Health Economics in Pediatric Orthopaedic Surgery

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Abstract: Healthcare expenditures in the United States continue to rise without corresponding improvements in outcomes. Because of this, there is increasing pressure on physicians to consider the economic impact of their medical decisions. Unfortunately, physicians in general are unfamiliar with interpreting and performing various health economic analyses. A basic understanding of health economics may help physicians understand and participate in key policy discussions which may shape the future of medicine and surgery.

In the field of pediatric orthopaedics specifically, the literature involving health economic evaluation is sparse. However, many interventions in this field are low cost with potential benefits that accrue over a child's long lifespan. Economic evaluation can help objectively quantify the impact of these interventions, as well as bolster responsible medical decision making.

The purpose of this review is to introduce commonly utilized healthcare economic tools including cost-benefit, cost-effectiveness, and cost-utility analyses. We focus on several key concepts including value, quality, time, cost, and discounting. To help illustrate these concepts, health economic literature relevant to pediatric orthopaedics is discussed. Finally, we highlight limitations inherent to health economic evaluations in general and those applicable to pediatric orthopaedics specifically. This discussion may help lay the groundwork for future studies and for further involvement in policy making.

Key Concepts:

- Healthcare economic evaluations like cost-benefit analysis (CBA), cost-effectiveness analysis (CEA), and cost-utility analysis (CUA) utilize concepts like value, quality, time, cost, and discounting.
- There are unique challenges when performing healthcare economic analyses in the pediatric orthopaedic literature.
- An adequate understanding of these concepts may help pediatric orthopaedists to understand and participate in key policy discussions that may shape the future of healthcare.

"All models are wrong, but some are useful." – George E. P. Box[1]

Introduction

Healthcare expenditures in the United States continue to rise disproportionately to those in other developed countries and do so without corresponding improvements in measured outcomes.[2-4] To curb this trend, approximately two-thirds of physician societies have begun to consider cost when developing clinical guidelines[5] and many industrialized nations are now considering cost-effectiveness when making insurance coverage recommendations.[6] Unfortunately, physicians as a whole have limited experience with the interpretation and analysis of health economic analyses.[7,8] Without a baseline understanding of the health economic literature,

how analyses are performed, and their advantages and limitations, physicians are ill-equipped to play an active role and participate in cost-driven policy discussions.[9]

This is particularly relevant in orthopaedic surgery where high procedural costs and questions regarding meaningful clinical benefit have resulted in attempts to reduce the frequency of certain orthopaedic procedures.[4,10] To increase economic evaluation and to engage policymakers on the value of orthopedic surgery, the American Academy of Orthopaedic Surgeons (AAOS) formed the AAOS Value Project Team in 2012.[4] Despite these efforts, there continues to be a dearth of economic analyses in the orthopaedic literature.[4,7,9]

Only a handful of health economic studies have been published in the field of pediatric orthopaedics in the United States,[11–15] and no detailed reports exist in our literature for executing the methodology to perform such studies. Here we seek to introduce commonly utilized healthcare economic tools including cost-benefit analysis (CBA), cost-effectiveness analysis (CEA), and cost-utility analysis (CUA), with a focus on several key concepts including value, quality, time, cost, and discounting. In addition to helping understand already published economic studies, this paper may help lay the groundwork for future studies that could guide policy making. At the minimum, these concepts allow one to understand and communicate effectively with policy makers who usually don't work in the patient and provider relationship.

Value

The concept of *value* in healthcare is simple, but contains complex undertones.[16] In his seminal paper, Porter defined value as "the health outcomes achieved per dollar spent."[16] Although seemingly simple, value takes into account an individual's needs, wishes, and preferences, and changes depending on historical and societal contexts, and it varies from the perspective of the patient, provider, employer, and economist.[17] With the advent of Evidence-Based Medicine, a foundation was laid for Value-Based Medicine (VBM), which factors in the quality of life perceived by a patient after an intervention.[18] According to Brown et al. who first introduced the concept of VBM, value can be thought of as the quality obtained for the cost expended.[18, 19]

$$Value = \frac{Quality}{Cost}$$

Health Economic Analyses

When determining value, several types of health economic studies can be used: cost-benefit analysis (CBA), cost-effectiveness analysis (CEA), and cost-utility analysis (CUA). These studies differ based on how they quantify quality. In a CBA, both cost and quality are assigned monetary values.[8] For example, Tjoumakaris et al. performed a CBA using revenue and overhead to determine the profitability of orthopaedic coverage of local high school football games. Ultimately they determined that team coverage is potentially profitable, resulting in an hourly wage of $116.24 in their study.[12] While widely utilized in other fields, CBA is rare in healthcare economics because it quantifies costs and quality (and therefore value) in terms of money, which some have argued may be ethically objectionable.[20]

CEAs avoid this issue by using "natural units" to assess quality.[8] Natural units can be thought of as disease-specific metrics like pain scores, infection rates, death rates, patient reported outcome measures, and any other measure of treatment effectiveness.[7,8] Stated in terms of the value equation:

$$Value_{CEA} = \frac{Quality}{Costs} = \frac{Disease - Specific\ Outcome}{Costs}$$

Limitations of CEAs include a lack of generalizability across different disease states and procedures. For example, if the number of dislocations prevented after a total hip arthroplasty is a disease-specific measure used in a CEA to assess THAs, the results cannot be compared to an analysis of carpal tunnel release.

