Evaluation of a New Model of Postoperative Care: A Preliminary Cost-effectiveness Analysis Using Markov Modelling

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Research

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Abstract

Background: Re-design of systems or models of care to manage perioperative care has the potential to generate higher value care (improved outcomes; ideally lower cost). However, this needs high quality measurement of cost-effectiveness to allow stakeholders to select those which provide most value, and to plan future interventions. Data on cost-effective analysis in this area are sparse, and trials often apply relatively simple analytic techniques.

Methods: This analysis utilised recently published data from a small feasibility trial of a new model of medium-acuity postoperative care for moderate-risk patients undergoing surgery

(Advanced Recovery Room Care; ARRC). The trial data were used to develop a Markov cost-effectiveness model of patient transition (model transition probabilities) between locations of care (model states), each with different effects and cost. Cost was taken from the perspective of hospitals. The effect chosen was patient postoperative days at home after surgery (DAH), an effect reflecting quality of in-hospital care, acknowledged financially by healthcare fundholders, and relevant to consumers. A model cycle time of 4 hours run out to 30 days after surgery reflected clinically relevant timelines and costs.

Results: This model showed the potential differences before and after introduction of ARRC in ICU use, re-admissions, and DAH, in particular, which reflected the findings from the ARRC trial. Incremental cost effectiveness ratio (ICER) of introduction of ARRC was minus $601 for every increased day at home. Sensitivity analysis revealed 805 of 1000 simulations found a negative ICER.

Conclusions: These data suggest that the ARRC model may have positive cost-effectiveness, something to be examined in a future prospective clinical trial. Such cost-effectiveness modelling may have utility in examination of other innovations in perioperative care.

Trial registration: The ARRC trial on which this analysis is based was prospectively registered: ANZCTRN 12617001173381

Keywords: postoperative complications, recovery room, PACU, Days at home, cost-effectiveness, health economics, enhanced postoperative care

Background

Major postoperative complications are common[1,2,3] and likely to increase substantially[4]. Innovations to address these include specific therapeutic interventions, such as fluid management[5], and broader interventions through models or systems of care which combine high quality elements, such as enhanced recovery after surgery (ERAS)[6], and prehabilitation programmes[7]. Systems changes perhaps provide a greater opportunity for measurable improvements[8]. Important impacts of innovations include the effect on sequelae of hospital complications of relevance to both patients and fundholders, such as length of hospital stay and re-admissions[9,10] and overall days at home after surgery (DAH)[11,12]. All these sequelae are closely associated with in-hospital quality of care, and thus provide a useful 'composite' endpoint of the impact of hospital interventions and innovations.

High value care, and cost-effectiveness of systems change, is increasingly critical in this Covid-19 era, with its negative impact on budgets. However, detailed high-quality cost-effectiveness analysis is relatively limited in systems or models of care in postoperative care. For example, in a recent ERAS umbrella systematic review[6], only 13 of over 200 studies even mentioned cost as an outcome. Those studies that do address cost and effectiveness frequently including simple estimates, or formal but simple cost-effectiveness calculations[13-17]. One recent systematic review of interventions to reduce hospital stay concluding that, overall, the evidence base is poor, and costs are rarely dealt with effectively[18].

More complex cost-effectiveness modelling has the potential to provide tools to compare different interventions, or to help assess where future interventions might best focus. Markov modelling achieves this by specifying different health states and probabilities of transitions between them, and predicting impacts on costs and effects. As such, it can be considered comparable to pharmacological pharmacokinetic-pharmacodynamic modelling, such as that applied clinically in target-controlled infusions. Markov modelling is commonplace for new therapies, such as cancer drugs[19], and has been successfully applied to perioperative care, with examples including appendicitis management[20] and deep vein thrombosis prophylaxis[21]. Its application to perioperatively systems of care is uncommon, however, it has been recently applied to the impact of a new hip fracture care team[22], a study which concluded that: "…a cohort simulation cost-effectiveness analysis (CEA) suggested that the H-FLS was cost-effective with potential to become cost-saving"[23].

