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Breast

Use of Decision Analysis and Economic Evaluation in Breast Reconstruction: A Systematic Review

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Background: Decision analysis allows clinicians to compare different strategies in the context of uncertainty, through explicit and quantitative measures such as quality of life outcomes and costing data. This is especially important in breast reconstruction, where multiple strategies can be offered to patients. This systematic review aims to appraise and review the different decision analytic models used in breast reconstruction.

Methods: A search of English articles in PubMed, Ovid, and Embase databases was performed. All articles regardless of date of publishing were considered. Two reviewers independently assessed each article, based on strict inclusion criteria.

Results: Out of 442 articles identified, 27 fit within the inclusion criteria. These were then grouped according to aspects of breast reconstruction, with implant-based reconstruction (n = 13) being the most commonly reported. Decision analysis (n = 19) and/or economic analyses (n = 27) were employed to discuss reconstructive options. The most common outcome was cost (n = 27). The decision analysis models compared and contrasted surgical strategies, management options, and novel adjuncts.

Conclusions: Decision analysis in breast reconstruction is growing exponentially. The most common model used was a simple decision tree. Models published were of high quality but could be improved with a more in-depth sensitivity analysis. It is essential for surgeons to familiarize themselves with the concept of decision analysis to better tackle complicated decisions, due to its intrinsic advantage of being able to weigh risks and benefits of multiple strategies while using probabilistic models.
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INTRODUCTION

Reconstructive breast surgery is evolving and innovating at a rapid pace. Patients are now offered a multitude of different options in breast reconstruction, including multiple variations of autologous and alloplastic techniques.[1] Certain patient-specific characteristics and preferences can suggest an optimal reconstructive option; however, absolute indications for a given technique are few in nature. This uncertainty in technique selection can be addressed by employing decision analysis.

Decision analysis is a tool that allows for the quantitative evaluation of internal algorithms developed by clinicians through experience. This is especially important for breast reconstruction surgery, as a plethora of new and improved techniques can regularly be presented to patients. Although clinical intuition often seems like a reliable way to make decisions, when looking at several surgical domains, it has been shown to be inferior to decision analysis.[2,3]

When no clear choice seems superior, decision analysis offers an evidence-based method of determining the most optimal strategy.[4,5] This is done by combining evidence from the literature, such as complication rates and costs, with specific patient-derived data, such as quality of life metrics. In the context of probabilistic models, this combination has proven to highlight the optimal selection in a variety of situations.[6–9]

The clinical decision in question is usually represented by a decision tree. An example and brief explanation of such can be found in Figure 1. Once structured, the branches of the decision tree are then assigned probabilities and the outcomes are assigned utilities, allowing for the mathematical interpretation of said model. A utility is a measure of quality of life expressed as a number between

