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CASE SERIES

Comparative cost–utility analysis of postoperative discharge pathways following posterior spinal fusion for scoliosis in non-ambulatory cerebral palsy patients

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Abstract

Purpose Accelerated postoperative discharge (AD) pathways have demonstrated numerous benefits for patients with adolescent idiopathic scoliosis undergoing PSF. Although early evidence supports the application of AD pathways over more traditional discharge (TD) approaches for patients with neuromuscular scoliosis, the economic impact of these pathways has not been investigated.

Methods A decision-analysis model was constructed using a hypothetical 15-year-old male with non-ambulatory CP with a 65-degree thoracolumbar scoliosis and pelvic obliquity undergoing operative treatment with PSF from T2-pelvis with pedicle screw fixation. The literature was reviewed to estimate costs, probabilities, and quality-adjusted life years (QALYs)) for identified complication profiles for discharge pathways. QALYs were constructed using age-matched values for US population average, applying a CP diagnosis corrective value. A probabilistic sensitivity analysis was performed using a second-order Monte Carlo simulations. Incremental cost–utility ratio and incremental net monetary benefit (NMB) were calculated. One-way sensitivity analyses were performed by selective variable variation.

Results AD pathway resulted in an average cost and effectiveness of $67,069 and 15.4 QALYs compared with $81,312 and 15.4 QALYs for TD. AD resulted in a 2.1% greater NMB with a cost-effectiveness ratio of $4361/QALY compared with $5290/QALY in the TD. The cost-effectiveness of TD was inversely sensitive to implant cost variation while the AD maintained effectiveness despite cost variations.

Conclusion This cost–utility analysis demonstrated that the implementation of an AD pathway following PSF for non-ambulatory CP scoliosis is economically more effective, providing a 17.5% cost reduction with enhanced value of care evidenced by a 2.1% greater NMB over a TD pathway. The cost-effectiveness of the AD was maintained despite implant cost variations.

Keywords Cerebral palsy · Neuromuscular scoliosis · Spinal fusion · Economic effectiveness · Cost-utility

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Introduction

Scoliosis has a known association with various neuromuscular disorders. Previous studies have demonstrated a high incidence of scoliosis with cerebral palsy (CP), with the development to scoliosis intimately related to the severity of the disease [1, 2]. Treatment for scoliosis in non-ambulatory CP patients has been a point of some contention, with advocates for both non-operative and surgical intervention.

A recent critical analysis review investigated the effect of both operative and non-operative treatment on quality of life measures and care-giver satisfaction for non-ambulatory CP scoliosis [3], finding improved patient outcomes and caregiver satisfaction with posterior spinal fusion (PSF). However, the cost-effectiveness of PSF is more difficult to quantitate. Lin et al. [4] performed a cost-effectiveness analysis of operative intervention for neuromuscular scoliosis reporting that the discounted life expectancy modestly decreased and quality-adjusted life years (QALY) increased for the operative treatment compared to the non-operative treatment.

More recently, the addition of an accelerated discharge (AD) pathway for children with severe CP-related scoliosis undergoing PSF has been reduced to reduce the hospital length of stay (LOS) with a trend toward lower post-operative complications [5]. Although these clinical outcomes have direct implications on treatment cost, no study to date has conducted a comparative economic evaluation of these different discharge pathways to enable physicians, patients, and payors to make more informed decisions in care. The objective of this study was to estimate the cost-effectiveness of a novel AD pathway after PSF in non-ambulatory CP in comparison to a traditional discharge pathway (TD), hypothesizing the AD pathway will be more cost-effective.

Materials and methods

Building upon a previously reported study design [6], we developed a decision-analysis model for a hypothetical 15-year-old male with an average life expectancy of 35 years [7] who has non-ambulatory cerebral palsy (CP) with a thoracolumbar scoliosis measuring 65 degrees and associated pelvic obliquity (Fig. 1). The hypothetical patient was assumed to present without any central neuromotor comorbid impairments, such as seizure disorders, presence of a tracheostomy or gastrostomy feeding tube. The decision-analysis model was built and analyzed using TreeAge Pro Healthcare 2020 (TreeAge Software, Williamstown, MA) and event rates/probabilities, costs, and health utility values

