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A Cost-Effectiveness Analysis of a Pediatric Operating Room in Uganda

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Abstract

This study examines the cost-effectiveness of constructing a dedicated pediatric operating room (OR) in Uganda, a country where access to surgical care is limited to 4 pediatric surgeons serving a population of over 20 million children under 15 years of age.

Methods: A simulation model using a decision tree template was developed to project the cost and disability-adjusted life-years saved by a pediatric OR in a low-income setting. Parameters are informed by patient outcomes of the surgical procedures performed. Costs of the OR equipment and a literature review were used to calculate the incremental cost-effectiveness ratio of a pediatric OR. One-way and probabilistic sensitivity analysis were performed to assess parameter uncertainty. Economic monetary benefit was calculated using the value of a statistical life approach.

Results: A pediatric OR averted a total of 6,447 disability-adjusted life-years /year (95% uncertainty interval 6,288–6,606) and cost $41,182/year (UI 40,539–41,825) in terms of OR installation. The pediatric operating room had an incremental cost-effectiveness ratio of $6.39 per disability-adjusted life-year averted (95% uncertainty interval of 6.19–6.59), or $397.95 (95% uncertainty interval of 385.41–410.67) per life saved based on the country's average life expectancy in 2015. These values were well within the WHO guidelines of cost-effectiveness threshold. The net economic benefit amounted to $5,336,920 for a year of operation, or $16,371 per patient. The model remained robust with one-way and probabilistic sensitivity analyses.

Conclusion: The construction of a pediatric operating room in Uganda is a cost-effective and worthwhile investment, endorsing future decisions to enhance pediatric surgical capacity in the resource-limited settings of Sub-Saharan Africa.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi: 10.1016/j.surg.2018.03.023.

Introduction

As global efforts are galvanized to expand essential surgical access, pediatric surgery has been a relatively neglected area. Pediatric surgery has been named the “unborn child” of neglected disease,[1] especially in countries like Uganda where 48% of the population is under the age of 15. As many as 85% of pediatric patients in Africa are estimated to have a surgically treatable disorder by the age of 15.[2] Uganda faces a huge unmet need for pediatric surgical care, because there are currently only 4 qualified pediatric surgeons in the whole country to serve a pediatric population of 20 million.[3] The effective pediatric surgical coverage by the current health care system in Uganda amounts to a mere 3.5%.[4] This dearth of care of delivery is a result of a severe lack of resources, most remarkably in the surgical infrastructure. Demonstrably, no dedicated pediatric operating rooms (ORs)existed in the country until very recently.

In 2015, the ARCHIE Foundation, a nongovernmental organization (NGO) that provides support to the surgical needs of children in Africa, partnered with local health care providers to fund the construction of the first dedicated pediatric surgical OR in Uganda by donating surgical and anesthetic equipment.[5] The benefits of such a facility with a dedicated pediatric OR remain poorly described. No study has demonstrated the construction of a pediatric OR to be a justifiable use of scarce resources in a low-income setting with competing health care needs, especially when expensive upfront investment is required. With the need for better metrics to justify the development of surgical interventions in the global setting, the aim of this study was to quantify the disease burden averted by a pediatric OR to provide a better estimate about the cost and health consequences of furnishing a pediatric OR.

Cost effectiveness analysis (CEA) as an economic tool has been recently popularized by the Disease Control Priorities series[6] and adopted by the global surgery community.[7] In this context, CEA can help guide otherwise difficult decisions to channel limited resources toward the most efficient avenues. To date, there has been no cost-effectiveness study to quantify the cost proportional to health utility gained from a pediatric OR. This study hoped to determine the cost effectiveness of furnishing a pediatric OR by including the costs of the large-scale equipment donation.