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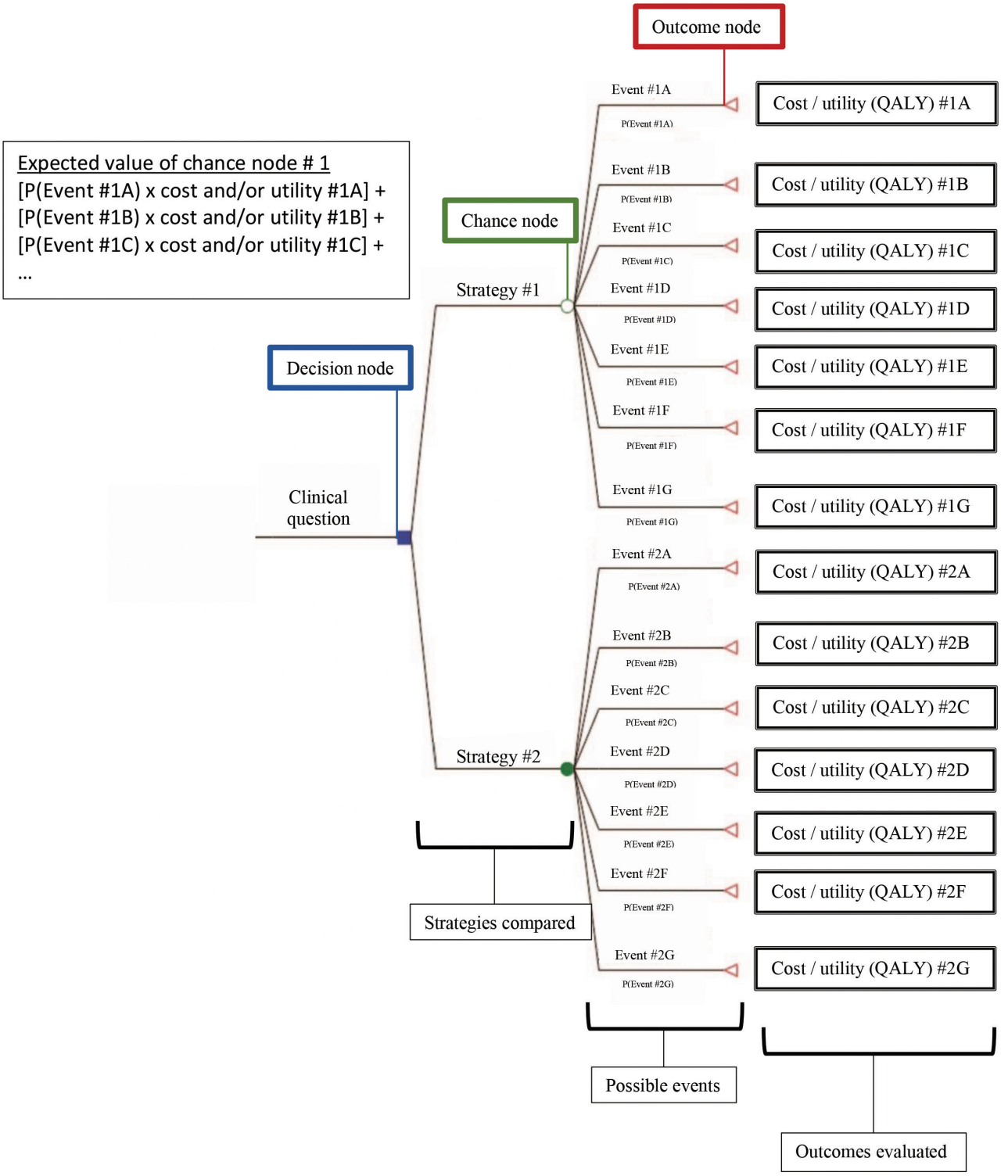

Fig. 1. Example of a decision tree. We read the tree from left to right, with the clinical question being the furthest left. A square represents a decision node, with the strategies being compared branching out from it. A circle represents a chance node, with possible events branching out from it. From there on, a line represents a strategy pathway, accompanied by a probability of experiencing this event. The sum of all probabilities at a chance node must equal to 1. A triangle represents an outcome node, accompanied by the cost and/or utility of that pathway. To quantifiably compare strategies, each chance node is then assigned a probability-weighted average of the outcomes stemming from it, yielding the expected value.

0 and 1, representing a scale from death to perfect health. Utilities and effectiveness measures can be generated using a variety of questionnaires, such as the BREAST-Q (a patient-reported outcome measure validated for use in cosmetic and reconstructive breast surgeries), the time-trade-off, or the visual model survey.[10] The utility value or effectiveness measure is then multiplied by the time spent in the health state used yielding values such as quality-adjusted life years (QALYs), which are classically used in decision analyses.[6,7] The more the utility is improved, the greater the benefit of the given intervention.

In addition to simple QALY analysis, decision analysis can also focus on the economic aspect of decisions, which can play a major role in private institutions and single-payer systems. In this case, either cost per utility or QALY can be calculated, yielding a cost–utility analysis. As well, the incremental cost–utility ratio or incremental cost-effectiveness ratio can be employed, which simultaneously contrast both the difference in cost and in benefit between the 2 interventions being studied.[11,12] This tool is of utmost importance because it is no longer enough for clinicians to only consider efficacy of interventions in the face of growing economic constraints in the healthcare field.