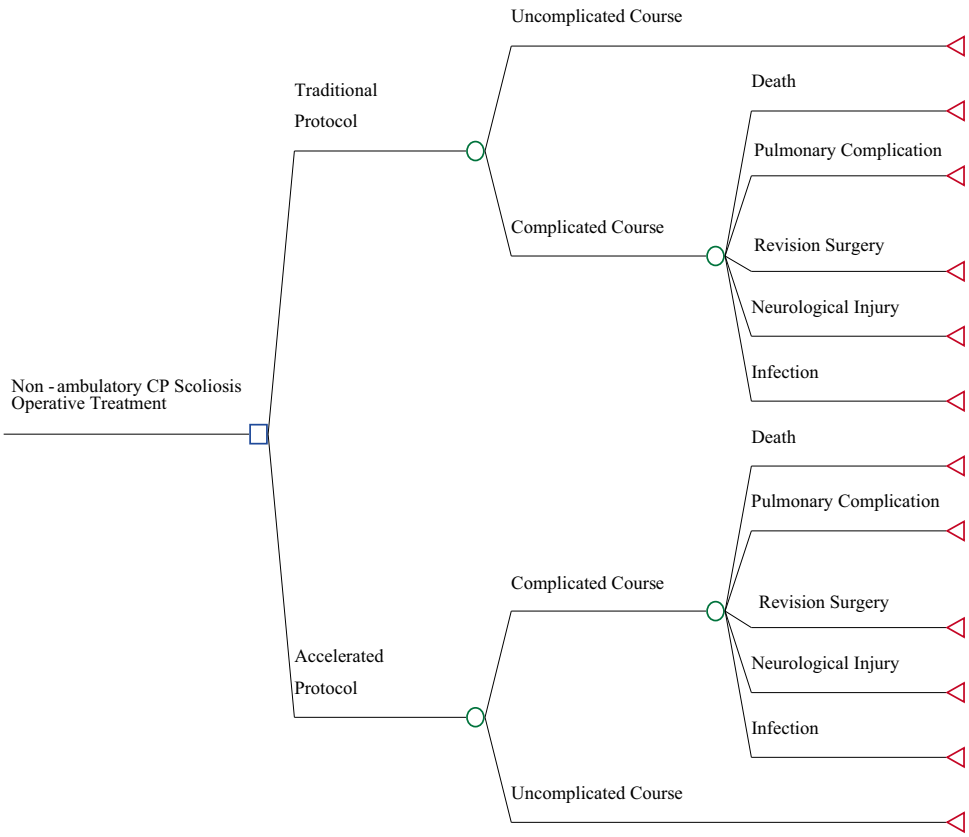

Fig. 1 Decision-tree model for comparison of traditional and accelerated operative pathway treatment of neuromuscular scoliosis (NM) in non-ambulatory cerebral palsy (CP) patients

at each decision-tree node (Fig. 1) were calculated from previously published peer-reviewed literature. Definitions of the economic terms can be found in Supplemental Data File 1. Institutional Review Board approval was not required for this study.

Probability estimates

Probability estimates were identified from the literature for the TD and AD pathways, indicating five major post-surgical complications following PSF: pulmonary complication, revision surgery, surgical infection, neurologic injury, and death [8] (Fig. 1). Mean values were obtained as well as reported minimum and maximum values to be included in the sensitivity analysis. Specifically, we assumed that for the TD pathway the probability of pulmonary complication at 20% with cost including both the cost of pneumonia treatment [9] and associated re-hospitalization costs [10]. Estimated probability for neurologic injury was 5% and associated cost was assumed to consist of catheter-associated cost given the patients underlying functional status [11]. Probability of surgical infection was estimated at 10% with an estimated cost of $109,052 (2019 dollars) [6]. Probability of revision surgery was estimated at 19% with an estimated cost of $136,315 [12]. The rate of death was estimated at 5% with associated costs assumed to only include the cost of surgical operation [8].

Probability estimates, including mean, minimal, and maximal values, for the AD pathway were identified from the literature for severe CP scoliosis [5]. Complication rates were aggregated and used for comparison to the TD pathway using the aforementioned defined complications with associated probabilities and costs (Table 1). Bellaire et al. [5] reported a 17% decrease (21% vs 38%) in pulmonary complications for children with severe CP undergoing PSF who were treated with an AD pathway in comparison to children treated with a TD pathway. Given the discrepancy between the cumulative mean pulmonary complication rate identified through literature review (20%) and the data reported by Bellaire et al. [5], we assumed a modest 5% decrease in the pulmonary complication rate in comparison to the TD pathway. We additionally assume a modest 5% decrease in the rate of revision surgery while maintaining the remaining variables unchanged given the lack of significant difference reported in the literature [5].

Economic variables

Using the 2014 life-expectancy data from the Social Security Administration, lifetime cost and quality-adjusted life-year (QALY) estimates were calculated [13]. Craig et al. [14] defined average QALY losses for children based upon underlying medical conditions, including CP. The QALY adjustment was applied to the calculated lifetime estimate to obtain a CP-corrected QALY. Cumulative QALYs were calculated by summing discounted health utility experienced each year from 15 to 35 years of age and were adjusted using the CP diagnosis corrective factor [14]. To create a conservative model, we assumed operative treatment would result in no gained QALY from baseline. QALY values for patients who developed pulmonary and neurologic complications, as well as infection and required revision surgery, were calculated to have a health utility using a previously utilized protocol [6] applied to the corrected CP baseline value. The QALY value for death was set at 0.