Methods

The cost-effectiveness model

A decision tree base template was constructed to compare life trajectories that pediatric surgical patients take with or without surgical intervention, based on previously suggested methods.[7] To emulate realistic patient outcomes, the tree identifies a range of post-treatment scenarios, including immediate death and discharge, as well as long-term mortality, disability, and successful cure. The incremental deltas between OR costs and disease burden averted by surgical treatment and the counterfactual is the difference between the two branches at the decision node (Fig. 1). To simulate a year of OR operation, the annual disease burden averted is the sum of cumulative procedures done in a year. Model parameters include number of patients per year, number of procedures, OR equipment costs,

and patient outcomes determined by severity of disease (in the form of disability weights) and probability of disease state.

Counterfactual

The counterfactual is defined as the natural course of disease in the absence of the pediatric OR, because prior to OR installation, no dedicated pediatric operating facility existed to provide curative treatment for these diseases in this area. The new pediatric OR allows surgery to proceed for all types of pediatric surgical conditions, especially for non-emergent and/or elective cases that still require treatment to avoid morbidity later in life. Additionally, non- surgical curative treatment may not exist for some pediatric surgical diseases, especially in resource-limited settings, though nonoperative treatment can attenuate or minimize the disease burden. Pediatric surgical conditions often involve anatomic defects that require manual repair, so it is reasonable to assume that the natural course of disease is most likely in the setting of no surgery, even though this may be a simplification of the true breadth of treatment options. For patients with umbilical hernias, hydroceles, and other mild conditions that may resolve spontaneously later in life, the assumption was that the disease was substantial enough to cause lasting disability necessitating surgical correction in the first place. In these cases,a stable natural course of the disease over the patient's lifetime was used as the counterfactual scenario.

Parameters

We used the disability adjusted life year (DALY) as a metric to quantify the disease burden of each possible patient outcome in the decision tree. The final outcome metric was the incremental cost-effectiveness ratio (ICER), defined as ($Cost_{OR\ intervention} - Cost_{natural\ disease\ course}$) / ($DALYs_{OR\ Intervention} - DALYs_{natural\ disease\ course}$), and is presented as an absolute value in units US dollars/DALY averted. According to the guidelines of the World Health Organization (WHO), a cost-effective intervention should be under the threshold of three times the country's gross domestic product (GDP) per capita, which is $2026 in Uganda in 2015.[8]

Data Sources—Costs From the NGO Perspective

Core surgical OR equipment (OR table, anesthesiamachines, cautery etc) was procured from suppliers who offered subsidized prices. Participating NGOs (ARCHIE Foundation and Medical Aid International) provided details of market and discounted prices. Composite replacement costs are reported, though individually marked items are not presented. Replacement costs for each piece of equipment is annualized by either its lifetime warranty from a product catalog, or if unavailable, an average of 9 years as reported by the US Government Office of Management and Budget.[9] Prices were adjusted for average inflation rate of 5.5% in Uganda in 2015-6.[10]

Data Sources—Outcomes

Outcome parameters are informed by previous literature and patient data collected from the ORdatabase in Uganda during the first year of service. Information collected on patient outcomes, namely death or hospital discharge, were corroborated with three other sources to

ensure accuracy: the death certificate log, daily nursing reports, and patient files. We identified 48 unique surgical diseases/interventions that could be represented by the decision tree model, grouped into 5 disease categories: noncongenital emergencies, elective procedures, fatal congenital anomalies, non- fatal congenital anomalies, and neoplasia (Supplemental data, Table I). We included 326 cases into the cost-effectiveness model. Additional patient data extracted from the database included age, sex, diagnosis, surgical intervention, patient outcomes, and duration of hospital stay. All entries were de-identified on collection prior to analysis. For the purposes of this study, we excluded cases performed by other surgical services, and those that were minor and only appeared once. We used the DALY as a metric to quantify the disease burden of each possible patient outcome in the decision tree. We report both nondiscounted and 3% time discounted values in our ICER calculations, because the WHO recommended against discounting in the most recent guidelines, though some studies still take time-discounting into account.[11] In the scenario-based sensitivity analysis, DALYs were time-discounted and subject to age-weighting following Fox-Rushby's method, and compared to the base case with no time discounting.[12]

Where applicable, disability weights (DWs) for each condition were taken from previous literature[4,13,14] or validated preference scales developed by McCord and McChowdhury.[15] Country-specific life-expectancy in 2015 was 60 years for males and 64 years for females.[16] Probability of successful treatment (PST) and probability of postoperative death are estimated from previously published literature, and any disease with a greater than 95% cure rate has a PST of 1.[15] DWs and probabilities were estimated by the consensus of the co-authors.