Disease-specific measures will be discussed in detail later in this article. The use of CEAs also rely on high-quality studies with good outcome reporting; given that only 3-6% of orthopedic studies are randomized controlled trials, this limitation is particularly important in the field of orthopedics.[7,8]

Cost utility analyses (CUA) differ from CEAs in that quality is expressed in terms of *utility* which, in general terms, is a preference-based assessment of various health states.[7,8] Utility is a *general measure of health* which can be applied to patients of different disease states and after different procedures. Hence, this allows one to compare the results of an intervention in one field to another and thus CUAs are the most popular in medicine and will be our focus in this paper.

$$Value_{CuA} = \frac{Quality}{Costs} = \frac{Utility}{Costs}$$

Quality and Utility

Quality in CUAs is assessed using the metric of utility which is derived from economic and decision theory and is a measure of general health.[21] General health is scored on a numeric scale from 0 to 1, with 0 defined as death and 1 defined as perfect health. Three methods are commonly used in healthcare literature to *directly* determine utility: the standard gamble method, the time trade-off method and the visual analog/feeling thermometer.[22-24]

Standard Gamble Method
With this method a patient must decide whether to 1) remain in the current state of health, or to gamble on an intervention with an assigned probability (*p*) for either perfect health (*p*) or death (*1-p*). For example, a standard gamble score of 0.7 signifies that a patient would accept a 30% chance of immediate death for a state of perfect health. Thus, the probability of death or perfect health are tipped on a scale from 1 to 0 until the patient becomes indifferent to the ultimate choice. The apathy) is defined as the utility weight of one's medical condition or life as a whole.

Time Trade-Off Method
The time trade-off method values utility by quantifying the hypothetical amount of life a person is willing to sacrifice to obtain their ideal state of health. For example, a time trade-off score of 0.4 signifies that a patient would sacrifice 60% of their remaining life for a state of perfect health. These scores have been utilized within orthopedics in areas such as adult reconstruction, but as one may imagine, this method would be inappropriate for the pediatric patient.[25]

Visual Analog Scale/Feeling Thermometer
In young patients for whom the mental exercise of standard gamble and time tradeoff are too abstract, the visual analog scale/feeling thermometer is utilized.[24,26-29] This involves providing a description of a given health state in plain language, and asking subjects to numerically rank their preference for each state from a scale of 0 to 100 (i.e., the feeling thermometer), with 100 being perfect health and 0 being equivalent to the worst health imaginable. Utilities obtained from the feeling thermometer are then converted to a score from 0 to 1 by dividing by 100 to convert utilities into the standardized format. While these are common ways to *directly* measure utility, it is more practical to *indirectly* ascertain utility from validated assessments of health quality (e.g., questionnaires).

Outcome Measures and Process Measures
In general, most measures of health quality are grouped into two main categories: outcome measures and process measures (Table I). *Outcome measures* can be further subcategorized into general or disease-specific measures. Of note, utility is an outcome measure which is general, whereas disease-specific measures are the type of outcome measures used in CEAs.

Disease-specific outcome measures focus on interventions related to a particular disease, area of the body, or injury pattern.[30] These include the Muscular Dystrophy Spine Questionnaire for Duchene's Muscular Dystrophy and the Caregiver's Priorities and Child

Table I: Health Quality Measures

Measure	Sub-measure	Examples	Applicable in Cost-Utility Analysis?
Outcome Measures	Disease-Specific	Muscular Dystrophy Spine Questionnaire	Less Applicable
	General	Child Health Questionnaire	Most Applicable
Process Measures	N/A	Mortality, Complications	No

Health Index of Life with Disabilities (CPCHILD) Questionnaire for cerebral palsy, which are valid and reliable for their respective diagnoses.[30-32] Disease-specific outcome measures are advantageous in detecting health changes in specific conditions. However, they may not reflect the patient's *overall* health status or quality of life, and thus may be less relevant to the holistic picture of the patient. They are difficult to generalize, cannot be used to make comparisons to other studies, and cannot be converted to utility for use in CUAs.

