A Cost-Effectiveness Analysis Comparing Clinical Decision Rules PECARN, CATCH, and CHALICE With Usual Care for the Management of Pediatric Head Injury

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Study objective: To determine the cost-effectiveness of 3 clinical decision rules in comparison to Australian and New Zealand usual care: the Children's Head Injury Algorithm for the Prediction of Important Clinical Events (CHALICE), the Pediatric Emergency Care Applied Research Network (PECARN), and the Canadian Assessment of Tomography for Childhood Head Injury (CATCH).

Methods: A decision analytic model was constructed from the Australian health care system perspective to compare costs and outcomes of the 3 clinical decision rules compared with Australian and New Zealand usual care. The study involved multicenter recruitment from 10 Australian and New Zealand hospitals; recruitment was based on the Australian Pediatric Head Injury Rules Study involving 18,913 children younger than 18 years and with a head injury, and with Glasgow Coma Scale score 13 to 15 on presentation to emergency departments (EDs). We determined the cost-effectiveness of the 3 clinical decision rules compared with usual care.

Results: Usual care, CHALICE, PECARN, and CATCH strategies cost on average AUD $6,390, $6,423, $6,433, and $6,457 per patient, respectively. Usual care was more effective and less costly than all other strategies and is therefore the dominant strategy. Probabilistic sensitivity analyses showed that when simulated 1,000 times, usual care dominated all clinical decision rules in 61%, 62%, and 60% of simulations (CHALICE, PECARN, and CATCH, respectively). The difference in cost between all rules was less than $36 (95% confidence interval −$7 to $77) and the difference in quality-adjusted life-years was less than 0.00097 (95% confidence interval 0.0015 to 0.00044). Results remained robust under sensitivity analyses.

Conclusion: This evaluation demonstrated that the 3 published international pediatric head injury clinical decision rules were not more cost-effective than usual care in Australian and New Zealand tertiary EDs. Understanding the usual care context and the likely cost-effectiveness is useful before investing in implementation of clinical decision rules or incorporation into a guideline. [Ann Emerg Med. 2018;■:1-11.]

Please see page XX for the Editor's Capsule Summary of this article.

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INTRODUCTION

Background

Pediatric head injury is a common emergency department (ED) presentation.[1,2] Despite high prevalence, few children have a serious outcome.[3,4] Most head injuries are mild, although some children may be at risk of preventable adverse outcomes.[5-7] Cranial computed tomography (CT) scanning offers a sensitive method for the identification of intracranial injuries and is the criterion standard investigation for the diagnosis of traumatic brain injuries.[2,7] Early identification of traumatic brain injury can help avert further brain damage by directing appropriate care.[2,7] Early imaging has been associated with improved outcomes and reduces hospital admissions by assisting in traumatic brain injury diagnosis.[2,8]

Importance

There are risks of CT,[1,2,4,9,10] including ionizing-radiation-induced malignancies, to which children have increased vulnerability.[11-14] Young children may require sedation to prevent movement, with risk of airway and hemodynamic compromise.[2,10]

Editor's Capsule Summary

What is already known on this topic

Pediatric head injury computed tomography (CT) clinical decision rules have been popularized.

What question this study addressed

Are any of these clinical decision rules more cost-effective than unstructured clinical judgment?

What this study adds to our knowledge

In this Australian and New Zealand decision analysis model based on 18,913 injured children, the cost-effectiveness was similar between the 3 clinical decision rules and unstructured clinical judgment.

How this is relevant to clinical practice

In Australia and New Zealand, pediatric head CT clinical decision rules are not more cost-effective than unstructured clinical judgment.

Rates of CT scans for the assessment of pediatric head injury have increased considerably in recent decades.[1,7,10,11] In addition to health risks, there are cost implications for EDs and the health care system more broadly.

Pediatric clinical decision rules have been derived to help clinicians make decisions concerning CT. These aim to avoid scanning without missing traumatic brain injury and include features of patient history and examination. Several systematic reviews[2,8,11] indicate that the most sensitive are the Children's Head Injury Algorithm for the Prediction of Important Clinical Events (CHALICE),[4] the Pediatric Emergency Care Applied Research Network (PECARN) rule[1] and the Canadian Assessment of Tomography for Childhood Head Injury (CATCH).[10]

The foci of the 3 clinical decision rules are different[9] and triggers for CT use vary across different settings.[12] A recent, prospective, multicenter cohort study in Australia and New Zealand determined that the PECARN clinical decision rule had higher point sensitivity than CATCH and CHALICE in a cohort of children with mild head injuries (although they had overlapping confidence intervals).[3]

Goals of This Investigation

We determined the cost-effectiveness of the 3 clinical decision rules compared with usual care in Australia and New Zealand EDs in the evaluation of children with head injury, in a single study population, to guide funding and treatment decisions. The primary outcome is expressed as quality-adjusted life-years incorporating traumatic brain injury and radiation-induced cancer effects.