Parameter uncertainty and statistics

A multivariate, probabilistic, Monte Carlo simulation was conducted to characterize the uncertainty of the ICER accumulated by the multitude of variables. To emulate a facility-based study, simulated patients were batched in cohorts of 200 to 500 randomized uniformly, and the probability of frequency for each presenting disease was empirically randomized to follow the proportion of cases of the Naguru OR. Cumulative DALYs were divided over the annual costs to obtain the simulation ICER. Randomization of uncertain parameters included life expectancy/age of presentation, DWs, probability of successful treatment, and probability of death. For life expectancy and age, continuous probability distributions (log-normal, Weibull, or gamma) were fitted with Java Math Pack-age (JMP) statistical software developed by Statistical Analysis System (SAS) for diseases/operation with at least 10 patients in the OR case log. For diseases with less than 10 patients to power a continuous function, we used uniform and triangle distributions. Disability weights and probabilities were fitted with a beta distribution using previously reported confidence intervals (CI), and when published data was unavailable, a CI range of +/−0.2 was constrained between 0 and 1. The simulation was run on Excel and VBA script over 200 and bootstrap confidence intervals were calculated for the ICER. Results of the Monte Carlo simulation are presented in a cost-effectiveness plane. One-way deterministic sensitivity analysis was also performed to model alternative scenarios in order to capture plausible ranges of parameters that were subject to the most variation. Scenarios reported include changing time discounts and

inflation rates, market value of equipment, age weighting, and number of patients treated without OR intervention.

A cost-benefit analysis was also conducted using a value of statistical life (VSL) approach following the third edition of the Disease Control Priorities (DCP3)[17] and demonstrated by a recent study on repair of cleft-lip and palate.[18] The economic benefit was calculated by converting the value of a statistical life in America to that of Uganda using the ratio between the two countries' GDP per capita, and an income elasticity of 1.5, as is consistent with low-income countries. Unless otherwise stated, costs are reported in 2015 USD.

Results

During April 2015 to April 2016, 326 patients with 48 unique pediatric surgical diseases underwent surgery in the Naguru OR with immediate outcomes recorded (Table 1). Based on the analysis confined to OR case log data, a total of 8,604 incremental DALYs with no time discount, or 3,973 with a 3% time discount, were averted within the yearlong study period. Surgery for fatal congenital anomalies averted the most disease, and nonfatal congenital anomalies had the most cases (152 cases, 46.6%) (Fig. 2).

The total cost of furnishing the pediatric OR purchased by the ARCHIE foundation was $101,847.57, which includes the surgical and anesthesia equipment as well as the installation and transportation freight fees. (Itemized list found in supplemental data, Table II). This value is decreased from the market value cost of $266,261.85, because ARCHIE purchased the equipment at subsidized prices.

A Monte Carlo simulation over 200, facility-based iterations was performed on the pediatric OR model. Accounting for an annual inflation rate of 5.5%, mean annualized cost of the OR construction and maintenance was $41,182 per year of operation (95% uncertainty interval(UI) of 40,539–41,825). Mean simulation DALYs accumulated with no time discounting or age-weighting were 10,421 per year (95% UI 10,168–10,674) for the counterfactual and 3,974 per year (95% UI 3,873–4,074) for the pediatric OR intervention. When a 3% time discount was included, the counterfactual DALYs accumulated is adjusted to 4,844 DALYs per year (95% UI 4,7234,965), and the OR intervention accumulated 1,834 DALYs per year (95% UI 1,787–1,881). The incremental disease burden averted by the OR was 6,447 DALYs averted (95% UI 6,288–6,606), or 2,989 DALYs averted (95% UI 2,903–3,075) with time-discounting.