General outcome measures, on the other hand, are used to assess a patient's overall health. Although some literature suggests that general outcome measures may not be as sensitive to changes in health for specific disease processes as disease specific measures, other literature suggests they capture quality measures in a similar fashion.[33] General outcome measures are preferred over disease-specific measures as they allow for the calculation of utility for CUAs.

Assessing the quality of an outcome measure is a difficult task and often involves nuanced statistics and unfamiliar terminology. Veihweger et al. propose an eleven-step guide to evaluating the quality of an outcome, citing critical analysis of the target domain, sample size, and appropriate measurement tools, amongst others.[34] These authors report that in various fields of pediatric orthopaedics, such as clubfoot and spine deformities; studies have not broadly evaluated pediatric outcome measures. However, there are some general outcome measures in pediatric orthopaedics, including the Child Health Questionnaire (CHQ) and the Pediatric Orthopaedic Data Collection Instrument (PODCI).[34,35]

The other common measure of health quality, *process measures*, encompass objective variables including surgical complications, hospital length of stay, surgical site infections, and mortality associated with an episode of care. The strength of process measures is the concrete and understandable nature of the data. However, their role in assessment of quality remains unclear as they do not incorporate patient-centered metrics, which are preferred for evaluating outcomes in surgical patients.[36]

In a systematic review, Kennedy et al. found that mortality and postoperative complications were the most commonly reported quality indicators after pediatric orthopedic surgery.[37] While process measures may be employed in CEAs, there is no feasible way to convert them to QALY or utility, precluding their use in CUAs.

In summary, (1) general outcomes are preferred over disease specific outcomes measures and process measures. (2) General outcomes measures should convert to utility for use in the value equation for CUAs. As found by Kennedy et al., this may not currently be the case.[37] A shift in the paradigm of value-based