Table 1 Estimates of net probabilities, net real costs, and net QALYs for non-ambulatory children with cerebral palsy undergoing posterior spinal fusion

Event	Net probability (%)	Probability value range for sensitivity analysis (%)	Real net cost (2019 $)[†]	Net QALY
Traditional pathway				
Uncomplicated	41	41	74,724	16.5
Death	5	0–5	74,724	0
Pulmonary complication	20	14–40	37,102	15.9
Revision surgery	19	10–40	136,315	16.3
Neurologic injury	5	2–5	47,186	12.9
Infection	10	5–30	109,052	16.3
Accelerated pathway				
Uncomplicated	51	51	64,510	16.5
Death	5	0–5	64,510	0
Pulmonary complication	15	10–20	37,102	15.9
Revision surgery	14	10–25	136,315	16.3
Neurologic injury	5	2–5	47,186	12.9
Infection	10	5–30	109,052	16.3

[†]Net costs were adjusted to 2019 dollars using medical care consumer price index

All costs were adjusted for inflation into 2019 dollars using the medical care consumer price index (CPI) from the Bureau of Labor Statistics (BLS). Costs associated with surgical treatment were adapted from Kamerlink et al. [10] indicating an estimated pedicle screw cost at $631. The surgical construct included instrumentation from T2 to pelvis using an all-pedicle screws and a screw density of 2.0 for an estimated implant cost of $28,300. The hospital charges associated with operative treatment were estimated at $46,424 [10]. Based on discharge pathway data in AIS patients reported by Sanders et al. [15], we assumed a 22% decrease in hospital charges with implementation of the AD pathway, estimated at $36,210. For all nodes, indirect costs such as those incurred through loss of work were excluded [6].

Sensitivity analyses

Probabilistic sensitivity analysis (PSA) was performed using methodology described by Doubilet et al. [16] and Jain et al. [6] to account for potential variability in reported values for complication rates, QALYs, and costs. A mixed first-order and second-order Monte Carlo simulation was performed for 1000 trials (random walks) with simultaneous sampling from estimated probability distributions of the 35-model input parameters (Supplemental Data File 1) to obtain 1000 sets of model input estimates. For each trial's model inputs, event probabilities were sampled from the PERT distribution, which is based on the β distribution and provides samples on a continuous curve in any bounded range. For the Pert distribution parameters, we specified input parameter minimum, maximum, and likeliest values [17, 18] based on probability ranges reported in the literature, Table 1. Costs and QALYs were sampled from normal distributions where mean estimates were derived from the literature (Table 1) and the relative standard deviation was set at 10% [6].

Cost–utility ratios (CUR), net monetary benefits (NMB), corresponding incremental cost–utility ratio (ICUR), and incremental net monetary benefits (INMB) were estimated. One-way deterministic sensitivity analyses were performed by varying our 35-model input parameters. Following a previous study [6], net cost and probability estimates were varied by 50%. Net QALY estimates were varied from the 50th to 99th percentile, which were calculated from the normal distribution using mean QALY values (Table 1) and a relative standard deviation of 10%. Parameters that contributed to the greatest variability in ICUR were identified.

Results

Rollback analysis

The decision-analysis rollback algorithm calculated average weighted cost and effectiveness values at each node (Fig. 1) starting with the terminal nodes and "folded back" to the initial decision note. This generated the final cost and effectiveness estimates for each strategy reported in Table 2. Results show that the average cost and effectiveness for the AD were $67,069 and 15.4 QALYs, respectively, compared to the $81,312 and 15.4 QALYs for TD. Corresponding cost-effectiveness ratio for AD was $4361/QALY and $5290/QALY for the TD. The NMB was $701,728 with AD and $687,284 with TD.

Probabilistic sensitivity analysis

Probabilistic sensitivity analysis was conducted as a mixed first-order and second-order Monte Carlo simulation model with 1000 trials (random walks) and simultaneous sampling from estimated probability distributions of the 35-model input parameters. Estimated values and

Table 2 Cost-effectiveness results from rollback and probabilistic monte carlo simulation analyses of accelerated and traditional discharge pathway following posterior spinal fusion

Decision strategy	Cost ($)	Effectiveness (life years)	Net monetary benefit ($)	C/E ratio ($/life year)
Rollback				
Accelerated (AD)	67,069	15.38	701,728	4361
Traditional (TD)	81,312	15.37	687,284	5290
Probabilistic simulation				
Accelerated (AD)	69,411 (3001)	15.57 (0.90)	709,089 (45,125)	4458
Traditional (TD)	79,957 (4601)	15.58 (0.92)	699,095 (45,909)	5132