MATERIALS AND METHODS

Study Design and Setting

Decision analytic health economic modeling was undertaken to compare costs, outcomes, and cost-effectiveness of the 3 clinical decision rules compared with Australasian usual care, using standard economic evaluation methods.[13] Clinical outcomes and probabilities were based on the Australasian Pediatric Head Injury Rules Study (APHIRST),[3,9] a multicenter prospective observational study involving 20,137 children presenting with head injuries to 9 tertiary pediatric EDs and one mixed ED across Australia and New Zealand.[14] APHIRST externally evaluated the performance accuracy of the 3 clinical decision rules.[3,9]

Selection of Participants

Children were enrolled in APHIRST if they presented to a participating ED between April 11, 2011, and November 30, 2014, and were younger than 18 years and had a head injury. Exclusion criteria were trivial facial injury only, patients referred from ED triage to an external provider, neuroimaging before transfer to a study site, or did not wait to be medically reviewed.[3,9] This analysis was performed on the APHIRST comparison cohort of 18,913 patients (93.9% of the evaluable cohort) who all had a Glasgow Coma Scale score of 13 to 15 and presented within 24 hours of injury. This cohort represents the group of children who create the greatest dilemma for clinicians, and consequently for whom a clinical decision rule is most likely to be followed. APHIRST patient characteristics are reported in Table 1.

Interventions

The decision analytic economic model was developed in TreeAge Pro (version 2016; TreeAge Software Inc., Williamstown, MA). The model compares the 3 clinical decision rules and Australasian usual care (Figure 1). The usual care strategy was defined as management by clinicians according to current, unstandardized, local practice in Australia and New Zealand, which does not follow any one specific clinical decision rule but may include knowledge derived from the rules more broadly. In our study cohort, the prevalence of clinically important traumatic brain injury (a composite outcome first published in PECARN and previously used to compare head injury clinical decision rules[1,3]) was 0.8% (160/18,913), and 0.1% (24/18,913) required neurosurgery. Baseline CT scanning rates

Table 1. Characteristics of the APHIRST comparison cohort.

Demographics	APHIRST Comparison Cohort (n=18,913)
Mean age (SD), y	5.7 (4.6)
Patients <2 y	5,046 (26.7)
Female patients	6,840 (36.2)
Presenting signs and symptoms	
Headache	3,785 (20.0)
History of vomiting	3,094 (16.4)
Witnessed disorientation	2,425 (12.8)
Known or suspected loss of consciousness	2,468 (13.1)
History of amnesia*	1,591 (8.4)
Mechanism of head injury	
Fall related	13,337 (70.5)
Head hit by high-impact object or projectile	1,228 (6.5)
Motor vehicle crash	745 (3.9)
Suspected nonaccidental injury	81 (0.4)

Data are presented as No. (%) unless otherwise indicated.
*Does not include preverbal children.

are 8.3% of pediatric ED presentations with suspected head injury. Clinicians were not restricted from using a clinical decision rule, but during recruitment none of the study institutions had formal processes in place for their use.[12] Clinical management and probabilities for usual care tests and hospitalizations were based on observed APHIRST data. For the 3 clinical decision rules, probabilities were derived by applying the rules based on indicated computer algorithms, without the addition of clinical judgment. All 18,913 children were used for the assessment of each clinical decision rule to most closely resemble an actual clinical application in which front-line clinicians would not usually be aware of all rule-specific inclusion and exclusion criteria. Patients were assessed by the clinical decision rules as being at high and low risk according to algorithms and then compared with actual observed outcomes to determine the number of correctly identified and missed brain injuries. This constitutes a pragmatic approach to modeling and compares the rules in a broad and inclusive patient population.

The CHALICE clinical decision rule recommends a dichotomous course of action. If one or more predictor characteristics are present, then a CT is indicated.[2,4] Similarly, the CATCH clinical decision rule recommends a CT if one or more predictor characteristics are present, even though the article in which the rule was derived separated risk factors into high and medium risk.[2,10] The PECARN clinical decision rule recommends not to conduct CT in the absence of predictor variables; however, in their presence clinician discretion and observation are used to determine CT use.[1,2]

An adjustment has been developed previously and includes "CT recommended," "observation versus CT on the basis of other clinical factors," and "CT not recommended."[1] Essentially, the algorithm categorizes patients as being at low, intermediate, or high risk. To provide consistency between rule comparisons, as a pragmatic means of modeling patients intermediate-risk patients were recategorized as being at high risk (observation followed by CT) in the presence of 2 or more intermediate-risk PECARN variables, or low risk (observation followed by no CT) if they had none or one intermediate-risk PECARN variable. This reflects the suggested actions in the PECARN algorithm[1] and a necessary assumption also used in the previously published cost-effectiveness analysis of the PECARN clinical decision rule. Alternative scenarios were evaluated in sensitivity analyses that represent the upper and lower bounds of the effect of allocating all intermediate-risk patients to receive observation followed by CT or observation followed by no CT (Table 2).

The economic model took a lifetime horizon, and both the economic and health care payer perspective comprised the Australian health care system (all hospitals in the study are government funded). The main assumption was that any patient categorized as being at low risk for a traumatic brain injury did not receive a CT and that high-risk children did immediately. In addition, CT scan is the criterion standard and a very accurate diagnostic tool for identification of structural pediatric head injury. APHIRST outcome measures focused on traumatic brain injury and neurosurgery when a CT was required and shown to have positive (abnormal) findings. Our study assumed CT was therefore 100% sensitive and specific for the purpose of the modeling, as have other published economic evaluations.[2,15] It was assumed that patients categorized as being at low risk (no CT) were discharged home, with the types and lengths of hospital observation and intervening management as recorded in APHIRST. Low-risk patients with missed traumatic brain injuries were assumed to re-present to the hospital (additional ED presentation and a CT).