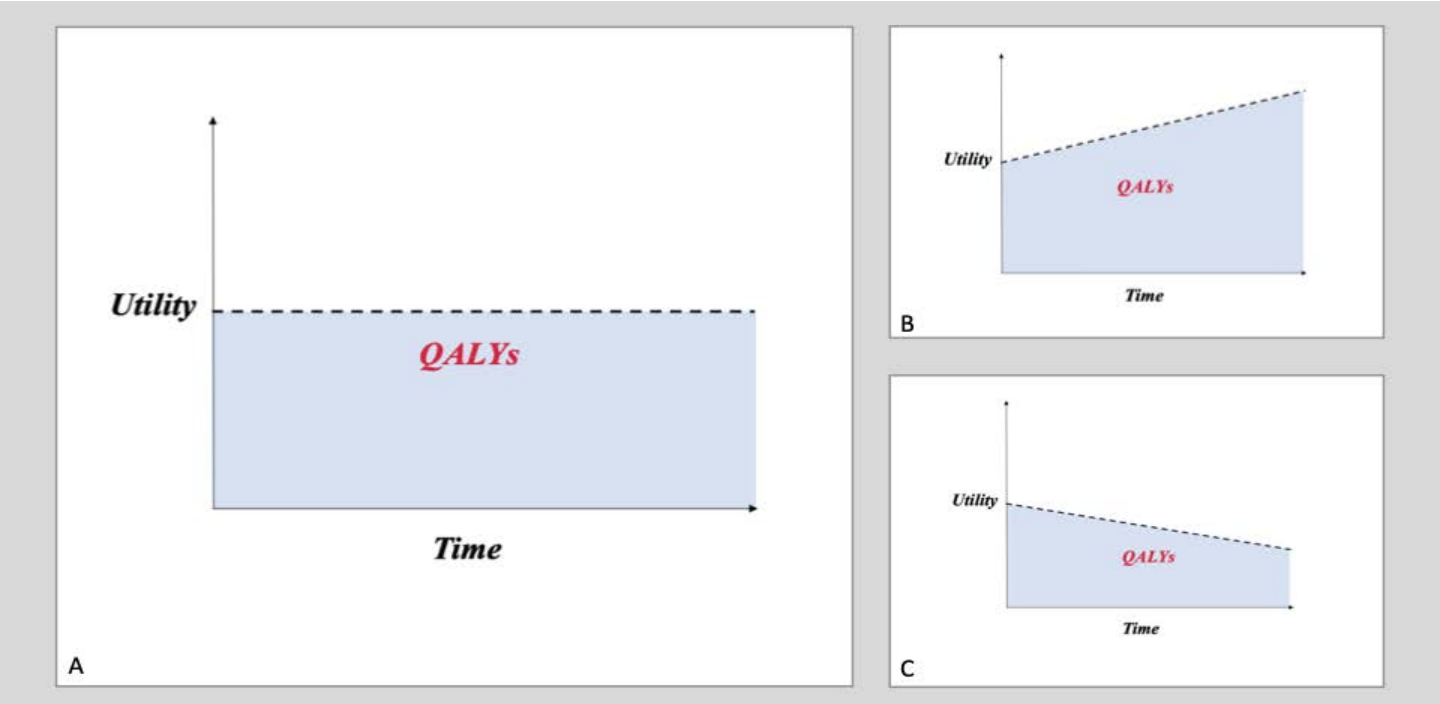

Figure 1. *Graphical representation of the relationship of time, utility and quality-adjusted life years (QALYs). The area under the curve is equal to QALYs. A) When utility remains constant over time, QALYs increase over time. B) When utility increases over time, QALYs increase over time. C) When utility decreases over time, QALYs decrease over time.*

research is essential to ensure pediatric orthopedic researchers are reporting the appropriate outcome measures in cost and value-related studies.

Time

Utility accrued over time is expressed as QALYs. In equation form:

$$Value_{CUA} = \frac{Value}{Costs} = \frac{Utility * Time}{Cost} = \frac{QALY}{Cost}$$

In graphical form, time lies on the X-axis and utility on the Y-axis, with QALYs being equal to the area under the curve.[38] (Figure 1)

Therefore, one can imagine that if a certain utility is derived from an intervention, and if that utility remains constant over time, then the area under the curve (or QALY) would increase over time (Figure 1A). In a scenario in which utility remains constant, the intervention is presumably successful thus minimizing or negating the need for future interventions, and thus maintaining or minimizing the future cost. Plugging cost, utility, and time into the value equation, we see that value can increase over time. A similar outcome is seen when utility increases over time (Figure 1B). On the other hand, if the utility of an intervention decreases over time, the area under the aforementioned curve would increase at a slower rate, and the value would decrease over time (Figure 1C). This highlights the importance of follow-up duration reported in health economic literature, as the value in the short-term after an intervention might not be an accurate representation of the long-term value.

When considering economic evaluation of pediatric interventions, the importance of time cannot be overemphasized. Compared to adults, children have a

longer lifespan during which the benefits of an intervention can accrue.[4] Furthermore, interventions like clubfoot casting, closed reduction and casting of fractures, and Pavlik harness use for hip dysplasia are low cost and high utility, and therefore may have a high value.[4] While this makes theoretical sense, it has not been confirmed in existing orthopaedic literature. There remains a dearth of CUAs and other health economic studies examining pediatric orthopedic interventions, and pediatric interventions in general. Jain et al. examined the management of adolescent idiopathic scoliosis and concluded that operative treatment was economically favorable; however, the findings were based on many assumptions over their analytical model's 69-year lifespan.[13] They noted that estimating QALYs in children is fraught with difficulties, including separating the success of an intervention from the natural resolution of a condition with aging. They also noted issues with combining pediatric and adult QALYs for the aging child who will become an adult, given the lack of validation of adult quality measures in children.[13]

Costs & Discounting

From an economic perspective, a cost is any use of a resource, whether it be a material or a service.[8] All costs should be represented using the same units like currency. Costs can be considered *direct* (e.g., medications, devices, and surgical fees) or *indirect* (e.g., facility costs, lost productivity, and wages).[8] Of note, direct costs are not the same as *charges*, which include markups and can deviate substantially from the true cost of a material or service.[7] Hospital charges can be used to back-calculate costs using cost-to-charge ratios; however, this method is historically inaccurate as it relies on population-level data, rather than direct measurement of patient-level costs.[15] Unfortunately, true costs are often not readily disclosed by hospitals and vendors. Even when they are, the cost of a product or service can vary substantially between institutions.[39] Despite these difficulties, direct costs are often obtained from reimbursement data, published literature, and estimates. This of course is problematic; Okike et al. showed that orthopedists correctly approximated the cost of orthopaedic implants only 17-21% of the time.[40] Methods to consolidate cost information have been proposed, like the time-driven activity-based costing (TDABC) method, which involves making process maps accounting for the cost of all resources used across a complete cycle of care for a certain condition over time. While accurate, this method is intensive and requires a lot of time and resources to perform.[41]

Estimating direct costs is similar for adult and pediatric populations. However, that is not the case for indirect costs, which are often more difficult to estimate in pediatric populations. In adults, one common method for determining indirect costs is the Human Capital Approach, which essentially sums the amount of lost income while out of work.[42] For obvious reasons, this is not applicable to a non-employed child. Instead, one must take into account the indirect losses stemming from the child's caregiver; for example, a parent missing work while their child is out of school.[43] This becomes more complicated for prolonged illnesses—when the child grows old enough to enter the workforce, but is unable to do so secondary to their illness. How does one accurately calculate indirect losses not knowing which profession the child will go into?