The decision-analysis rollback algorithm calculates average weighted cost and effectiveness values at each node starting with the terminal node and "folds back" to the initial decision note, thus, generating the final cost and effectiveness of each strategy. Probabilistic simulation is implemented as a mixed first-order and second-order Monte Carlo simulation model with 1000 trials (random walks) and simultaneous sampling from estimated probability distributions of the 35-model input parameters. Each trial represents the path of a hypothetical patient through the decision model. Standard deviations of simulation results are listed in parenthesis

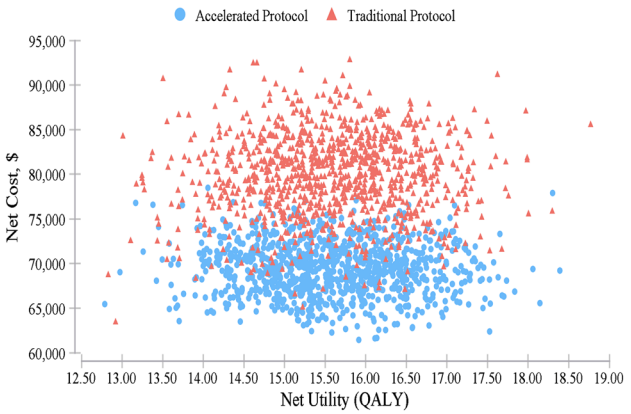

Fig. 2 Scatter plot of net cost versus net utility of simulated patients treated with AD ($n = 1000$) and TD ($n = 1000$) pathways

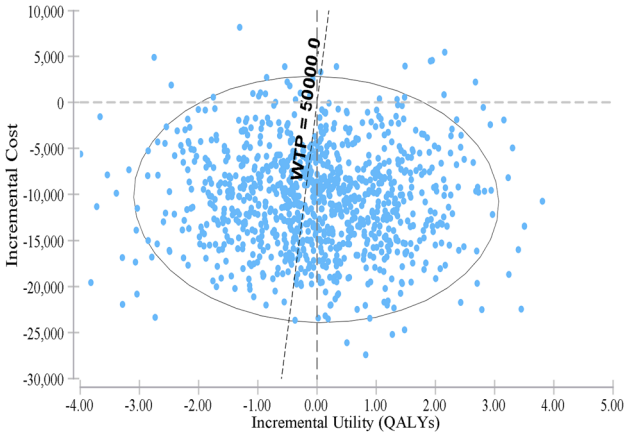

Fig. 3 Incremental cost versus incremental utility of Accelerated versus Traditional Discharge pathway for 1000 hypothetical patients. Ellipse represents 95% confidence interval

corresponding standard deviations are listed in Table 2. Results showed that the mean (± standard deviation) net cost was \$69,411 ± \$3001 with AD and \$79,957 ± 4601 with TD. Corresponding lifetime QALYs were 15.57 ± 0.90 with AD and 15.58 ± 0.92 with TD. Cost-effectiveness of AD was \$4458/QALY and \$5132/QALY for TD. The median difference in net costs was \$10,727 (95% CI \$10,387-\$11,068) and the median difference in net QALYs was 0.05 years (95% CI − 0.03 to 0.13). Simulated NMB was \$709,089 ± \$45,125 with AD and \$699,095 ± \$45,909 with TD. The mean NMB difference between and AD and TD was 2.1% or \$9995 (95% CI \$6005–\$13,984) and median NMB difference was \$8335 (95% CI \$4345–\$12,325).

Simulation results (Fig. 2) also indicate that the AD was mostly associated with lower costs and improved QALYs compared to the TD. AD was favored in 57.1% of simulations. Compared to the TD, AD yielded lower costs in 97% of simulations and higher QALY in 50.1% of simulations. AD was superior in 49% simulations, in which it yielded higher QALYs and lower costs than TD (Fig. 3).

Deterministic sensitivity analysis

One-way deterministic sensitivity analysis reported that the parameters having the largest influence on the ICUR were the net costs of uncomplicated AD and TD treatments and net costs of undergoing revision surgery with AD and TD, respectively (Fig. 4). Further, results showed that the NMB was mostly influenced by the QALY measures in both pathways as well we probability estimates for post-surgical complications and death with AD (Fig. 5). Finally, a parameter of specific interest is the cost of implants which is dependent upon the choice of the pedicle screw density. Results, reported in Fig. 6, illustrate that, compared to the AD, the average cost-effectiveness and NMB of the TD is more sensitive to the implant cost variations, indicating an inverse relationship of implant cost and value of care when using a TD pathway. In contrast, the AD pathway maintained its value despite fluctuations in cost as much as 50%.