Outcome Measures

Performance accuracy and clinical outcomes for applying the CATCH, CHALICE, and PECARN clinical decision rules versus usual care for APHIRST have been previously reported[3] but are presented here in the format used for the economic evaluation (Table 2).

Patient outcomes after traumatic brain injury were estimated by applying the criterion standard Glasgow

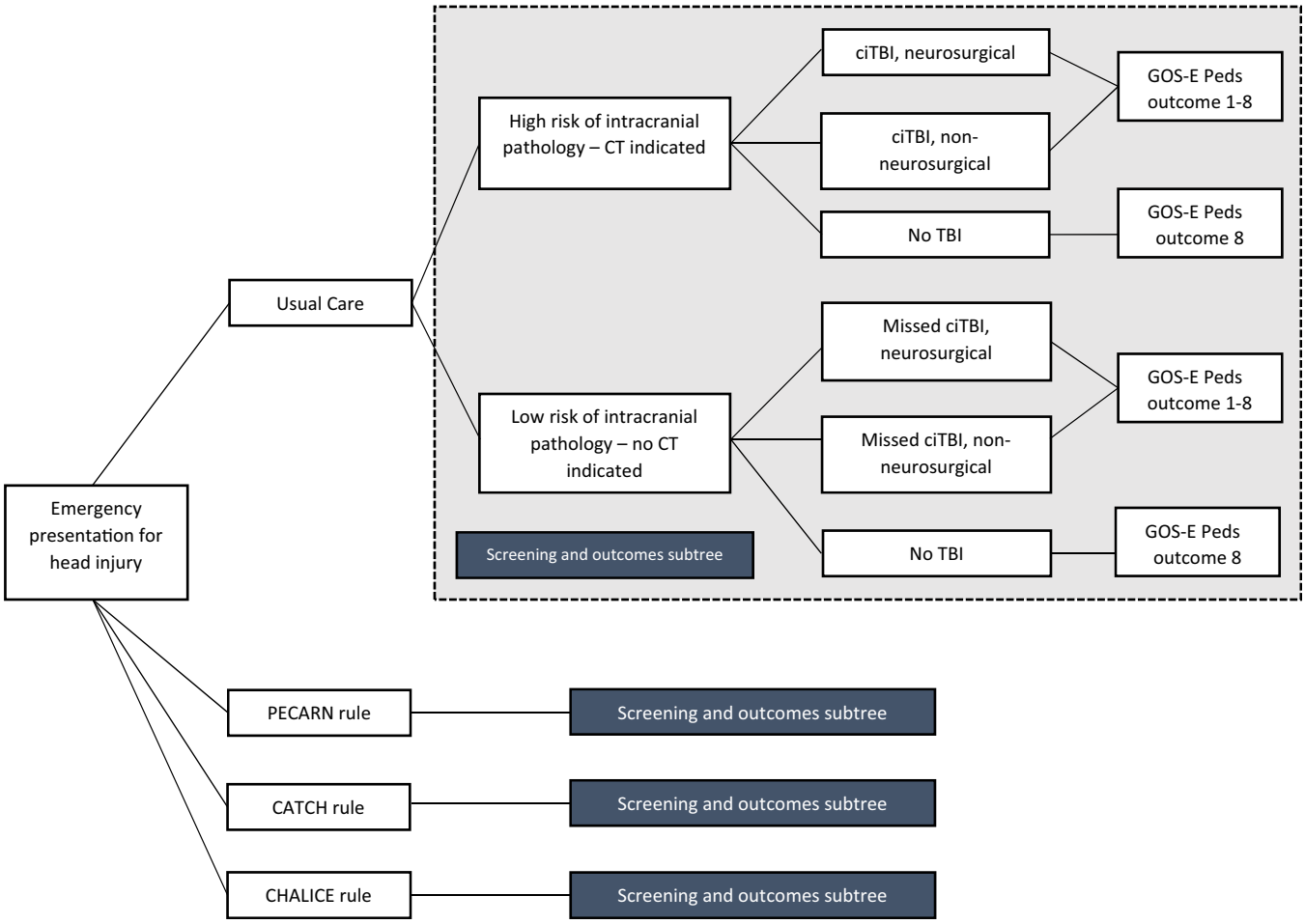

Figure 1. Economic model (abbreviated). The decision tree shown for usual care is repeated for the CATCH, CHALICE, and PECARN CDRs. *CDR*, Clinical decision rule; *ciTBI*, clinically important traumatic brain injury; *neurosurgical*, ciTBI that requires neurosurgical intervention; *nonneurosurgical*, ciTBI that does not require neurosurgical intervention; *GOS-E Peds outcome*, Glasgow Outcome Scale–Extended Pediatrics score; *TBI*, traumatic brain injury.