These issues highlight the complexity and limitations of cost evaluation in the pediatric population. One potential solution is to focus solely on one indirect cost over a short time period. For example, Carabin et al. determined the indirect cost of common daycare-acquired infections in toddlers; they focused solely on the cost of finding a caregiver for the child over a 6-month window.[44] While this strategy simplifies the model mathematics, it may not be appropriate for illnesses and interventions with longer natural histories.

With longer follow-up times, costs and health effects will diminish over time.[8,18,45] This is based on the idea that people value current costs and benefits more than

future costs and benefits. Another way to rationalize this principle is through a simple monetary example—$100 today can be worth $102 next year if invested in a riskless government bond with 2% interest accrual, whereas $100 next year is only worth $100.[45] Similarly, health today is valued more than future health; the resultant productivity may increase income or other commodities over time.[18] Health economic evaluations adjust for these value changes over time by *discounting* both costs and health effects.[8,18,45] Discounting usually falls between 0-5% per annum based on national guidelines, with Canada discounting at 1.5% annually, U.S., Italy and Germany at 3%, and Australia at 5%. [45,46] Of note, Belgium, Poland, Russia, and the Netherlands discount costs and health effects at different rates, but this is less common and often fraught with methodological issues.[14] In the UK, the National Institute of Health Care Excellence (NICE) set discount rates at 3.5% in 2004.[45] In 2011, NICE released an amendment allowing for differential discounting at 3.5% for costs and 1.5% for health effects in cases where substantial treatment effects would last over 30 years.[14] In the case of mifamurtide, a drug used to treat pediatric osteosarcoma, the transition to differential discounting brought the incremental cost effectiveness ratio down from £57000/QALY to £36000/QALY, demonstrating the impact that discounting has on pediatric economic evaluations.[14] Discounting remains a controversial topic, with analysts continuing to debate discount rates, equal versus differential discounting, and whether discount rates should decline or remain constant over time.[45]

Cost-Effectiveness

Once the QALY/costs has been determined from the value equation in a CUA, the inverse can be taken to derive the final unit: costs/QALY.

$$Value_{CUA} = \frac{Value}{Costs} = \frac{Utility * Time}{Cost} = \frac{QALY}{Cost}$$

$$\frac{1}{\frac{QALY}{Cost}} = \frac{Costs}{QALY}$$

Taking the inverse makes the unit more intuitive in that one is now asking how much an intervention costs to gain a single QALY. The additional cost per extra unit of effect is termed the Incremental Cost Effectiveness Ratio (ICER).[47] This is usually compared to a societal willingness-to-pay threshold which is a monetary value assigned to a person's willingness to pay for a reduction in risk.[7] In the United States, this number has historically been between $50,000-$100,000 per QALY, with most authors using $50,000/QALY as a threshold for cost effectiveness.[48] For example, Jain et al. performed a CUA looking at the cost-utility of operative versus nonoperative treatment of Adolescent Idiopathic Scoliosis (AIS) and found an incremental cost utility ratio of $20,600/QALY below the societal willingness-to-pay threshold of $50,000/QALY.[13]

Besides calculating a cost/QALY below the willingness-to-pay threshold, another way to utilize health economic data to make a cost-effective decision is through a decision-analysis model.[7] This is a way to organize probabilities of events and their outcomes to assess potential impacts of a clinical decision.[8] In general, this is done by estimating the probability of a change in the patient's health following an intervention, with this process repeated for multiple possible outcomes. This can be done using a decision tree, which flows unidirectionally, beginning with the decision of whether to implement the intervention (Figure 2). From there, the tree branches to include multiple subsequent outcomes with various treatment strategies, all associated with probabilities that are estimated from clinical, epidemiological, patient-centered, and economic data.[8] Because these trees can become overly complex, they are best used for shorter time frames without recurrent health events. For longer time frames, and to model a disease in which the patient flows bidirectionally between health states, a Markov model may be utilized.[49] In this model, patients are considered to be in discrete health states, and events are represented as transitions between health states. Similar to decision trees, probabilities and economic data can be applied. Unlike