Discussion

In this comparative cost–utility analysis of postoperative discharge pathways following PSF for neuromuscular scoliosis in a model non-ambulatory CP patient, the AD pathway was found to average cost and effectiveness of \$67,069 and 15.4 QALYs compared with \$81,312 and 15.4 QALYs for TD. AD resulted in a 17.5% cost reduction with a 2.1% greater NMB with a cost-effectiveness ratio of \$4361/QALY compared with \$5290/QALY in the TD. Additionally, probabilistic sensitivity analyses demonstrated that AD yielded lower costs in 97% of simulations and higher QALY in 50.1% of simulations.

Accelerated discharge pathways, also referred to as Enhanced Recovery After Surgery (ERAS) protocols, have seen tremendous expansion in orthopedic surgery [19]. In pediatric scoliosis surgery, the tenets of AD pathways include postoperative admission to the hospital floor with early transition to oral pain medication, Foley catheter removal, surgical drain removal, mobilization with physical therapy, and transition to oral diet [20]. Fletcher et al. [20] first reported on the application of an AD pathways for children undergoing PSF for adolescent idiopathic scoliosis (AIS), finding a one-third reduction in hospital LOS without a difference in post-operative complications. Subsequent AIS studies in multiple hospital centers further confirmed the ability to reduce LOS, upwards of 50% [21], with an associated 22% reduction in hospital costs [15].

Bellaire et al. [5] applied the AD pathway to children undergoing PSF for neuromuscular scoliosis with