Outcome Scale–Extended Pediatric, consisting of levels 1 to 8.[16] Transition probabilities from each injury state were based on clinical data for the subset of patients from the APHIRST cohort at the Royal Children's Hospital in Melbourne who sustained traumatic brain injuries (n=39). After reviewing medical records, a senior ED clinician (J.A.C.) categorized each patient with the Glasgow Outcome Scale–Extended Pediatric. Probabilities were then calculated for different combinations of risk (high or low) and outcome. Patients who did not sustain a traumatic brain injury in either the high- or low-risk groups were assumed to be in full health and were allocated to the highest category, upper good recovery.

Glasgow Outcome Scale–Extended Pediatric utility weights have been previously mapped,[17] and these values were included in the economic model (Table E1, available online at http://www.annemergmed.com). For patients who sustained brain injuries (clinically important traumatic brain injury with or without neurosurgery) but were missed by either the clinical decision rule or usual care, a utility decrement of 10% was applied to reflect a worse outcome through delayed treatment. Utility values were discounted at 5% per annum, as per Australian convention.[18]

The estimated cancer risk of 0.12 and the quality-of-life decrement from a single cranial CT scan of 0.0130 were used according to the results for aged 5 and aged 4 to 9 years, respectively, of a meta-analysis conducted by Stein et al[19] (Table E1, available online at http://www.annemergmed.com).

Resource costs and associated probabilities are listed in Table 3. All costs are reported in 2016 Australian dollars, and earlier data were inflated by using the general consumer price index from the Reserve Bank of Australia (July 20, 2017) in accordance with current economic evaluation guidance.[20]

An assumed 10% loading, or additional cost, was applied to costs for children whose traumatic brain injury

Table 2. Comparison of application of clinical decision rules to APHIRST data for economic evaluation: numbers indicated for CT scan and numbers of clinically important traumatic brain injuries identified and missed.

	Base Case Analysis				Sensitivity Analysis for PECARN	
Outcome Measures	**Usual Care**	**PECARN**	**CATCH**	**CHALICE**	**Intermediate Allocated to Low Risk***	**Intermediate Allocated to High Risk†**
High risk (received cranial CT scan), No. (%)	1,579 (8.3)	3,324 (17.6)	5,707 (30.2)	4,166 (22.0)	1,808 (9.6)	8,812 (46.6)
ciTBI, neurosurgical	24	21	23	22	18	24
ciTBI, nonneurosurgical	134	120	124	126	102	135
No TBI	1,421	3,183	5,560	4,018	1,688	8,653
Low risk (no cranial CT scan), No. (%)	17,334 (91.7)	15,589 (82.4)	13,206 (69.8)	14,747 (78.0)	17,105 (90.4)	10,101 (53.4)
Missed ciTBI, neurosurgical	0	3	1	2	6	0
Missed ciTBI, nonneurosurgical	2	16	12	10	34	1
No TBI	17,332	15,570	13,193	14,735	17,065	10,100

*Patients considered to be at intermediate risk of head injury were allocated to the low-risk group (no CT indicated).
†Patients considered to be at intermediate risk of head injury were allocated to the high-risk group (CT indicated).

(with or without neurosurgery) was missed on initial presentation to account for the likely greater severity attached to an injury that was initially missed compared with the same injury treated immediately.

Primary Data Analysis

The economic evaluation results are presented as a cost per quality-adjusted life-years gained because of traumatic brain injury (short- and long-term management and care) and radiation-induced cancers for the usual care group compared with the 3 clinical decision rules. Incremental cost-effectiveness ratios were calculated to compare each strategy with usual care (difference in costs divided by difference in quality-adjusted life-years). Multiple comparisons of the 3 clinical decision rules were made according to published reporting guidance.[20] Results are reported according to the Consolidated Health Economic Evaluation Reporting Standards guideline.[21] Statistical preparation of original data was performed with Stata (version 14.0; StataCorp, College Station, TX).

Sensitivity Analyses

Probabilistic sensitivity analysis using 1,000 simulations was conducted to investigate the effect of parametric uncertainty (see Table 4, Figure 2, and Tables EXXXX [available online at http://www.annemergmed.com] for parameters and distributions). The 95% confidence intervals for utility and cost decrements (Tables EXXXX, available online at http://www.annemergmed.com) for missed brain injuries, costs of CT, probability of cancer, Glasgow Outcome Scale–Extended Pediatric utility values, other hospital costs, utility decrement of cancer, cancer cost and Glasgow Outcome Scale–Extended Pediatric costs were used in one-way sensitivity analyses, along with various discount rates (3.5% and 6%) and various cancer latency periods (5 and 20 years).

RESULTS

Usual care, CHALICE, PECARN, and CATCH strategies cost on average AUD $6,390, $6,423, $6,433, and $6,457 per patient, respectively (Table 4). The CT scanning rates were 8.3% for usual care, 17.6% for PECARN, 22.0% for CHALICE, and 30.2% for CATCH. From an Australian health care system perspective, the usual care strategy was more effective in detecting traumatic brain injuries and used fewer CT scans. The magnitude of differences in cost and quality-adjusted life-years between the clinical decision rules was small. Usual care was more effective and the least costly and therefore dominated all other strategies. When multiple comparisons of clinical decision rules were made, CHALICE was mostly likely to be cost-effective. The cost-effectiveness results are presented in Table 4.