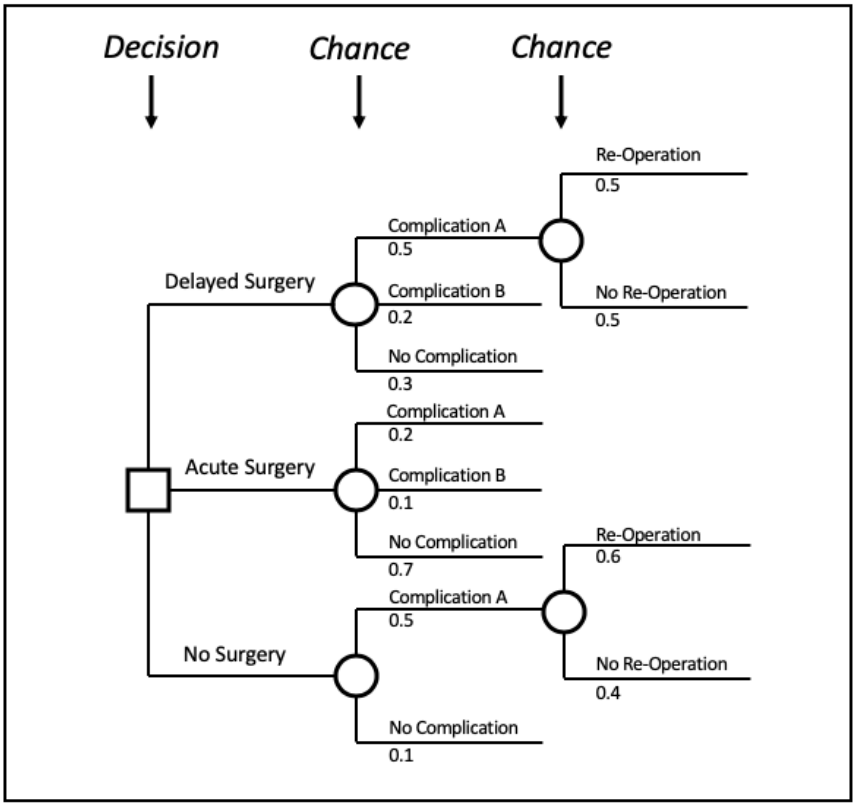

Figure 2. *Hypothetical example of a decision tree used in clinical decision analysis (incomplete for simplicity). Square nodes represent decision points. Circular nodes represent outcomes dictated by chance. For example, if delayed surgery is chosen, one can follow the decision tree to determine the probability of Complication A and subsequent Re-Operation.*

decision trees, Markov models are usually evaluated by matrix algebra, allowing for more complex calculations and decision modeling.[49] Despite this advantage, simple decision trees are frequently favored for a limited number of health state possibilities. Although they model only a finite number of health state transitions, when those health state transitions represent the large majority of real-world clinical situations, the accuracy gained by Markov modeling is unlikely to change the conclusions on whether an intervention is cost-effective. Adding more granular and time-varying outcomes may detract from a functional and coherent decision tree model that is applicable to the majority of patients undergoing treatment for a given condition. Therefore, the small proportion of patients who might experience these rarer outcomes would be unlikely to shift the model results.[50]

Conclusion

The orthopaedic community is working hard to understand and minimize surgical costs, yet there remains a paucity of health economic analyses in the realm of pediatric orthopedic surgery. In particular, we lack comprehensive data that demonstrates the personal and societal benefits that are provided via contemporary treatment of pediatric orthopaedic conditions. Patient-centered outcome measures are an essential metric for determining value and should be the focus of value-related pediatric orthopaedic surgery research, yet orthopedic studies in children commonly focus on process measures such as mortality. When compared to analysis of treatment in adults, economic analyses in children differ in significant ways. Children have longer life expectancies; thus, value may accrue more profoundly over time. Outcome measures in adults often are not validated in children. Cost measurements are more challenging and less tangible in the pediatric population who do not work yet have many years of future earning potential.

In summary, clinicians and researchers are in the nascent stages of understanding value in pediatric orthopedic surgery, and work is needed to overcome shortcomings in current economic analyses when studying the pediatric population. Increasing our understanding and participation in health economic evaluation may allow pediatric orthopedic surgeons to partake in policy discussions that will shape the field going forward. As Professor Box taught, although all models are wrong, some are useful. Knowing how to create a useful model allows us to take charge of the narrative around cost and value in pediatric orthopaedics.

Additonal Links

https://www.aaos.org/aaosnow/2020/jan/research/research03/

https://www.aaos.org/aaosnow/2014/oct/research/research3/

References

1. Box GEP. Science and Statistics. *J Am Stat Assoc*. 1976;71(356):791-799.

2. Papanicolas I, Woskie LR, Jha AK. Health Care Spending in the United States and Other High-Income Countries. *JAMA*. 2018;319(10):1024-1039.

3. Bozic KJ, Rosenberg AG, Huckman RS, Herndon JH. Economic evaluation in orthopaedics. *J Bone Joint Surg Am*. 2003;85(1):129-142.