There is currently limited evidence consolidating the various decision and cost analyses in breast reconstruction. Sheckter et al[13] performed a systematic review to summarize the cost-effectiveness studies available in breast reconstruction, and Yoon et al[14] performed a systematic review to summarize the utility scores used in breast surgery. Our review differs from these by also including studies looking at just cost, and not including those looking at solely utility measures. Otherwise, there is a paucity of articles consolidating evidence regarding decision analysis in breast reconstruction. The aim of the authors is to consolidate literature where economic evaluations and/or decision analyses have been performed to address aspects of breast reconstruction. Secondarily, methodologic quality of the articles included will be assessed.

MATERIALS AND METHODS

Data Sources and Search Strategy

The study followed the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses.[15] Two reviewers independently conducted a search of 3 databases (Pubmed, Ovid, and Embase). The search (carried out on January 24, 2019) was performed using the keywords "Breast" or "Breast Reconstruction," which were combined with "Decision Analysis," "Algorithm," "Economic Analysis." The search was confined to the English language and included articles regardless of date of publication. It is worthy to mention that although this search strategy is ideal for the goal of this article, many studies regarding solely economics that were not included in this review also exist in the literature.

Study Selection and Data Extraction

Two independent reviewers (G.B. and T.S.) performed the study selection process and then assessed the articles according to the strategy outlined in Figure 2. Duplicates were first omitted, followed by initial screening which consisted of assessing the relevance of titles and abstracts. Relevant articles were then further assessed through the full text and then appropriateness of data. The senior author (P.G.D.) was involved to settle any discrepancies between the 2 reviewers. Studies were only deemed eligible if aspects of breast reconstruction were described in the context of a decision or cost analysis. The main data endpoints included study target, decision analysis type, outcome measure, source of costing data, and sensitivity analysis characteristics.

Quality Assessment

Using the *Journal of the American Medical Association* (*JAMA*) User's Guide to evaluating decision analysis, 2 reviewers independently assessed relevant articles by assigning a grade out of 12, based on several domains relating to risk of bias and quality of evidence.[16–18] This checklist includes clarity of the clinical question, validity and credibility of the results, clarity of the final result, and clinical usability of the results. As well, the framework or the Consolidated Health Economic Evaluation Reporting Standards statement for economic evaluation publications by Mastracci et al[19,20] was used to assess the reporting quality of the decision analysis evidence.

Data Synthesis

Relevant studies were first grouped within specific aspects of breast reconstruction surgery, and then further divided based on study characteristics, outcome measure, and costing data. The data were assessed from a qualitative standpoint.

RESULTS

A total of 442 abstracts were initially identified and subsequently narrowed to 27 articles that fit within the inclusion criteria, corresponding to the search strategy shown in Figure 2.[21–47]

Study Characteristics

Studies that were retained (Tables 1 and 2) originated mostly from the United States (n = 17) and Canada (n = 6). Studies also trended more toward the current decade compared with the previous one: from 2000 to 2009 (n = 6) and 2010 onward (n = 21). These were also grouped according to the aspect of breast reconstruction which they discussed (Table 3).

Quality of Study

Based on the quality assessment tool of *JAMA*, each article was assigned a score (Tables 1 and 2). The main area where studies lost points is the lack of sensitivity analysis (n = 9). No study was removed due to poor quality based on the *JAMA* assessment or poor reporting of findings based on the framework or the Consolidated Health Economic Evaluation Reporting Standards statement by Mastracci et al.[19,20]

Model Characteristics

The targets of the studies included were varied and most commonly included the surgeons/physician's