The mean simulation ICER was $6.39 per DALY averted (95% UI 6.19–6.59), which amounts to $397.95 (95% UI 385.41–410.67) per life saved based on average life expectancy in Uganda in 2015 (62.3 years). With a 3% time-discount, the ICER increased to $13.63 per DALY averted (95% UI $13.24–14.26) or $852.43 per life saved (95% UI 824.67–888.40). Regardless of time discounting, the ICER of the OR intervention and cost per life saved are well below the cost-effectiveness threshold of 1 and 3 times the GDP per capita of Uganda in 2015 ($2026.71). In absolute terms, this means that the intervention is likely to be cost-effective in the perspective of the NGO. This ICER remains cost-effective when the highly conservative World Bank threshold of $240 is applied.

One-way deterministic sensitivity analysis was performed for likely alternative case scenarios by changing parameters with significant variation. With all one-way scenario analyses, the ICER remained cost-effective and was relatively insensitive to scenarios for different time discounts of both costs and DALYs averted, DALYs age-weighting, market pricing for equipment, and a 20% proportion of met need in the counterfactual (Table 2). The ICER was most sensitive to time discounting (228% of base case) combined with age-weighting (182% of base case) and was relatively insensitive to increasing met need in the counterfactual scenario (125% of base case).

The calculated and simulation incremental cost-effectiveness frontiers are shown in the cost-effectiveness plane (Fig. 3). The economic benefit of the pediatric OR was derived from the DALYs averted multiplied by a value of statistical life year in Uganda (calculated at $827.32 with an income elasticity of 1.5). The net economic benefit of the pediatric OR is $5,336,920 in a year, or $16,371 per patient. This value is divided by the annualized cost of the OR construction to calculate the economic productivity earned, with a return of investment of $129.59 per every dollar spent on building the OR. The likelihood that the pediatric OR will be cost- effective is represented in the net monetary benefit curve (Fig. 4), spanning a range of stakeholder's willingness to pay (WTP) thresholds per incremental DALY averted. The construction of the pediatric OR becomes more cost-effective than no intervention at a WTP level of $6.39 (X-intercept).

Discussion

The first dedicated pediatric ORin Uganda has an ICER of $6.39 per DALY averted, and a $397.95 per life saved compared to the prior practice where there was no consistently available curative treatment for pediatric surgical disease. Based on the current WHO guidelines, the OR appears to be well below the cost-effective threshold of 3 times the country's GDP per capita and remains cost effective when a 3% time discount is applied. Recently, however, the validity of the WHO-CHOICE method for establishing cost-effectiveness has been called into question for being too forgiving. To address this issue, we were also able to show that this intervention is les than the more stringent WTP thresholds, including 1 times the country's GDP per capita and the World Bank threshold. We showed additionally that the OR intervention becomes cost-effective at a WTPlevel of $6.39 per DALY averted. Because the intervention remains less than multiple established WTP thresholds, installing a pediatric OR in Uganda is likely to remain a cost- effective strategy.

Perhaps the most important interpretation of this study is the comparison of the OR ICER to existing (surgical and nonsurgical) health care interventions, which demonstrates the strength of this analysis supporting the cost-effectivnesss of this program. To our knowledge, this is the first study to examine the cost- effectiveness of a pediatric surgical facility in a low-income country, because most studies focus on disease-specific interventions, and cost-effectiveness studies in pediatric surgical disease remain sparse in general. We can, nevertheless, compare this intervention to existing inventions within the area.