Sensitivity analysis showed that when intermediate-risk PECARN patients were allocated to low risk, this rule became closer in cost to usual care, but less effective (because of reduced CT scanning with a greater number of missed injuries). Under this scenario, usual care remained dominant. When intermediate-risk PECARN patients were moved to high risk, this rule became costlier (more CTs) and more effective; however, usual care remained dominant. The model is sensitive to the reallocation of

Table 3. Immediate and long-term costs used in the economic model for each health state.

Immediate Costs*	**Abbreviation**	**Mean (95% CI, SE), $**	**Distribution**	**Source**
ED presentation (ED)	cED	380 (372–388, 4)	γ[†]	Hospital cost data[‡]
Emergency SSU	cSSU	459 (396–522, 32)	γ	Hospital cost data[‡]
Inpatient stay, general ward	cWard	2,886 (2,715–3,057, 87)	γ	Hospital cost data[‡]
Inpatient stay, ICU	cICU	45,694 (37,160–54,228, 4,354)	γ	Hospital cost data[‡]
Cranial CT scan	cCT	290[§] (5.80–574)	γ	Australian Government, (2017)[27]
Intubation[‖]	cIntubation	283[§] (5.66–560)	γ	Tvede et al (2012)[28]
Neurosurgery	cNeurosurgery	3,702 (3,341–4,063, 184)	γ	Hospital cost data[‡]
Health state		**Summary of resources used**		
	Assessed as high risk and received a CT scan			
ciTBI, neurosurgical		cED+cCT+cNeurosurgery+(cIntubation×pIntubation)+(pAttendance×cSSU, cWard, cICU)		
ciTBI, nonneurosurgical		cED+cCT+(cIntubation×pIntubation)+(pAttendance×cSSU, cWard, cICU)		
No TBI		cED+cCT+(pAttendance×cSSU, cWard, cICU)		
	Assessed as low risk and did not receive CT scan initially			
Missed ciTBI, neurosurgical		Initial costs: cED+(pAttendance×cSSU, cWard, cICU) Re-presentation costs: cED+cCT+(cIntubation×pIntubation)+cNeurosurgery+(pAttendance×cSSU, cWard, cICU)×10% loading		
Missed ciTBI, nonneurosurgical		Initial costs: cED+(pAttendance×cSSU, cWard, cICU) Re-presentation costs: cED+cCT+(cIntubation×pIntubation)+(pAttendance×cSSU, cWard, cICU)×10% loading		
No TBI		cED+(pAttendance×cSSU, cWard, cICU)		
Probabilities	**Abbreviation**	**Probability**	**Distribution**	**Source**
Intubation	pIntubation	0.0083	β	Original patient data from Nishijma et al (2014)[15]
Attendance	pAttendance=pSSU+pWard+pICU	Neurosurgical ciTBI[§]=0.083+1.0+0.292 Nonneurosurgical ciTBI=0.067+0.941+0.081 No TBI=0.759+0.247+0.0093	β	Babl et al (2017)[3]
Long-term costs	**Variable name**	**Mean (95% CI, SE), $**	**Distribution**	**Source**
Cost of care for GOS-E state 2	cGOS-E2: year 1 Year 2 onward	343,495[§] (6,870–680,120) 55,362 (5,166–511,408, 133,981)	γ	Fields et al, (2003)[29‖]
Cost of care for GOS-E state 3	cGOS-E3	80,976[§] (1,620–160,332)	γ	Beecham et al (2009)[30]
Cost of care for GOS-E state 4	cGOS-E4	42,235[§] (845–83,625)	γ	Beecham et al (2009)[30]
Cost of cancer[¶]	cCancer	35,030 (19,826–50,234, 7,757)	γ	Adult hospital cost data[#]

CI, Confidence interval; *SSU*, short-stay unit.

*Costs of the ED are based on average triage times in the cubicle and are reported in minutes: level 2=231 (SD 150), level 3=180 (SD 142), level 4=136 (SD 100), and level 5=98 (SD 98). The SSU had an average time of 1.03 days (SD 0.34).

[†]A γ distribution was chosen for costing data to reflect their skewed nature.

[‡]ED, SSU, and inpatient cost data were drawn from the individual patient level 2013 to 2014 financial data for the APHIRST patients at a specialist pediatric hospital in Melbourne, Australia. Admitted episodes were for children aged 0 to 18 years and presenting with *International Classification of Diseases, 10th Revision* (*ICD-10*) codes indicating head injury (*ICD-10* S00-S16 and T20).

[§]In the absence of reported data on measures of variance, the SEs are assumed to be half the mean.

[‖]Cost data taken from literature have been converted to Australian dollars and inflated to 2016 values with Reserve Bank of Australia figures from February 13, 2018.

[¶]Costs of cancer were applied in the economic model during a 5-year period, with a 10-year latency period assumed.

[#]Based on 481 episodes of care in 2014 and 2015 for 55 patients presenting to a specialist cancer center in Melbourne, Victoria, with a primary diagnosis of high-grade glioma.

intermediate-risk PECARN patients, but under neither scenario is PECARN likely to be cost-effective or preferred according to economic evaluation results.