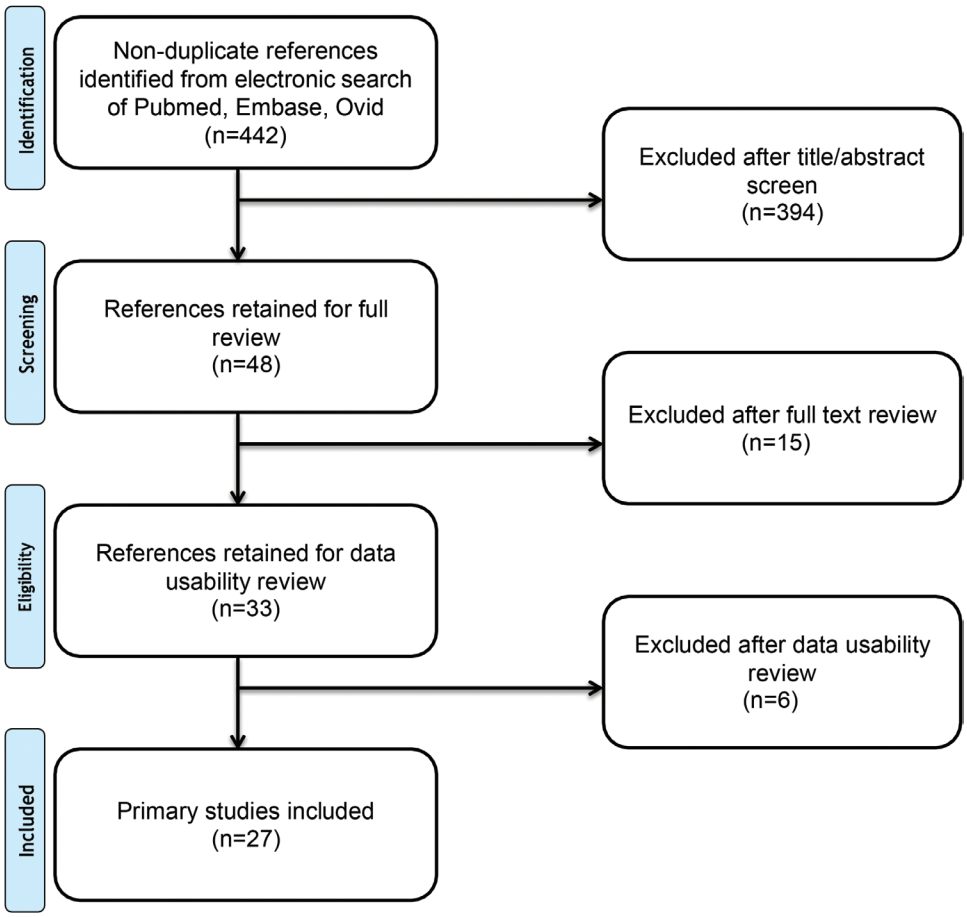

Fig. 2. PRISMA search strategy. PRISMA indicates Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

perspective (n = 13) and the third-party payer's perspective (n = 9). The time horizon of included studies was very wide as it encompassed all the way from lifetime of the patient (n = 4) to 30 days (n = 3). Results can be seen in Tables 1 and 2.

Decision Analysis

Decision Analysis versus Economic Analysis

Decision analysis includes models which evaluate an outcome based on utility measures, such as QALYs. An economic analysis, in turn, does so by assessing cost or some cost-related measure. Studies retained for review were subject of decision analysis (n = 19) (Table 1) and/or economic analyses (n = 27) (Table 2). The individual outcomes measured for each of these articles can be seen in Table 4.

Model Inputs

There are several ways to determine a utility value or effectiveness measure for specific interventions. Included studies utilized time-trade-off surveys (n = 3), visual model surveys (n = 3), BREAST-Q survey (n = 3), nonspecific questionnaires/surveys (n = 8), and literature reviewed sources (n = 3) (with some studies using >1 method). Probabilities and complications were determined through existing literature (n = 19) or retrospective review (n = 1).

For economic analyses (n = 27), data extracted also included costing sources and currency used. Most costs reported in these studies were in currencies corresponding to the same origin as the article (seen in Tables 1 and 2). Table 5 provides a visual summary of the various costing sources utilized in the studies using costing data.

Decision Analysis Models

The decision tree model was the most prevalent (n = 18). Figure 1 shows an example of a decision tree (based on the work by Chatterjee et al[21]). Different types of models were reported only twice in the studies retained: Hummelink et al[22] utilized headroom, scenario, and threshold analyses, and Preminger et al[23] created a Markov cohort model for their analysis.