A systematic review of 26 CEA studies show that many essential operations have similar cost-effectiveness to that of vaccinations or mosquito nets in resource-limited settings.[19] A

Kenyan refugee camp, where a mere 13.5% of operationss needed for common congenital conditions were actually performed, showed that the cost-effectiveness of congenital anomalies ranged from $40 to $88 per DALY averted.[20] Our ICER is also less than a pediatric inguinal hernia repair in Uganda, another very cost-effective procedure at $12.41 per DALY averted, though this study reported discounted and age-weighted DALYs in their base analysis, which came closer to our corresponding age- and time-adjusted ICER of $11.92/DALY averted.[21] Cleft lip repairs, which are assocated with a mean averted 3.7 DALYs per patient, also had an ICER higher than our OR intervention at $81/DALY averted.[22]

Despite the general perception that surgical intervention would be unacceptably costly, the OR is at least 30 times more cost- effective than antiretroviral therapy treatment for HIV in Sub- Saharan Africa, for which the ICER ranges from $350 to $1,494 per DALY averted.[23] When compared to existing CEAs on other pediatric interventions such as pediatric inguinal hernia repair in Uganda, the ICERs are similar,[21] further corroborating the cost-effectiveness of performing pediatric surgery in the country. We can also evaluatecomparisons between facility-based CEAs. The ICER also is favorable when compared to other facility-based studies on surgical interventions, such as that of the private hospital in India[24] and a small hospital in Sierra Leone (with an ICER of $32.78/DALY averted)[25].

The low ICER of the pediatric OR islikely due to the following reasons: (1) young patient demographics and (2) life-saving procedures, both contributing to a large amount of DALYs averted. The young age of pediatric patients allows for substantial potential disease burden averted. Furthermore, a large proportion of the surgical procedures are considered life-saving, and therefore, the DALYs averted are whole life-years, and not just years lived in disability. This is an importantdistinction, because previous cost-effectiveness studies on pediatric operations revolve mainly around disability- averting procedures, such as cleft lip/palate and inguinal hernia. This is the first study to date that explores the cost-effectiveness of treating life-threatening congenital anomalies, such as anorectal malformations, Hirschsprung's disease, intestinal atresias, and pediatric cancers, interventions that contribute substantially to alleviation per case of the disease burden and therefore, the dramatic ICER values. Of note, our empiric evidence on patient outcomes includes discharge or death postoperatively, which means that our outcomes data are verified by actual patient prognosis. This type of real-time patient information is not usually recorded in cost-effectiveness studies, because other studies derived data mainly fromcase logs and had little or no outcomes data. Thus, this added empirical data for patient outcomes is a strength in our study.

Casting implications of the study more broadly, our method of cost-effectiveness analysis has not been adequately utilized previously in low-income countries like Uganda, especially in the surgical sphere. Nevertheless, stakeholders express resounding enthusiasm to take advantage of this practice, and the importance of such data was also emphasized in the recent DCP3 publication. One recent study showed that 78% of advanced health care personnel in Uganda had no exposure to CEA, even though 95% perceive this method to be important for clinical and policy decision-making.[26] Collaborating with our local partners in

the health care system on this analysis can introduce key economic methods of evaluation into the medical education system as an integral component of public health investigation. By demonstrating that the CEA can be extremely useful in informing changes in health care policy in the resource-limited settings of Uganda, this study could act as a knowledge broker in formulating a sustainable scholarly program to further pursue economic analyses on health care decision making.

Limitations

The biggest limitation of this study is the lack of supporting data surrounding the counterfactual. We assumed that in the absence of the OR, no operationsoccur, and all patients live out their natural diseases. The pediatric surgical health care personnel predate the OR and are trained to perform operationsin adult ORs, so some operations would have occurred regardless of the presence or absence of the pediatric OR. The one-way analysis where 20% of the disease burden is averted by existing hospital services without the pediatric OR serves to simulate this situation of partial met need, and the ICER remains robust under this scenario. Generalizability is limited to a new pediatric OR introduced into a health-care-naive setting where no prior pediatric surgical service was available.

In terms of calculating costs, it is important to note that the analysis only takes into account the installation and maintenance of the surgical and anesthesia equipment. The other operating costs including worker's wages and patient out-of-pocket, costs are omitted. There are several reasons that allow for this omission. Because the host facility is a public hospital, the health care workforce is previously staffed by the Ministry of Health and would have been compensated whether the OR was present or not. Furthermore, the surgical procedures are theoretically subsidized by the government, the patients do not need to pay for the service, and therefore, the surgical procedures should not add a substantial amount to the cost of surgery. Regardless of these factors, the value must still be considered from solely the perspective of NGO in order for the study to be generalizable. Future directions will explore costs covered by other providers, including the public sector and the patient out-of-pocket spending to provide a thorough estimate from all perspectives. The dominant portion of overall cost, however, would still be the equipment donation.