A recent feasibility before and after trial of a new model of care for moderate risk patients after surgery, entitled Advanced Recovery Room Care (ARRC) suggested that intervention with ARRC may have a benefit in terms of re-admissions, and days at home after surgery in particular[24]. Hospital business cases from the participating hospitals suggest positive benefits, but these have limited ability to determine uncertainty, to allow ready comparison between institutions, or to identify the potential cost-effectiveness impact of potential future model iterations.

To address this, data from one site from the ARRC trial, Royal Adelaide Hospital (RAH), were used to build a transition cost-effectiveness Markov model of recovery after surgery. The general aim was to examine whether Markov modelling may be a useful tool for cost-effectiveness evaluation of future changes in perioperative care delivery. The specific aim of this project was to create a cost-effectiveness model to allow formal cost-effectiveness analysis of ARRC compared to existing care. The hypothesis was that creating a cost-effectiveness model was feasible, and could provide information relevant to decision makers.

Methods

The Markov model structure was based on the pathway of postoperative hospital care before and after introduction of ARRC, aiming to reflect patient flow as much as possible. This structure is shown in Figure 1. Instead of model States reflecting health status or progress of disease[19], these were instead physical locations representing in-hospital low-, medium-, and high-acuity care, each with their own capacities, effects, and costs. These were a conventional recovery room or post anaesthesia care unit (Recovery), Intensive Care (ICU), a medium-acuity care area (ARRC), and a surgical general ward (Ward). To account for out of hospital locations or health status, the States reflecting any out of hospital care (Home) and postoperative mortality (Death) were added. The model without ARRC was accounted for using transition probabilities to and from ARRC of zero. Rescue from the Ward by ICU, and re-admission to hospital from Home, were accounted for by new States, ICU2 and Ward2, respectively.

Transition probabilities were estimated from the ARRC trial data for the main trial site, Royal Adelaide Hospital, acknowledging there is uncertainty due to the small numbers in this trial. For example, the ARRC trial suggested the addition of ARRC may have decreased the probability of re-admission within 90 days from 35% to 22%, with the duration of re-admission stay decreasing 10.3 to 5.5 days[24]. The transition probabilities from Ward to Home, and Home to Ward 2, were then estimated from these data. Instead of a single risk ratio to account for a treatment effect on the set of transition probabilities, two individual Transition Probabilities sets were estimated from the before and after phases of the ARRC trial. These probabilities are displayed in Table 1.

The effect chosen was days at home after surgery (DAH), an endpoint relevant to consumers and hospitals. Use of the more common effect measure, Quality Adjusted Life Years (QALYs), was not feasible, but may be in the future as data on any delayed effects of improved early care become available. Costs were from the perspective of the hospital, derived from Royal Adelaide Hospital's Finance Department's lumped daily costs at each location broken down to costs of 4 hours of care, and are displayed in Table 2. A cycle time of 4 hours was chosen, reflecting a time period clinically relevant to decisions on patient movement between States. The starting number of patients was nominally 100, and the model was run out to 30 days after surgery, a period commonly chosen for measurement of re-admissions.

Discounting of costs for such a short-term model is probably unnecessary, but was included at a nominal rate of 4% per annum to allow for future longer-term modelling. All patient numbers at each location (State) for each cycle were summed to ensure all patients were accounted for at each of the 180 cycles. An Incremental Cost Effectiveness Ratio (ICER) from overall days at home after surgery gained versus overall cost change was calculated.

For sensitivity analysis, the deterministic model was converted to probabilistic model, adding uncertainty to model parameters. Beta distribution was used to simulate the probability of binary events occurring, and Dirichlet distribution used, approximated by a Gamma distribution, for events with more than two outcomes. A random number generator selected possible values within each distribution, and 1000 simulations were run. The mean cost and effects of the two interventions, as well as the mean ICER, were then calculated for each intervention – postoperative care with and without ARRC. The mean ICER was calculated as the ratio of mean incremental costs to mean incremental effectiveness. All individual ICERs from 1000 simulations, as well as the mean, were then plotted as cost against effect (DAH).

Microsoft Excel was used for all modelling, with spreadsheets adapted from those used in London School of Economics' Masters in Health Economics, Policy and Management to analyse the effect of a new cancer therapy[19].