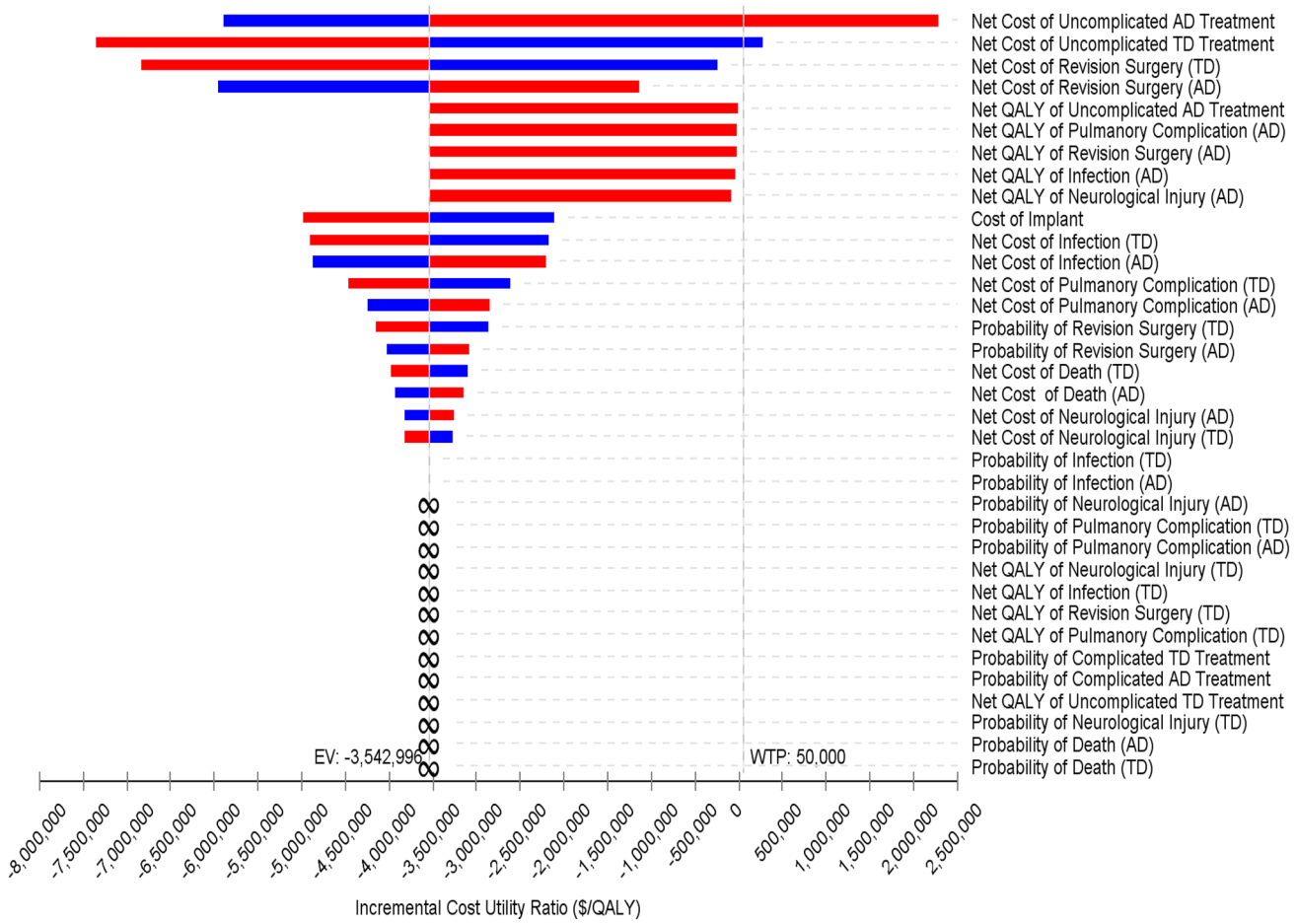

Fig. 4 Tornado diagram illustrating the relative importance of the model input parameters in variability in the ICUR. Blue bars represent decreasing parameter values and red bars represent increasing parameter values. The left vertical bar represents the median ICUR and the right vertical bar represents the $50,000/QALY societal WTP thresholds. Toward the middle of the tornado diagram, there is no bar for the parameters Probability of Infection, because changes to that parameter have no effect on the ICUR. A set of bottom parameters have an infinity sign rather than a bar. Within the uncertainty range for that parameter, the incremental effectiveness passes through zero, which makes the ICUR calculation undefined. Therefore, a bar would be invalid

non-ambulatory CP. In comparison to a historic control group, the AD pathway had a 19% reduction in hospital LOS. Although there was no difference in postoperative complication rates, children treated with AD pathway trended toward lower total complications and lower pulmonary complications. Applying the concept of the AD pathway to an economic model, the current study indicated that the AD pathway had a significant cost benefit and cost-effectiveness compared to the TD pathway after PSF for non-ambulatory CP scoliosis. This suggests that by minimizing the post-operative complication rates and enhancing patient recovery following surgery, the AD pathway not only provides a 17.5% cost savings in care but also an improvement in the value of care, evident in the improved NMB.

Determining the optimal treatment approach for non-ambulatory children with CP and progressive scoliosis, is a challenging clinical decision. A recent critical analysis review demonstrated moderate evidence to support improved patient outcomes and limited evidence to support improved caregiver satisfaction following PSF for non-ambulatory CP scoliosis [3]. Lin et al. [4] were the first to report on the economic outcomes of PSF compared with non-surgical treatment for neuromuscular scoliosis in CP. Using a Medicare database, the treatment costs for PSF were estimated at $75,400/patient and resulted in a favorable gain in QALY compared with non-surgical treatment with a cost of $50,100/QALY gained. However, Lin et al. [4] reported that the quality of life data for this patient population are limited and the true extent of its impact is not fully known. Additionally, there is a continuum of severity in children with non-ambulatory CP based upon the extent of central neuromotor involvement, including the need for tracheostomy and/or gastrostomy tube, and seizure disorders which have direct implications