Sensitivity Analysis

Most articles included in the study employed one form or another of a sensitivity analysis (n = 18), with the most common being 1-way (n = 10) (Tables 1 and 2). A sensitivity analysis is an indication of the robustness of the model utilized and is helpful in eliminating possibilities of error.

Table 1. Characteristics of All Decision Analysis Studies

Aspect(s)/ Category	Country	Reference	Target	Model	Time Horizon	Outcome Measure	Strategies	Currency	Costing Data	Sensitivity Analysis	Quality Score
Implant-based and large volume displacement oncoplastic surgery/surgical technique	United States	Asban et al[41]	- Third-party payer - Surgeon	Decision analysis Economic analysis	36 yr (lifetime)	Utility QALY Cost ICUR	(1) Large volume displacement oncoplastic surgery (2) Mastectomy with single-stage implant reconstruction	USD	- Medicare CPT codes - DRG codes	1-way and probabilistic	11
Perioperative angiography/ adjunct	United States	Chatterjee et al[21]	- Third-party payer (Medicare)	Decision analysis Economic analysis	/	Utility Cost QALY ICUR	(1) Clinical judgment (2) Laser-assisted indocyanine green angiography	USD	- Medicare reimbursement CPT costs - LifeCell Corporation 2011 pricing catalog (laser cost)	1-way	12
Implant-based and single/2-stage reconstruction and free/ pedicled flap and latissimus dorsi flap/type comparison	United States	Grover et al[47]	- Surgeon	Decision analysis Economic analysis	7 y	Cost QALY Cost/QALY (ICER)	(1) Autologous flaps with pedicled tissue (2) Autologous flaps with free tissue (3) Latissimus dorsi flaps with breast implants (4) Expanders with implant exchange (5) Immediate implant placement (6) No reconstruction	USD	Medicare	Univariate and Bayesian multivariate probabilistic	12
Perioperative angiography/ adjunct	The Netherlands	Hummelink et al[22]	- Surgeon	Decision analysis Economic analysis	/	Cost Utility QALY	(1) DIEP flap breast reconstruction (2) Virtual surgical planning using CTA in DIEP flap breast reconstruction	EUR	- Radboud University Medical Center - Literature review	/	11
Implant-based and acellular dermal matrix and autologous dermal flap/ type comparison	United States	Krishnan et al[46]	- Third-party payer (Medicare)	Decision analysis Economic analysis	30 d	Utility Cost QALY ICUR	(1) Single-stage, implant-based immediate breast reconstruction using acellular dermal matrix (2) Single-stage, implant-based immediate breast reconstruction using an autologous dermal flap	USD	- Medicare reimbursement CPT costs - Retail costs (AlloDerm)	Multivariate	12
Implant-based and acellular dermal matrix/ surgical technique	United States	Krishnan et al[38]	- Surgeon - Government	Decision analysis Economic analysis	30–34 mo	Utility QALY Cost/QALY Cost	(1) 2-stage, expander-implant immediate breast reconstruction with acellular dermal matrix (2) 2-stage, expander-implant immediate breast reconstruction without acellular dermal matrix	USD	- Medicare reimbursement CPT costs - Retail costs (AlloDerm)	Univariate	12
TRAM flap and DIEP flap/ autologous	United States	Krishnan et al[32]	- Third-party payers - Society	Decision analysis Economic analysis	30 d (mentions 3 mo and 1 y)	Utility Cost QALY ICUR	(1) DIEP flap (2) TRAM flap	USD	- Medicare reimbursement CPT codes - DRG codes	2-way	12
Implant-based and single/2-stage reconstruction/ surgical technique	United States	Krishnan et al[36]	- Third-party payer (Medicare) - Patient	Decision analysis Economic analysis	30 d	Utility Cost QALY ICUR	(1) 2-stage (expander-implant) breast reconstruction (2) Single-stage (direct-to-implant) breast reconstruction	USD	- Medicare reimbursement CPT costs - Estimated national billing charges and out-of-pocket costs for patients with and without insurance	Multivariate	12

(*Continued*)

Table 1. (*Continued*)