The results of probabilistic sensitivity analyses are presented in Table 4 and Figure 2*A* and show that for 61%, 62%, and 60% of simulations, usual care is dominant compared with CATCH, CHALICE, and PECARN, respectively. The cost-effectiveness acceptability curve (Figure 2*B*) shows that for a willingness to pay of $50,000 per quality-adjusted life-year gained, more than 70% of the

Table 4. Economic evaluation results, each strategy compared with usual care, head-to-head comparison of clinical decision rules, and PECARN alternate allocation to low- and high-risk groups (per child presenting to the ED).

	Mean Cost, $	Mean QALYs	ICER, $
Economic comparison of each clinical decision rule with usual care			
Usual care vs	6,390	16.97686	Dominant* strategy
PECARN	6,423	16.97567	Dom
CHALICE	6,433	16.97604	Dom
CATCH	6,457	16.97581	Dom
Comparison of multiple CDRs[†]			
PECARN vs	6,423	16.97595	22,727[‡]
CHALICE	6,433	16.97639	
Sensitivity analysis, economic comparison of allocating intermediate-risk PECARN patients to low- and high-risk groups with usual care			
PECARN (low)[§] vs usual care	6,408	16.97464	Dom
	6,390	16.97686	Dominant strategy
PECARN (high)[‖] vs usual care	6,500	16.97706	550,000[¶]
	6,390	16.97686	
Probabilistic sensitivity analysis: each rule compared with usual care			
Usual care vs	6,431 (2,690)	16.97706 (0.0060)	Dominant strategy
CHALICE	6,467 (2,668)	16.97681 (0.0061)	Dom
PECARN	6,461 (2,714)	16.97693 (0.0064)	Dom
CATCH	6,465 (2,656)	16.97680 (0.0061)	Dom

QALY, Quality-adjusted life-year; *ICER*, incremental cost-effectiveness ratio, cost per QALY gained; *DOM*, dominated strategy (more costly and less effective).
*"Dominant" refers to a strategy's being less costly and more effective and therefore preferred.
[†]Note that CATCH is excluded from the multiple comparison of CDRs because of being dominated by the other CDRs (more expensive and less effective).
[‡]CHALICE is likely cost-effective for a threshold of less than $50,000 per QALY gained.
[§]All intermediate-risk PECARN patients according to CDR were reallocated to the low-risk modeling group for analysis.
[‖]All intermediate-risk PECARN patients according to CDR were reallocated to the high-risk modeling group for analysis.
[¶]PECARN (high) is unlikely to be cost-effective with a threshold of less than $50,000 per QALY gained.

simulations indicate usual care as the preferred strategy. Cost-effectiveness results remained robust to a number of sensitivity analyses performed (Figure 3). The usual care strategy remained the dominant strategy under all sensitivity analyses performed. The economic model was most sensitive to the number and cost of cranial CTs, the method for allocation of PECARN intermediate patients, the probability of cancer, and the rate at which future outcomes and costs are discounted. The model trades off the loss of utility and increased costs associated with missed head injuries against the additional cost of imaging. For example, a scenario in which no patients are given a CT leads to a lower price compared with usual care but also fewer quality-adjusted life-years and is not likely cost-effective.

LIMITATIONS

This evaluation has several limitations. Cost data from a single center may limit generalizability of results. Nevertheless, results remained robust under sensitivity analyses when cost inputs were varied (Figure 3) and the same cost data were applied to usual care and all 3 clinical decision rules. The usual care strategy involves additional periods of patient observation, which are associated with an opportunity cost for another patient who may have been treated in that cubicle or bed in the previous patient's place. The cost of the ED and short stay unit is based on minutes in the cubicle or bed and is incorporated, but additional benefits to another patient are not included. Long-term outcomes for children with neurosurgical traumatic brain injuries were based on a small sample of 39 children from APHIRST; however, the model was not overly sensitive to these utility values. The ability to use original data from the same study to inform the distribution of longer-term outcomes for the economic evaluation could be considered a strength compared with other published economic evaluations that rely on secondary data from a different sample.[15,22]

Treating physicians collected information on all clinical decision rule predictor variables, and it is possible that the collection of data influenced decisionmaking. This may have led to increased effectiveness and therefore cost-