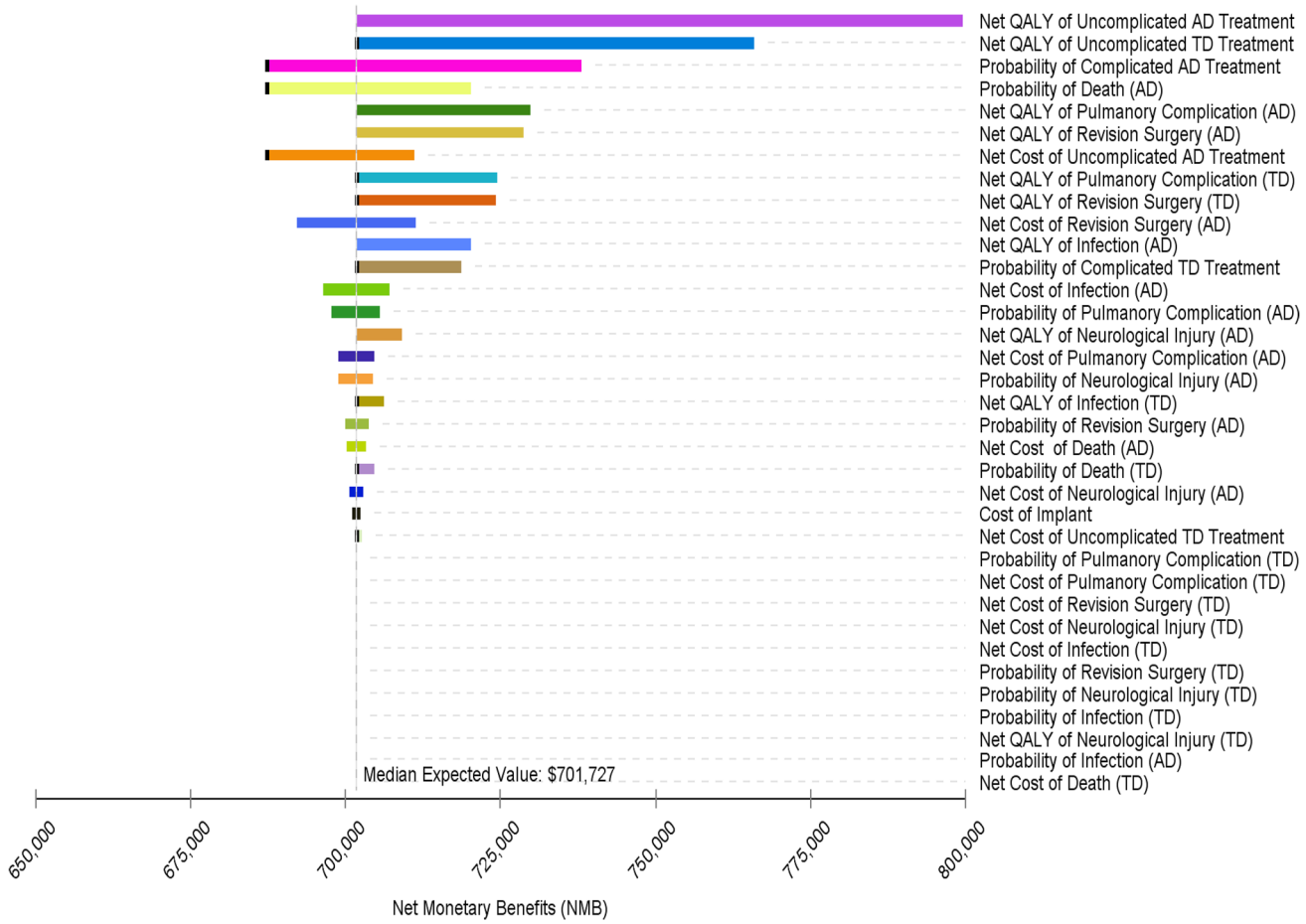

Fig. 5 Tornado diagram illustrating the relative importance of the model input parameters in variability in the Net Monetary Benefits. The vertical bar represents the median expect value of the NMB. All calculations are done for $50,000/QALY societal WTP. Toward the middle of the tornado diagram, there are no bars for a set of parameters, because changes to that parameter have no effect on the NMB

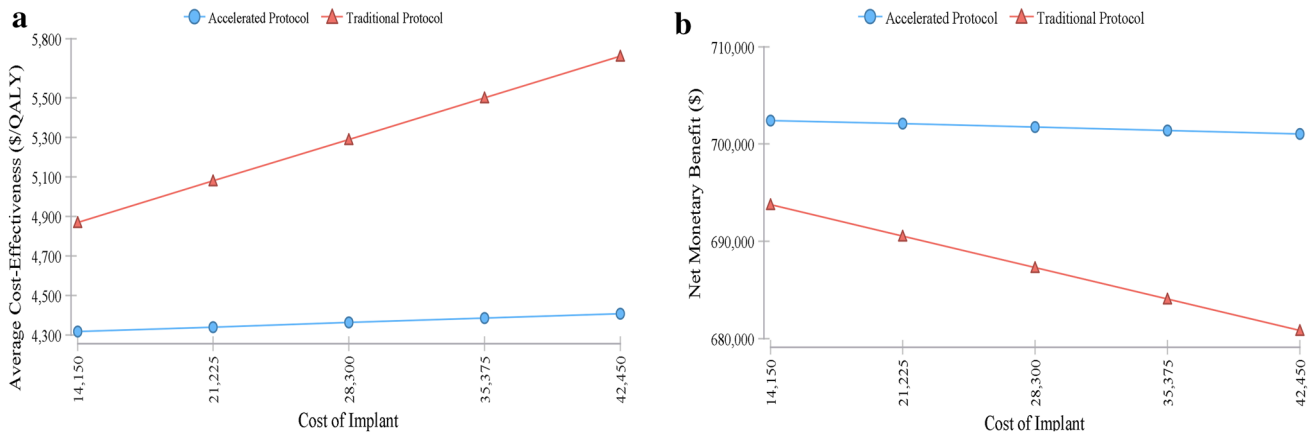

Fig. 6 Sensitivity of discharge pathway cost-effectiveness (**a**) and net monetary benefit (**b**) estimates to the implant costs

on quality of life and the risk of post-operative complications following PSF [2].

The incremental cost-effectiveness analysis identified that the most sensitive variable for the modeling was the underlying treatment costs. Previous studies have shown implant costs and inpatient hospital costs are the largest contributors to treatment cost in PSF [10]. LOS directly impacts inpatient room costs and neuromuscular surgery patients are known to have prolonged LOS compared with AIS patients [22, 23]. The AD pathway has a demonstrated record for decreasing LOS following PSF in AIS with early corroborating results in children with CP [5], suggesting its adaptation can not only decrease the treatment costs but can also enhance the cost-effectiveness of surgery compared with TD pathway ($4361/QALY versus $5290/QALY). Additionally, the Monte Carlo probabilistic simulation modeling found a 2.1% greater NMB with the use of the AD pathway.