4. Kocher MS. Value of Pediatric Orthopaedic Surgery. *J Pediatr Orthop*. 2015;35(5 Suppl 1):S9-S13.

5. Schwartz JAT, Pearson SD. Cost consideration in the clinical guidance documents of physician specialty societies in the United States. *JAMA Intern Med*. 2013;173(12):1091-1097.

6. Weinstein MC, Skinner JA. Comparative effectiveness and health care spending--implications for reform. *N Engl J Med*. 2010;362(5):460-465.

7. Vavken P, Bianchi T. In Brief: cost-effectiveness analyses in orthopaedics. *Clin Orthop Relat Res*. 2011;469(8):2395-2398.

8. Angevine PD, Berven S. Health economic studies: an introduction to cost-benefit, cost-effectiveness, and cost-utility analyses. *Spine*. 2014;39(22 Suppl 1):S9-S15.

9. Jain V. Time to take health economics seriously-medical education in the United Kingdom. *Perspect Med Educ*. 2016;5(1):45-47.

10. Wennberg JE. Practice variation: implications for our health care system. *Manag Care*. 2004;13(9 Suppl):3-7.

11. Swart E, Redler L, Fabricant PD, Mandelbaum BR, Ahmad CS, Wang YC. Prevention and screening programs for anterior cruciate ligament injuries in young athletes: a cost-effectiveness analysis. *J Bone Joint Surg Am*. 2014;96(9):705-711.

12. Tjoumakaris FP, Eck B, Freedman KB, Pepe MD, Austin L, Tucker BS. Cost Benefit Analysis of Sports Medicine Team Coverage: Is It Worth Our While? *Orthopaedic Journal of Sports Medicine*. 2013;1(4 Suppl). doi:10.1177/2325967113S00113

13. Jain A, Marks MC, Kelly MP, et al. Cost-Utility Analysis of Operative Versus Nonoperative Treatment of Thoracic Adolescent Idiopathic Scoliosis. *Spine*. 2019;44(5):309-317.

14. O'Mahony JF, Paulden M. NICE's Selective Application of Differential Discounting: Ambiguous, Inconsistent, and Unjustified. *Value Health*. 2014;17(5):493-496.

15. Fabricant PD, Seeley MA, Rozell JC, et al. Cost Savings From Utilization of an Ambulatory Surgery Center for Orthopaedic Day Surgery. *J Am Acad Orthop Surg*. 2016;24(12):865-871.

16. Porter ME. What is value in health care? *N Engl J Med*. 2010;363(26):2477-2481.

17. Marzorati C, Pravettoni G. Value as the key concept in the health care system: how it has influenced medical practice and clinical decision-making processes. *J Multidiscip Healthc*. 2017;10:101-106.

18. Brown GC, Brown MM, Sharma S. Value-based medicine: evidence-based medicine and beyond. *Ocul Immunol Inflamm*. 2003;11(3):157-170.

19. Wegner SE. Measuring Value in Health Care: The Times, They Are A Changin'. *N C Med J*. 2016;77(4):276-278.

20. Mooney GH. Cost-benefit analysis and medical ethics. *J Med Ethics*. 1980;6(4):177-179.

21. Morimoto T, Fukui T. Utilities measured by rating scale, time trade-off, and standard gamble: review and reference for health care professionals. *J Epidemiol*. 2002;12(2):160-178.

22. van Stel HF, Buskens E. Comparison of the SF-6D and the EQ-5D in patients with coronary heart disease. *Health Qual Life Outcomes*. 2006;4:20.

23. Ryder HF, McDonough C, Tosteson ANA, Lurie JD. Decision Analysis and Cost-effectiveness Analysis. *Semin Spine Surg*. 2009;21(4):216-222.

24. Parkin D, Devlin N. Is there a case for using visual analogue scale valuations in cost-utility analysis? *Health Econ*. 2006;15(7):653-664.

25. Calkins TE, Darrith B, Okroj KT, Drabchuk R, Culvern C, Della Valle CJ. Utilizing the Time Trade-Off, Standard Gamble, and Willingness to Pay Utility Measures to Evaluate Health-Related Quality of Life Prior to Knee or Hip Arthroplasty. *J Arthroplasty*. 2019;34(1):9-14.

26. Juniper EF, Guyatt GH, Feeny DH, Griffith LE, Ferrie PJ. Minimum skills required by children to complete health-related quality of life instruments for asthma: comparison of measurement properties. *Eur Respir J*. 1997;10(10):2285-2294.

27. Schünemann HJ, Griffith L, Stubbing D, Goldstein R, Guyatt GH. A clinical trial to evaluate the measurement properties of 2 direct preference instruments administered with and without hypothetical marker states. *Med Decis Making*. 2003;23(2):140-149.