Aspect(s)/ Category	Country	Reference	Target	Model	Time Horizon	Outcome Measure	Strategies	Currency	Costing Data	Sensitivity Analysis	Quality Score
Implant-based and DIEP flap/type comparison	Canada	Matros et al[43]	- Payer	Decision analysis Economic analysis	36 y	Cost Breast-Q QALY (breast health-related QALYs) ICER	(1) DIEP flap reconstruction (2) Implant-based reconstruction	/	- 2010 Nationwide Inpatient Sample Database	1-way	12
Perioperative angiography/ adjunct	United States	Offodile et al[25]	- Hospital - Surgeon	Decision analysis Economic analysis	/	Utility Cost QALY ICUR	(1) CTA (2) Doppler ultrasonography	USD	- Medicare reimbursement CPT codes - DRG codes	1-way	12
BRECONDA decision aid/ adjunct	Australia	Parkinson et al[27]	- Healthcare	Decision analysis Economic analysis	6 mo	Utility Cost QALY ICER	(1) Use of BRECONDA decision aid (2) No use of BRECONDA decision aid	AUD	- Australian Public Hospitals Cost Report 2013 to 2014 and the Medicare Benefits Schedule	Yes, but type not specified	10
Single/2-stage reconstruction/ surgical technique	Colombia	Perea and Rosselli[40]	- Third-party payer - Columbian health system	Decision analysis Economic analysis	1 y	Utility Cost QALY Cost/QALY (ICER)	(1) Immediate reconstruction (2) Delayed reconstruction	COP	- Colombian Instituto de Seguros Sociales 2001 IETS - Billing model of the Centro Javeriano de Oncología at the Hospital Universitario San Ignacio	Univariate and probabilistic	12
Implant-based and TRAM flap and free/pedicled flap/type comparison	United States	Preminger et al[23]	- Patients - Surgeons	Decision analysis Economic analysis	Lifetime	Utility Cost Cost/QALY (ICER)	(1) Implant-based reconstruction (2) Free TRAM flap reconstruction	USD	- Healthcare Cost and Utilization Project based on International Classification of Diseases	1-way	12
Implant-based and single/2-stage reconstruction/ type comparison	United States	Razdan et al[45]	- Payer	Decision analysis Economic analysis	7 y	Cost Breast-Q QALY (breast QALY) Cost/QALY (ICER)	(1) Immediate tissue expander placement followed by exchange to permanent implant with subsequent PMRT (2) Mastectomy followed by PMRT with delayed autologous reconstruction (3) Mastectomy (do-nothing option)	USD	- Nationwide Inpatient Sample 2010 database	1-way	12
Implant-based/ implants	United States	Siotos et al[35]	- Patients - Surgeons	Decision analysis Economic analysis	1 y	Cost Breast-Q QALY (breast health-related QALYs) Cost/QALY (ICER)	(1) Silicone implant-based breast reconstruction (2) Saline implant-based breast reconstruction	USD	- Center for Medicare and Medicaid Services - Physician fee schedule/ hospital costs	1-way	12
TRAM flap and DIEP flap and free/pedicled flap/autologous	Canada	Tan et al[33]	/	Decision analysis Economic analysis	2 y	Breast-Q Cost ICER	(1) DIEP flap (2) Free MS-TRAM flap	CAD	- UHN case costing system	/	9
TRAM flap and free/pedicled flap/autologous	Canada	Thoma et al[30]	- Ministry of Health	Decision analysis Economic analysis	/	Utility Cost QALY ICUR	(1) Free TRAM flap (2) Unipedicled TRAM flap	CAD	- Ontario Ministry of Health Schedule of Benefits - Budgeting Services at St. Joseph's Healthcare	1-way	12

(*Continued*)

Table 1. (*Continued*)