In terms of calculating health utility saved, there are limitations in calculating the actual disease prevented. It is known that the OR was not functioning at full capacity due to staff time and resource constraints, because limitations of human resource and a shortage in medical suppliesoccur throughout the year. Furthermore, the OR is also shared by 3 other surgical specialties, allotted approximately 33% of the operative time. Therefore, DALYs averted may be underestimated, because the fully functional potential of the surgical unit was not realized, and a substantial proportion of performed cases were omitted.

Several of the disease disability weights and probabilities of successful treatment and residual burden were estimated from expert opinion and may be subject to bias, because there has been little standardization (e.g. from the global burden of disease) on pediatric conditions in current literature. Therefore, the theoretic sources of these parameters must be

considered when interpreting results. Nevertheless, the one-way and probabilistic sensitivity analyses have evaluated the potential sources of uncertainty, and the model remains robust.

The OR also serves as the only dedicated base for training pediatric surgical specialists in the country. Thus, the benefits of the operating room extend beyond the number of lives saved by building surgical capacity of the health care personnel and educating pediatric surgeons and anesthetists. Workforce expansion is one of the benchmarks that the 2015 Lancet Commission lists as goals on improving global surgery;[27] This benefit, however, is not quantified in the traditional DALY averted approach of the CEA, so there must be other methods to be able to assess the benefits of such a facility.

In conclusion, this study is the first to demonstrate the cost-effectiveness of furnishing a pediatric OR in a low-income setting from the NGO perspective, showing that OR installation in an existing hospital is a viable intervention provided that suitable health care personnel and infrastructure is present. With the net monetary benefit of more than a hundred times the investment, the construction of a pediatric OR is a very attractive option for the building of health care capacity in Uganda and possibly other developing nations. Furthermore, this study demonstrates the utilization of economic analysis in a low-income setting in order to inform resource allocation.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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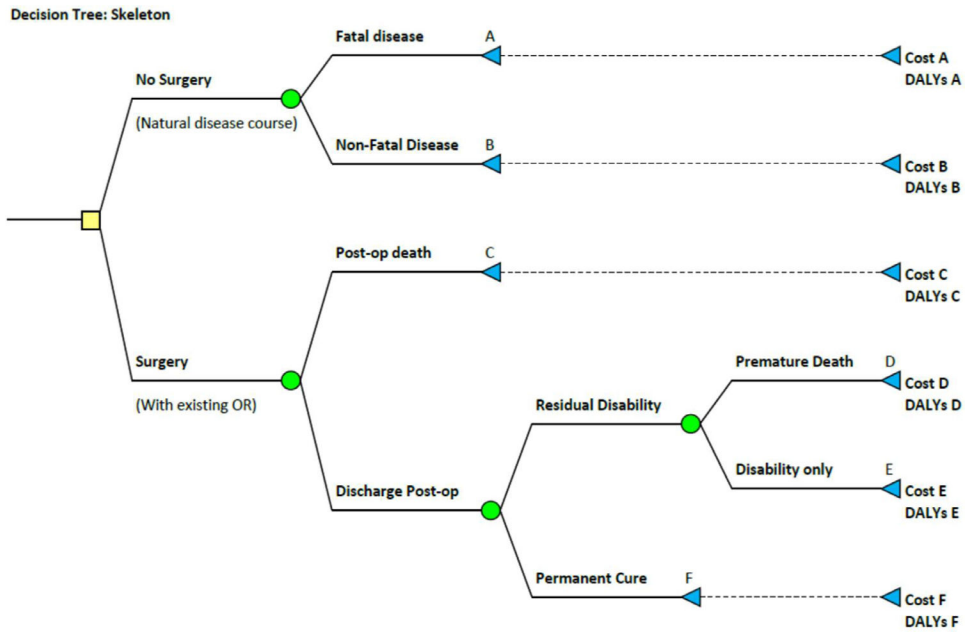

Fig. 1.