Results

The sum of all patient numbers at each location (State) for all 180 cycles was 100, confirming the model was balanced. The output from the model in terms of patient movement between States is displayed in Figure 2. Before ARRC, patients predominantly spent time in Recovery, and then transitioned to the Ward, and ultimately Home. Time in Ward2 reflects re-admissions from Home. Time in ICU reflects planned transitions from ARRC (because of delayed recovery by the morning of Day 1), and time in ICU2 reflects unplanned 'rescue' from the ward. Notable observations from this model once ARRC was included were (i) faster transition to Home (ii) decreased ICU usage, (iii) decreased re-admissions, and (iv) decreased rescue from the ward.

The key findings from ICER calculation are shown in Table 3. This revealed, with the addition of ARRC in a cohort of 100 patients (i) increased overall DAH, (ii) decreased overall hospital cost, and (iii) an ICER of negative $601.20 per additional day at home after surgery.

For sensitivity analysis, the ICER results from 1000 simulations based on randomly generated transition probabilities and costs are displayed in Figure 3. The mean ICER value (mean of the means) was negative $482, but with substantial variability.

Discussion

Techniques utilised for estimation of cost-effectiveness perioperatively are frequently relatively simple. However, as cost and resources become increasingly sparse, especially with Covid-19, detailed cost-effectiveness analysis will become more critical for fundholders.

A recent systematic review of clinical interventions, or models of care, was conducted in the perioperative space[18], specifically patient work up before surgery (not currently a part of this modelling) and early enhanced postoperative care. Key findings and conclusions were: "Studies were usually of moderate or weak quality. Enhanced recovery and prehabilitation interventions were associated with reduced hospital stay without detriment to other clinical outcomes. The impacts on patient-reported outcomes, health-care costs, or additional service use are not well known". This identifies the need for better quality studies of clinical interventions, but also a need for robust cost-effectiveness analysis in perioperative care. This was a specific recommendation of a recent Australian National Summit on Postoperative Complications[25], a recommendation made even before the financial impact of Covid-19 was evident.

For early postoperative care, the original retrospective observational study on medium-acuity postoperative care on which ARRC planning was based[26] found large differences in mortality and hospital stay when medium-acuity care was withdrawn, although re-admissions were not reported. This study did attempt some basic cost comparison before and after loss of high acuity care. which suggested little difference in hospital costs with either approach. Whilst a positive approach, a more detailed analysis may provide better opportunities for future improvement. For preoperative care, a recent study of preoperative prehabilitation has demonstrate benefit in terms of effect, or consequences[7]. Notably, it included re-admission data and found a positive benefit, which aligns with our choice of re-admissions (or DAH) as an effect, and a subsequent paper on cost-effectiveness ('consequences') of these data found a positive impact[13]. However, this type of analysis can only provide relatively limited insight into what elements contributed to cost-effectiveness, and hence where attention may be focussed in the future.

In contrast, Markov modelling of a new model of care to reduce repeat fractured neck of femur found an ICER, using QALYs as an effect, below the standard cost-effectiveness threshold, suggesting this was a cost-effective approach[23]. Importantly, it also projected that two future model iterations, removing the 9-month visit, and reducing the 6-month visit, may result in the model actually becoming cost-saving, something which presumably can be prospectively tested.

This demonstrates the opportunities provided by formal cost-effectiveness modelling for not just testing overall model of care utility, but in hypothesis-generation for subsequent care refinement. Identification of the major factors affecting cost-effectiveness, and a focus on adjusting these elements, is fertile work for iterative improvement. In this sense, this mirrors the hypothesis-generating use of pharmacological pharmacokinetic-pharmacodynamic modelling to generate, and then test, new dose regimens in clinical trials. A Tornado-type analysis of the relative impacts of different model parameters has not been performed on the data provided here. A better degree of certainty from the larger datasets will provide opportunities for such analysis.