Aspect(s)/ Category	Country	Reference	Target	Model	Time Horizon	Outcome Measure	Strategies	Currency	Costing Data	Sensitivity Analysis	Quality Score
TRAM flap and DIEP flap and free/pedicled flap/autologous	Canada	Thoma et al[31]	- Ministry of Health for Ontario	Decision analysis Economic analysis	Lifetime	Utility Cost QALY ICUR	(1) DIEP flap (2) TRAM flap	CAD	- Ontario Ministry of Health Schedule of Benefits - St. Joseph's Healthcare	Yes, but type not specified	12
DIEP flap and SIEA flap/ autologous	Canada	Thoma (2008)[34]	- Ontario Ministry of Health	Decision analysis Economic analysis	/	Utility Cost QALY ICUR	(1) SIEA flap (2) DIEP flap	CAD	- Schedule of benefits: Physician Services Under the Health Insurance Act (25) - Hospital (St Joseph's Healthcare) cost (OR) - Mentor Canada (material)	1-way	12

AUD, Australian dollar; BRECONDA, Breast Reconstruction Decision Aid; CAD, Canadian dollar; COP, Columpian peso; CPT, Current Procedure Terminology; CTA, computed tomographic angiography; DRG, diagnosis-related group; EUR, Euro; ICER, incremental cost-effectiveness ratio; ICUR, incremental cost–utility ratio; IETS, Instituto de Evaluación Tecnológia en Salud; MS, Muscle Sparing; PMRT, Post-Mastectomy Radiation Therapy; SIEA, superficial inferior epigastric artery; USD, US dollar; UHN, University Health.
/ indicates data not available.

Breast Reconstruction Topics Evaluated

Adjuncts in Breast Reconstruction

Decision and economic analyses were utilized within the realm of adjuncts in breast reconstruction surgery (n = 7). Four articles studied the topic of perioperative angiography.

Chatterjee et al[21] conducted an economic analysis, comparing the cost, QALY, and cost per QALY gained of laser-assisted indocyanine green angiography (LAICGA) to clinical judgment.[21] Similarly, Kanuri et al[24] looked at the cost-effectiveness of using LAICGA through an economic analysis, which is important considering the high cost of this technique. Offodile et al[25] compared computed tomographic angiography with the standard Doppler ultrasonography to assess the cost-effectiveness of this potential new technique, whereas Hummelink et al[22] studied the cost and QALY of Virtual Surgical Planning using computed tomographic angiography through economic and decision analyses.[22] In terms of other adjuncts, an economic analysis was employed by Gabriel and Maxwell[26] to determine the cost savings associated with the use of closed-incision negative pressure therapy as a potential way to address the high risk of postoperative complications in breast reconstruction. As well, the use of the Breast Reconstruction Decision Aid was evaluated through utility, cost, QALY, and cost per QALY measures by Parkinson et al.[27] Finally, Fishman et al[28] discussed the utility and cost-effectiveness of histologic analysis of the mastectomy scar at the time of expander-to-implant exchange, given the possible recurrence and interference with cancer screening.

Autologous Reconstruction

Six articles compared the autologous types of breast reconstruction through decision analyses and economic evaluations. Hwang et al[29] conducted an economic analysis to look at the cost of a clinical pathway associated with transverse rectus abdominis myocutaneous (TRAM) reconstruction, and Thoma et al[30] compared the free and unipedicled variations by looking at utility, cost, QALY, and cost per QALY. TRAM and deep inferior epigastric perforator (DIEP) flaps were compared because of the proposed decrease in donor-site morbidity and postoperative hernias for the DIEP flap; Thoma et al[31] and Krishnan et al[32] similarly looked at utility, cost, QALY, and cost per QALY, whereas Tan et al[33] focused on the incremental cost-effectiveness ratio. Finally, Thoma et al[34] also contrasted the DIEP flap with the superficial inferior epigastric artery flap by looking at the cost/QALY, among other factors.

Implant-based Reconstruction

Only Siotos et al[35] discussed exclusively implant-based reconstruction in the context of decision and economic analyses. Silicone and saline implant-based reconstructions were compared by looking at cost, QALY, and cost per QALY, showing that patient and surgeon preference are the most important factors, rather than cost.