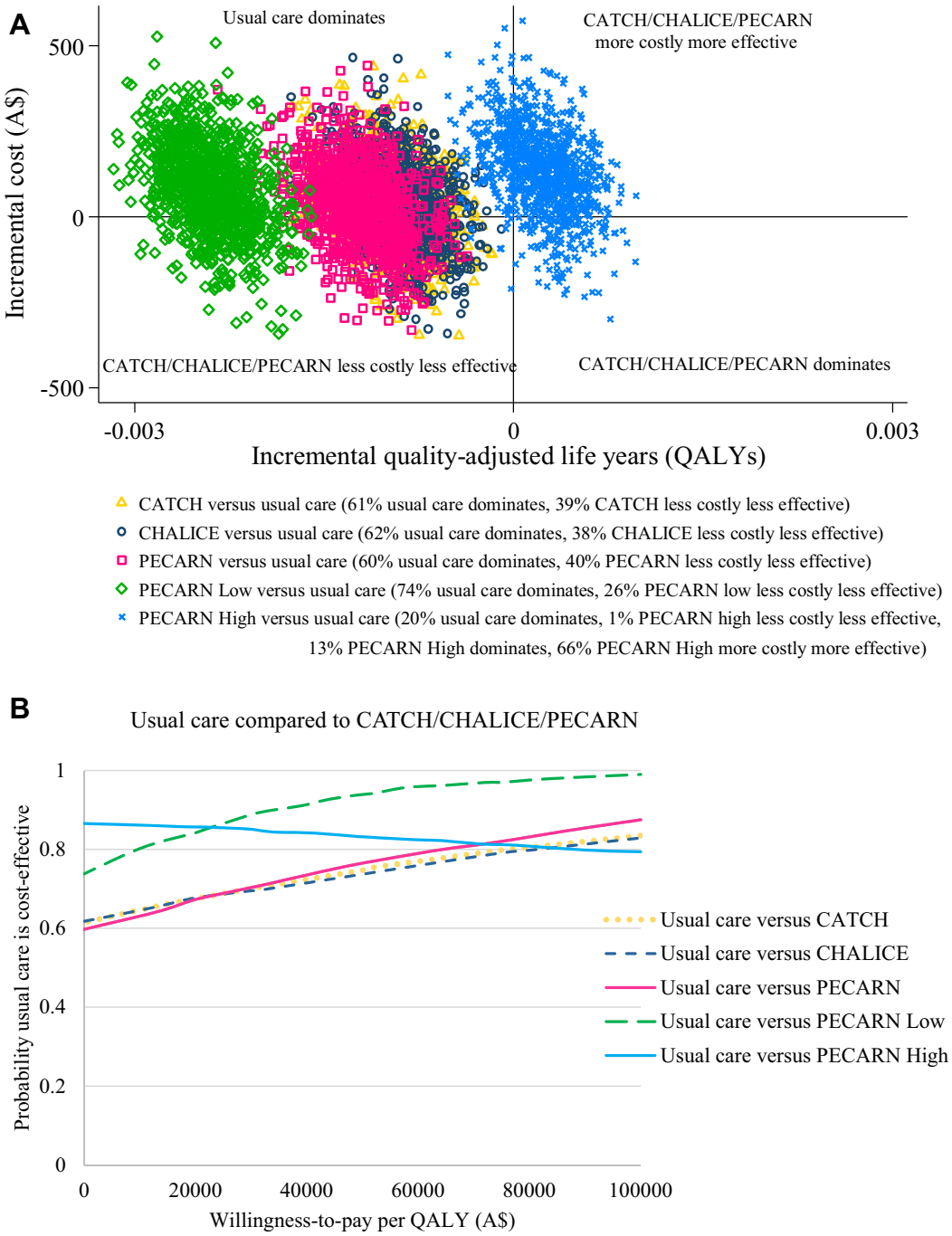

Figure 2. *A*, Sensitivity analysis and *B*, cost-effectiveness acceptability curve comparing clinical decision rules.

effectiveness of the usual care strategy. However, the overall rate of CT use in the prospective APHIRST study is consistent with a previous retrospective report in the same setting.[5,23]

Although we did not find systematic or large-scale use of clinical decision rules, according to a survey we conducted across the PREDICT network before the study,[12] clinicians may have used one or all of the rules for their individual decisionmaking. It remains possible that usual care includes principles from the clinical decision rules gathered through training and practice and that the clinical decision rules represent formal or informal supplements to care. However, widespread use any of the rules should have increased the usual care CT rate over the known long-term stable prestudy baseline; this did not happen. A further limitation relates to the inclusion of clinical discretion in

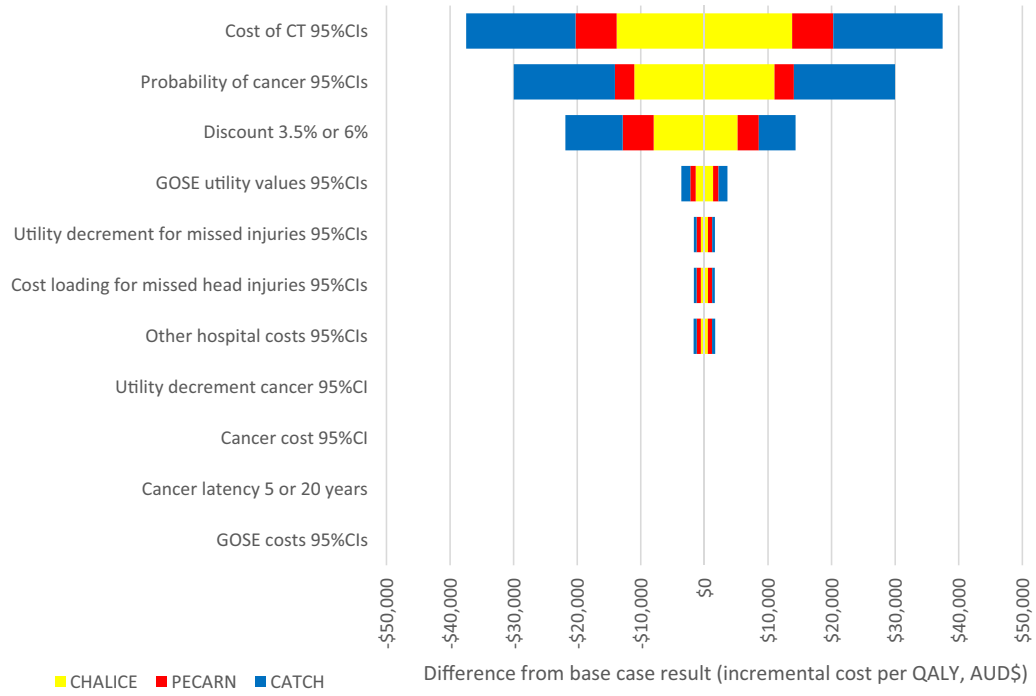

Figure 3. Results of one-way sensitivity analyses showing difference in cost per quality-adjusted life-year from base case for CATCH, CHALICE, and PECARN compared with usual care.