A simple example of hypothesis generation is apparent in the structures and functions within ARRC itself. Considering the large contribution of staff costs, opportunities to reduce staff to patient ratios, especially overnight, would improve costs, may not affect outcomes, and could improve the ICER. To achieve this, repeated re-assessment of risk after early ARRC treatment may be able to identify the 50% of moderate-risk patients who were unlikely to develop major adverse events overnight[27]. Considering the high incidence of hypotension in this study, there may be a role in this for devices with the capacity to predict hypotension[28]. The potential impact of this can then be estimated prospectively using this model, with costs (to now include device consumables and fewer staff) appropriately adjusted. Similarly, impacts of enhanced out of hospital postoperative care[29] can be prospectively estimated, based on published data on cost and effect.

There are a number of limitations in this current modelling. There is the uncertainty in the data as a result of small numbers in the ARRC trial, also evident from the simulations in Figure 3.

However, the mean (of means) ICER still found positive effects on cost and effect. This will be addressed in the larger RAH trial of ARRC starting this year. Whilst a Markov model can reflect clinical flows, fixed Transition Probabilities between States over time have been utilised. This is a reasonable initial estimation, as early and late postoperative complications do tend to decline over time, but exploration of more complex techniques with probabilities which vary with time may have merit. To a limited degree this was addressed with the model structures, where two ICU and two Ward states can account for differential durations of stay for initial admissions and re-admissions to these locations, for example.

The choice of effect of DAH does limit the generalisability of this model to compare to non-perioperative care fields (see below), however, it does allow comparisons of many activities and innovations within the field of perioperative care. It is feasible to add longer-term impacts, such as 90-day re-admissions, and QALYs, if data emerge supporting longer-term effects of early enhanced care.

Costs were lumped costs used by hospital finance department in their business cases, and do not more detailed effects such as consumables, and laboratory or radiology testing. Nevertheless, they provide a sound starting point, especially because workforce usually accounts for the majority of hospital maintenance costs. Asset depreciation was not included at this stage, as the timeframe of the current model makes this largely insignificant. There are other elements which can be included to improve such models over time. Better identification of actual care locations, and costs, rather than the use of a single out of hospital state (Home) is feasible, providing effects of enhanced early care on overall healthcare costs. Addition of preoperative care is also feasible, to provide a model of the overall perioperative patient journey.

This model needs prospective testing. A larger powered trial of ARRC at RAH will commence shortly, providing a larger dataset to be used to adjust transition probabilities, in particular. It has cost-effectiveness as a primary endpoint. Addition of other hospitals to this trial will also identify inter-institutional differences, something suggested by the ARRC trial data from a specialist elective surgery cancer hospital[24].

Conclusion

Cost-effectiveness Markov modelling of the Advanced Recovery Room Care (ARRC) model, an example of medium-acuity postoperative care, appears feasible and potentially useful in evaluating its impact on healthcare. An initial model based on data from a small feasibility trial suggests ARRC may be highly cost-effective, with a negative ICER – lower costs and more days at home after surgery, but larger trials are needed to validate this model. This type of modelling may have applications to other areas of perioperative care re-design.

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Declarations

Ethics approval and consent to participate

The trial on which this post-hoc analysis is based received approval for opt-out consent from The Queen Elizabeth Hospital Human Research Ethics Committ, approval number HREC/17/TQEH/104.

Consent for publication

Not applicable. No identifiable individual patient data.

Availability of data and materials

All data generated or analysed during this study are included in this published article, and in Reference 24.

Competing interests

The author has received meeting sponsorship from, and is an advisory board member for, Edwards Life Sciences.

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Author’s contributions

GL analyzed the data, performed the modelling, and wrote and approved the manuscript.

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Figure and table titles

Figure 1. Markov model of patient disposition after surgery, showing model States and Transition Probabilities.

Figure 2. Model output, patient transition between model states (locations). Note that after introduction of ARRC: 2a - the appearance of ARRC, faster transition to Home, and reduced ICU use; 2b – reduced readmissions and intensive care 'rescue' (ICU2) from the Wards.

Figure 3. Model sensitivity analysis showing 1000 simulations to estimate the variance in ICER. Effect (days at home; horizontal axis) versus costs (dollars, vertical axis).

Table 1. Markov model of patient disposition after surgery – estimated transition probabilities every 4 hours.

Table 2. Markov model of patient disposition after surgery – location costs for 4 hours of care. Costs are from the perspective of the hospital.