28. Teitelbaum JE, Rajaraman RR, Jaeger J, Para S, Rakitt T. Correlation of health-related quality of life in children with inflammatory bowel disease, their parents, and physician as measured by a visual analog scale. *J Pediatr Gastroenterol Nutr*. 2013;57(5):594-597.

29. Adjei J, Nwachukwu BU, Zhang Y, et al. Health State Utilities in Children and Adolescents With Osteochondritis Dissecans of the Knee. *Orthop J Sports Med*. 2019;7(12):2325967119886591.

30. Bowen RE, Abel MF, Arlet V, et al. Outcome assessment in neuromuscular spinal deformity. *J Pediatr Orthop*. 2012;32(8):792-798.

31. Narayanan UG, Fehlings DL, Campbell K, Weir S, Knights S, Kiran S. Caregiver priorities & child health index of life with disabilities (CPCHILD): development & validation of an outcome measure of health status and well being in children with severe cerebral palsy. *Orthopaedic Proceedings*. February 2018. https://online.boneandjoint.org.uk/doi/10.1302/0301-620X.90BSUPP_I.0880117. Accessed April 28, 2020.

32. Wright JG, Smith PL, Owen JL, Fehlings D. Assessing functional outcomes of children with muscular dystrophy and scoliosis: the Muscular Dystrophy Spine Questionnaire. *J Pediatr Orthop*. 2008;28(8):840-845.

33. Patrick DL, Deyo RA, Atlas SJ, Singer DE, Chapin A, Keller RB. Assessing health-related quality of life in patients with sciatica. *Spine*. 1995;20(17):1899-1908; discussion 1909.

34. Viehweger E, Jouve J-L, Simeoni M-C. Outcome evaluation in pediatric orthopedics. *Orthop Traumatol Surg Res*. 2014;100(1 Suppl):S113-S123.

35. Matsumoto H, Vitale MG, Hyman JE, Roye DP Jr. Can parents rate their children's quality of life? Perspectives on pediatric orthopedic outcomes. *J Pediatr Orthop B*. 2011;20(3):184-190.

36. Murray AC. Value-based surgical care: a view from the surgeon's knife. *Br J Hosp Med*. 2018;79(6):316-321.

37. Kennedy A, Bakir C, Brauer CA. Quality indicators in pediatric orthopaedic surgery: a systematic review. *Clin Orthop Relat Res*. 2012;470(4):1124-1132.

38. Kepler CK, Wilkinson SM, Radcliff KE, et al. Cost-utility analysis in spine care: a systematic review. *Spine J*. 2012;12(8):676-690.

39. Haas DA, Kaplan RS. Variation in the cost of care for primary total knee arthroplasties. *Arthroplast Today*. 2017;3(1):33-37.

40. Okike K, O'Toole RV, Pollak AN, et al. Survey finds few orthopedic surgeons know the costs of the devices they implant. *Health Aff* . 2014;33(1):103-109.

41. Kaplan RS. Improving value with TDABC. *Healthc Financ Manage*. 2014;68(6):76-83.

42. Robinson R. Economic evaluation and health care. What does it mean? *BMJ*. 1993;307(6905):670-673.

43. Wang LY, Zhong Y, Wheeler L. Direct and indirect costs of asthma in school-age children. *Prev Chronic Dis*. 2005;2(1):A11.

44. Carabin H, Gyorkos TW, Soto JC, Penrod J, Joseph L, Collet JP. Estimation of direct and indirect costs because of common infections in toddlers attending day care centers. *Pediatrics*. 1999;103(3):556-564.

45. Attema AE, Brouwer WBF, Claxton K. Discounting in Economic Evaluations. *Pharmacoeconomics*. 2018;36(7):745-758.

46. Haacker M, Hallett TB, Atun R. On discount rates for economic evaluations in global health. *Health Policy Plan*. 2020;35(1):107-114.

47. Cleemput I, Neyt M, Thiry N, De Laet C, Leys M. Using threshold values for cost per quality-adjusted life-year gained in healthcare decisions. *Int J Technol Assess Health Care*. 2011;27(1):71-76.

48. Neumann PJ, Cohen JT, Weinstein MC. Updating cost-effectiveness--the curious resilience of the $50,000-per-QALY threshold. *N Engl J Med*. 2014;371(9):796-797.

49. Sonnenberg FA, Beck JR. Markov models in medical decision making: a practical guide. *Med Decis Making*. 1993;13(4):322-338.

50. DeFrancesco CJ, Lebrun DG, Molony JT Jr, Heath MR, Fabricant PD. Safer and Cheaper: An Enhanced Milestone-Based Return to Play Program After Anterior Cruciate Ligament Reconstruction in Young Athletes Is Cost-Effective Compared With Standard Time-Based Return to Play Criteria. *Am J Sports Med*. 2020;48(5):1100-1107.