The cost for PSF treated with the TD in the current study was reported at $74,724/patient, comparable to the $75,400/patient reported by Lin et al. [4]. This value includes the instrumentation costs, assuming surgery was performed from T2 to the pelvis using an all-pedicle screw construct with a screw density of 2.0. A screw density of 2.0 was selected for this analysis to obtain a maximal assessment of surgical costs. The sensitivity analysis identified that, in contrast to the AD pathway, the TD pathway was sensitive to changes in cost of surgical implants, indicating that implant cost fluctuations could significantly impact the cost-effectiveness of surgery. Although pedicle screw implants provide a powerful construct to address spinal deformity, they also result in significant cost increases in scoliosis surgery [24]. Previous AIS studies have shown mixed results for differences in clinical and radiographic outcomes between high- and low-density constructs [25, 26]. Although the influence of screw density has not been investigated in non-ambulatory CP scoliosis, lower-density constructs are associated with lower operative times, less blood loss, and lower cost [27] which could have a significant impact on the estimated cost-effectiveness of PSF.

This study cannot be viewed without recognition of its limitations. As an economic model built upon historical data and cost assessments instead of as-treated cumulative cost values, the current data may not be a true representation of the exact costs associated with treatment. The decision-tree analysis was built from the available literature. Although well described in AIS patients, the AD pathway is a novel approach following PSF in non-ambulatory CP populations reported in only one study [5] with short-term follow-up at the time of this publication and was compared with the collation of numerous articles reported over a 15-year period for the TD pathway. As such, this decision-tree may not provide a complete, long-term analysis of this pathway. The extent of this decision-tree analysis does not provide a complete representation of all potential post-operative complications. The additional complications of gastrointestinal, pressure sores, urinary retention, pancreatitis, seizures among others have been reported [28–30], however, the lack of corresponding QALY and cost values was not available to allow inclusion. This analysis, also, does not take into account the potential for associated central neuromotor impairments. As Jain et al. [2] indicate in their analysis of GMFCS 5 CP patients undergoing PSF, the presence and number of associated central neuromotor impairments significant influence the risk of complication development. As such, further research is needed to determine if the AD pathway is advisable for CP patients with greater central neuromotor impairment undergoing PSF.

Additionally, several cost assumptions were made by extrapolating trends identified in AIS patients and as such, may serve as an underestimation of surgical costs in non-ambulatory CP patients. However, these estimated treatment cost variables are comparable to data reported by Lin et al. [4] based upon a Medicare database. Indirect costs of treatment were also not included in this analysis due to a lack of reference data. Without accounting for these, the current results may under-represent the true costs associated with treatment. The QALY data in this patient population are difficult to fully ascertain and to best estimate these values, the use of corrective factor approach using the data by Craig et al. [14] was employed. However, these data were not specific to non-ambulatory CP and may not provide a true assessment of the net QALY associated with each identified parameter or the true treatment effects.

In conclusion, this study demonstrated that the incorporation of an accelerated discharge pathway following PSF for non-ambulatory CP scoliosis resulted in a 17.5% reduction in treatment costs. Although the cost reduction combined for a 2.1% greater NMB in the AD pathway, representing a modest improvement in comparison to a TD pathway, but one that does indicate an improvement in the value of care that is maintained despite fluctuations in surgical implant costs. Future research is needed to better investigate the as-treated treatment costs of postoperative pathways following PSF for non-ambulatory CP scoliosis.

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Authors' contribution KAS, VH: Study design, Data analysis, Data interpretation, Manuscript drafting, Manuscript approval; NF, JSM: Data interpretation, Manuscript editing, Manuscript approval.

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Declarations

Conflict of interest Dr. Shaw is a committee member for NASS and AAOS; Dr. Heboyan has nothing to disclose; Dr. Fletcher is a paid consultant for Medtronic, is a unpaid consultant for OrthoPediatrics, is a paid speaker for Nuvasive, Zimmer, Medtronic, and OrthoPediatrics, is a committee member for SRS and POSNA; Dr. Murphy is a consultant for Depuy and OrthoPediatrics, receives research support from OrthoPediatrics, and board member for Journal of Pediatric Orthopedics, POSNA, Spine Journal, Journal of Spine Deformity, and Scoliosis Research Society.

Ethical approval This study was determined to be exempt from review by the Institutional Review Board at Dwight D. Eisenhower Army Medical Center.

Informed consent The opinions or assertions contained herein are the private views of the authors and are not to be construed as official or reflecting the views of the Department of Defense or US Government. The authors are employees of the US government. This work was prepared as part of their official duties and, as such there is no copyright to be transferred.

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