Table 3. Cost and days at home after surgery (DAH) before and after introduction of ARRC, and the estimated ICER ($AUS per extra day at home).

Figures

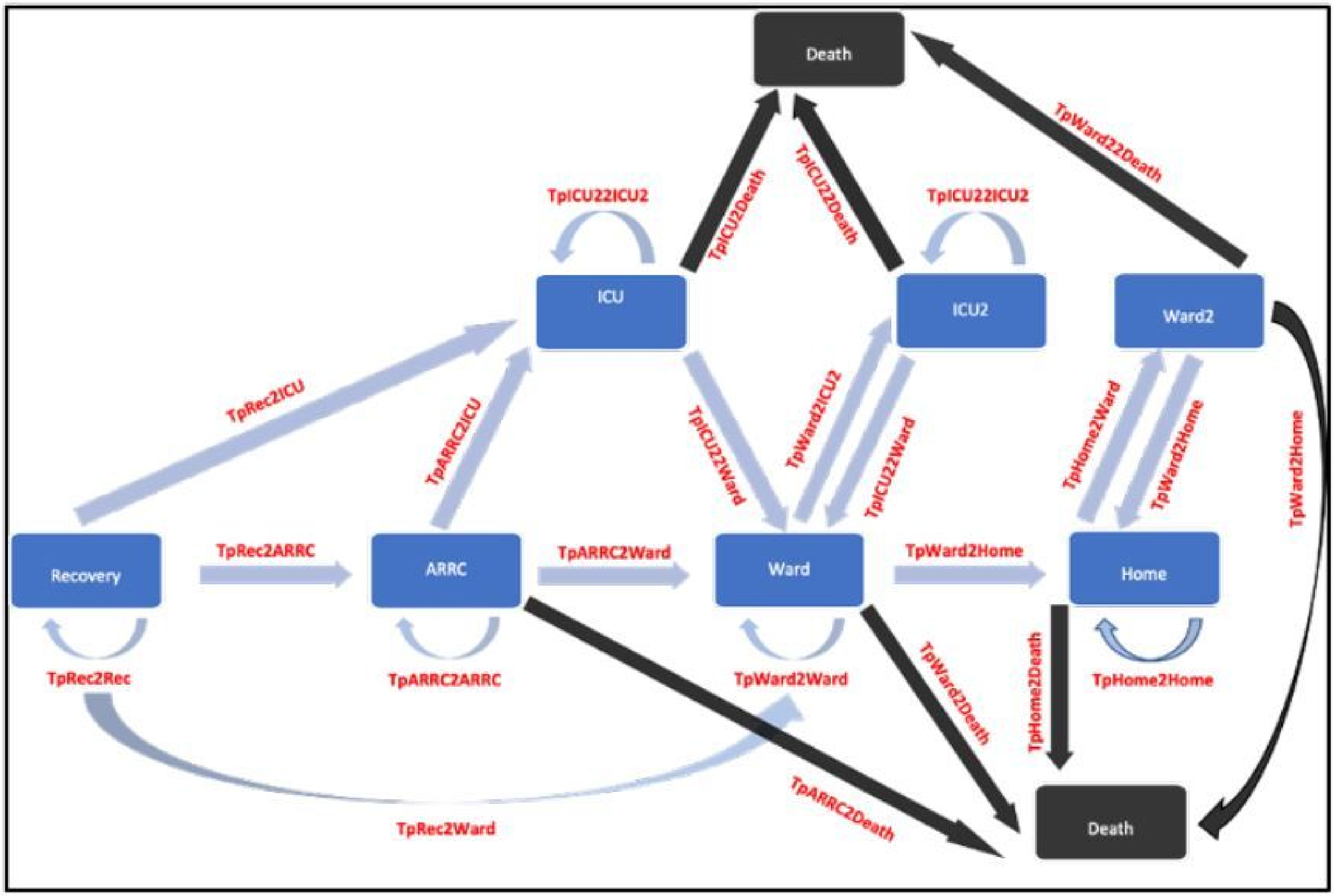

Figure 1

Markov model of patient disposition after surgery, showing model States and Transition Probabilities.