The skeleton of the decision tree to model pediatric surgical diseases treated in the OR Square = Decision node between surgery and no surgery. Circle = chance nodes with probabilities attached to each branch. Triangle = end nodes with cost and outcomes for each possible scenario.

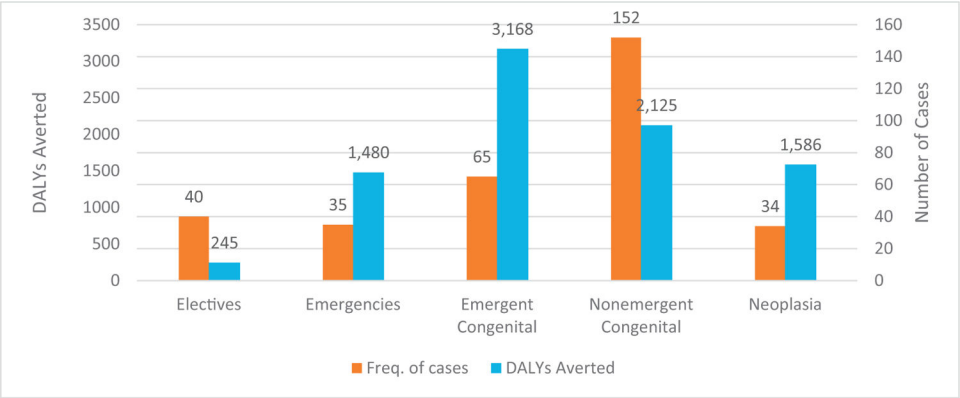

Fig. 2.

Disease burden averted by a year of procedures conducted in the pediatric OR categorized into 5 disease groups (in DALYs averted).

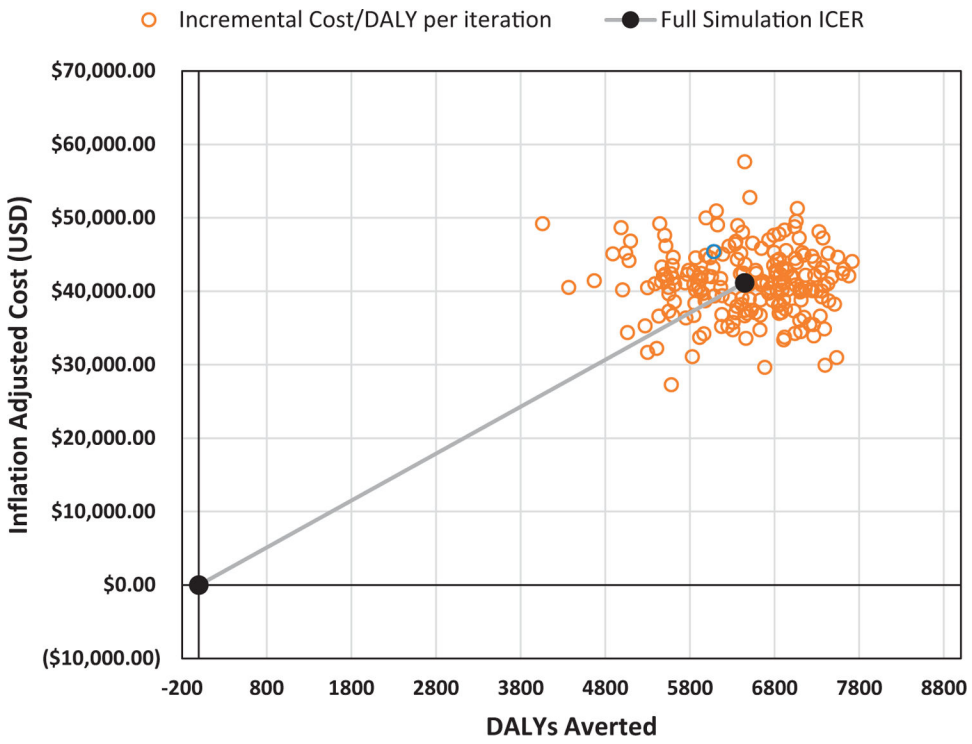

Fig. 3.