the usual care strategy but not for clinical decision rule strategies, which is inevitable, given the data source. In practice, clinical decision rules are always implemented with clinical discretion.[3,23] There could be significant variation of usual practices across the 10 sites. The usual care group demonstrates that high-quality decisions are being made by clinicians, but further research using the APHIRST data set would be needed to quantitatively describe usual care.

The rules were applied in a pragmatic manner in which all children in the comparison cohort were made eligible for assessment with each clinical decision rule. The APHIRST cohort assessed with each rule is therefore different from the cohorts in the derivation studies that maintained varied eligibility criteria. This could affect the performance accuracy of the clinical decision rules. However, this method constitutes a real-world approach and may reflect the practices and population in which the rules will be implemented. The economic model relies on a computer algorithm applied to data, and in actual practice clinician judgment would play a significant role. Additionally, the PECARN rule was developed to allow clinician discretion (in regard to observation for intermediate-risk patients[1]), and in applying PECARN to the data set we have no way of including this. In an actual application of the clinical decision rules, in particular the PECARN rule, all of these factors may result in different probabilities than those imputed, which could affect results. We carefully varied the assumptions around the allocation of PECARN intermediate-risk patients to high- and low-risk categories to assess the effect of this assumption.

DISCUSSION

This economic evaluation for the first time, to our knowledge, directly compares the cost-effectiveness of 3 clinical decision rules and Australasian usual care for the assessment of pediatric head injuries presenting to EDs. The results of the economic modeling demonstrate that the 3 published head injury clinical decision rules are not more cost-effective than Australian and New Zealand usual care strategy. The absolute differences between the rules were small, with the largest difference in bootstrapped cost of $36 (95% confidence interval –$7 to $77) and 0.00097 (95% confidence interval 0.0015 to 0.00044) quality-adjusted life-years per child (equating to an additional 8.5 hours of quality-adjusted life). The cost-effectiveness results were robust under all one-way and probabilistic sensitivity analyses. It is therefore unlikely in this patient setting that the economic evaluation results would suggest the use of any specific clinical decision rule over another.

The strengths of the analysis include a large data set, the use of multiple centers, and that the analysis was able to compare the rules hypothetically using standardized modeling techniques and assumptions.

The clinical decision rules were derived to optimize the balance between identifying significant brain injuries and minimizing the exposure of the developing brain to radiation. However, the results presented here do not indicate high value in investing in strategies to switch from usual care, or from one rule to another in our setting. In comparison, a cost-effectiveness analysis conducted in the United States by Nishijima et al[15] reported that PECARN was the dominant strategy compared with usual care (characterized by a 33.8% CT rate).[15] Another cost-effectiveness analysis, conducted in the United Kingdom by Holmes et al,[22] investigated CHALICE and PECARN and demonstrated that both are a cost-effective approach. The comparators for this study were not usual practice, but theoretical: CT for all patients and discharge all without testing. It is possible that implementing clinical decision rules in countries where the baseline CT rate is significantly higher than the 8.3% scanning rate in Australia and New Zealand will lead to more advantageous cost-effectiveness ratios. Interventions to appropriately reduce existing imaging rates are likely to be more cost-effective in countries known to have higher unit costs of health care such as the United States. It is likely that patterns of usual care are critical to the choice of clinical decision rule. Initiatives such as Choosing Wisely,[24-26] which aim to inform evidence based on cost-effective practice choices, should more fully account for usual care contexts when making recommendations. Australian and New Zealand usual care remained cost-effective, indicating no economic imperative for investing in change. We failed to observe important differences in cost or effectiveness between the rules, indicating a lack of economic imperative for switching from any rule to another. Other important factors to the decision are likely to include physician experience and rule-specific sensitivities and specificities for outcomes, which were not considered in this economic evaluation. The use of clinical decision rules outside of specialist pediatric hospitals or by clinicians who are less experienced in evaluating children may generate different results.

In summary, the practice of usual care in our setting is an effective strategy and is cost saving. Compared with usual care in the Australasian specialized pediatric hospital setting, the CATCH, CHALICE, and PECARN clinical decision rules are all projected to scan more children and may miss more neurosurgical and nonneurosurgical traumatic brain injuries that are likely to result in increased hospital costs, with a potential reduction in positive health outcomes. These results were robust under several one-way and probabilistic sensitivity analyses. Further analysis is required to provide a comprehensive definition about what usual care constitutes. This evaluation highlights the importance of understanding usual practice before investing in the implementation of international clinical decision rules derived within other health care settings and countries.

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