surgical site infection after major surgery with active warming	0.30	Log-normal (-1.17, 0.15)	Kurz et al., (1996)(19)
Percentage of infections after major surgery that are deep	30%	Beta ( $\alpha=47$ , $\beta=109$ )	Diener et al., (2014)(20)
Percentage of major surgery patients at high risk of cardiac events	20%	Beta ( $\alpha=20$ , $\beta=80$ )	Frank et al., (1997)(22)
Risk of cardiac event after major surgery in high-risk patients without active warming	7%	Beta ( $\alpha=10$ , $\beta=148$ )	Frank et al., (1997)(22)
Risk of cardiac event after major surgery in high-risk patients with active warming	1.4%	Beta ( $\alpha=2$ , $\beta=140$ )	Frank et al., (1997)(22)
Baseline risk of blood transfusion during major surgery	0.17	Beta ( $\alpha=52$ , $\beta=304$ )	Madrid et al., (2016)(18)
Relative risk of blood transfusion during major surgery	0.79	Log-normal (-0.23, 0.19)	Madrid et al., (2016)(18)
Cost of treating superficial surgical site infection	\$250	Gamma ( $\alpha =4$ , $\beta =0.02$ )	Graves et al., (2006)(24)
Cost of treating deep surgical site infection	\$10000	Gamma ( $\alpha =4$ , $\beta =0.0004$ )	AR-DRGs (AIHW)
Cost of treating a post-operative cardiac event	\$20000	Gamma ( $\alpha =80$ , $\beta =0.004$ )	Stokes et al., (2016)(26)
Cost of a blood transfusion	\$400	Gamma ( $\alpha =2000$ , $\beta =5$ )	Australian Red Cross (2017) (33)
Cost of active warming	\$20	Gamma ( $\alpha =100$ , $\beta =5$ )	Market price
Cost of implementing the thermal care bundle	\$10630 per		Fixed cost calculated from prior study(7)

	hospital for one year		
Utility with no surgical complications	0.91	Beta ( $\alpha=185$ , $\beta=18$ )	Clemens et al., (2014)(27)
Disutility of superficial surgical site infection	0.2	Beta ( $\alpha=8$ , $\beta=41$ )	Lipsky et al., (2012)(28)
Disutility of deep surgical site infection	0.4	Beta ( $\alpha =16$ , $\beta =40$ )	Lipsky et al., (2012)(28)
Disutility of cardiac event	0.16	Beta ( $\alpha =0.835$ , $\beta =0.165$ )	Rao et al., (2008)(29)

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