Figure 1a

Figure 1b

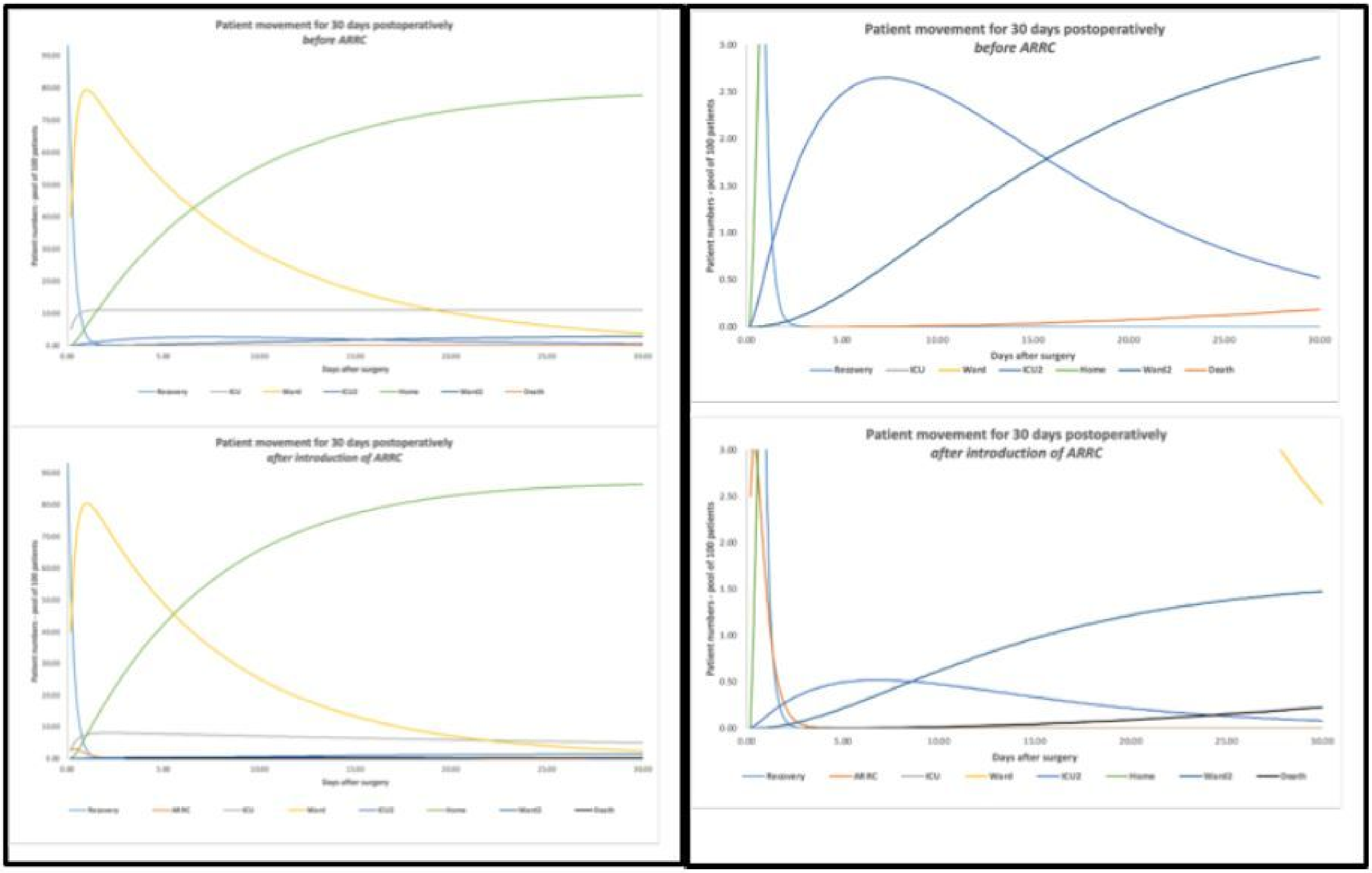

Figure 2

Model output, patient transition between model states (locations). Note that after introduction of ARRC: 2a - the appearance of ARRC, faster transition to Home, and reduced ICU use; 2b – reduced readmissions and intensive care ‘rescue’ (ICU2) from the Wards.