Cost-utility analysis: results of 200 Monte Carlo simulations with corresponding simulated incremental cost-effectiveness ratio (ICER).

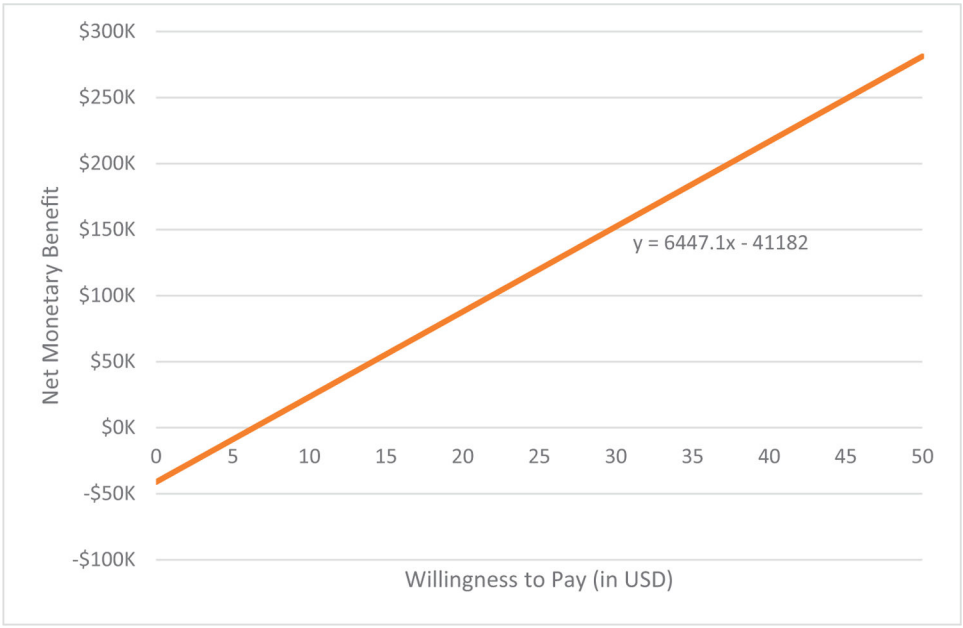

Fig. 4.

Net monetary benefit (NMB) of the pediatric OR for a range of willingness to pay thresholds.

Table 1

Patient demographics from the Uganda pediatric OR case log.

Number of patients	**N = 326**	
Mean age (years)	2.90	(3 days-16 years)
Sex		
Male	206	(67%)
Female	117	(36%)
Disease group		
Elective surgery	47	(14.4%)
Emergencies	28	(8.6%)
Emergent congenital	65	(19.9%)
Nonemergent congenital	152	(46.6%)
Neoplasia	34	(10.4%)
Outcome		
Discharged/Transferred	309	(94.8%)
Immediate death post-op	17	(5.2%)
Lifesaving procedures	123	(37.7%)
Disability averting procedures	186	(57.1%)

Table 2

One-way sensitivity analysis of plausible alternative scenarios.

Scenario (cost inflation, DALY time discount)	Incremental cost	Incremental DALYs averted	ICER	% of base case
Base case (cost 5.5%, DALYs 0%)	$41,182	6,447	$6.39	100%
No inflation (cost 0%, DALYs 0%)	$37,355	6,447	$5.79	91%
3% discounting (cost 5.5%, DALYs 3%)	$41,182	2,828	$14.56	228%
Age-weighting at 4% (cost 5.5%, DALYs 3%)	$41,182	3,545	$11.62	182%
Market value of costs (cost 5.5%, DALYs 3%)	$64,330	6,447	$9.98	156%
Market value of costs (cost 0%, DALYs 3%)	$59,925	6,447	$9.30	146%
Counterfactual meets 20% of need	$41,182	5,158	$7.98	125%