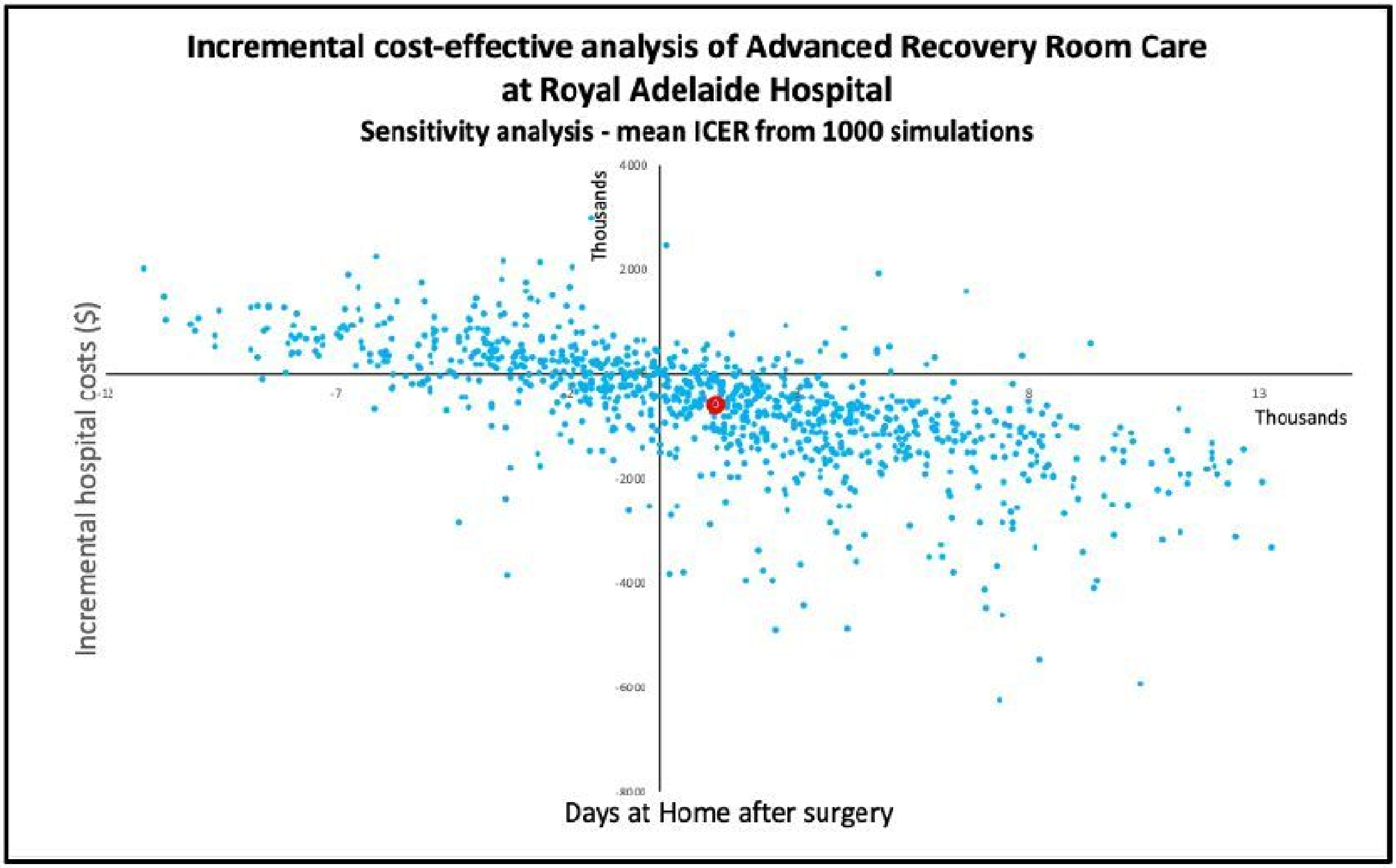

Figure 3

Model sensitivity analysis showing 1000 simulations to estimate the variance in ICER. Effect (days at home; horizontal axis) versus costs (dollars, vertical axis).

Supplementary Files

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- Table3.pdf
- Table2.pdf
- Table1.pdf