Table 2. Characteristics of All Economic Evaluation Studies

Aspect(s) / Category	Country	Reference	Target	Model	Time Horizon	Outcome Measure	Strategies	Currency	Costing Data	Sensitivity Analysis	Quality Score
Implant-based and large volume displacement oncoplastic surgery/surgical technique	United States	Asban et al[41]	- Third-party payer - Surgeon	Decision analysis Economic analysis	36 y (lifetime)	Utility QALY Cost ICUR	(1) Large volume displacement oncoplastic (2) Mastectomy with single-stage implant reconstruction	USD	- Medicare CPT codes - DRG codes	1-way and probabilistic	11
Implant-based and pre-/subpectoral reconstruction/ surgical technique	Italy	Cattelani et al[39]	- Surgeon - Hospital	Economic analysis	/	Cost	(1) Prepectoral breast reconstruction (2) Subpectoral breast reconstruction	EUR	- Hospital financial department (University Hospital of Parma)	/	9*
Perioperative angiography/ adjunct	United States	Chatterjee et al[21]	- Third-party payer (Medicare)	Decision analysis Economic analysis	/	Utility Cost QALY ICUR	(1) Clinical judgment (2) Laser-assisted indocyanine green angiography	USD	- Medicare reimbursement CPT costs - LifeCell Corporation 2011 pricing catalogue (laser cost)	1-way	12
Histologic analysis/ adjunct	United States	Fishman et al[28]	- Surgeon - Hospital	Economic analysis	/	Cost	(1) Histologic analysis of mastectomy scar at reconstruction (2) /	USD	- Institutional charge (for scar analysis)	/	9*
ciNPT/adjunct	United States	Gabriel and Maxwell[26]	- Surgeon - Hospital	Economic analysis	2 y	Cost	(1) ciNPT (2) SOC incision management	USD	- MarketScan (GOXIBM Watson Health, Somers, NY) Commercial Claims and Encounters database (complication costs)	/	10*
Implant-based and single/2-stage reconstruction and free/pedicled flap and latissimus dorsi flap/type comparison	United States	Grover et al[47]	- Surgeon	Decision analysis Economic analysis	7 y	Cost QALY Cost/ QALY (ICER)	(1) Autologous flaps with pedicled tissue (2) Autologous flaps with free tissue (3) Latissimus dorsi flaps with breast implants (4) Expanders with implant exchange (5) Immediate implant placement (6) No reconstruction	USD	Medicare	Univariate and Bayesian multivariate probabilistic	12
Perioperative angiography/ adjunct	The Netherlands	Hummelink et al[22]	- Surgeon	Decision analysis Economic analysis	/	Cost Utility QALY	(1) DIEP flap breast reconstruction (2) Virtual surgical planning using CTA in DIEP flap breast reconstruction	EUR	- Radboud University Medical Center - Literature review	/	11
TRAM flap/ autologous	United States	Hwang et al[29]	- Care providers	Economic analysis	/	Cost	(1) TRAM pathway (2) No TRAM pathway	USD	- Medical Center Finance Department	/	9*
Implant-based and single/2-stage reconstruction and acellular dermal matrix/surgical technique	Canada	Jansen and Macadam[37]	- Surgeon - Hospital	Economic analysis	1 y	Cost	(1) Direct-to-implant with AlloDerm reconstruction (2) 2-stage non-AlloDerm reconstruction	CAD	- Ministry of Health in British Columbia (direct medical costs), Medical Services Plan for British Columbia (surgeon fees), Institution costs (OR cost, AlloDerm, implants, etc)	1-way (3 times)	11*
Perioperative angiography/ adjunct	United States	Kanuri et al[24]	- Surgeon	Economic analysis	7 y and 10 mo	Cost	(1) Use of laser-assisted indocyanine green angiography (2) No use of laser-assisted indocyanine green angiography	USD	- Institutional costs - Medicare CPT codes (complications) - Company costs (SPY Elite System [LifeCell Corp., Branchburg, N.J.])	/	9*

(*Continued*)

Table 2. (*Continued*)

Aspect(s) / Category	Country	Reference	Target	Model	Time Horizon	Outcome Measure	Strategies	Currency	Costing Data	Sensitivity Analysis	Quality Score
Implant-based and acellular dermal matrix and autologous dermal flap/type comparison	United States	Krishnan et al[46]	- Third-party payer (Medicare)	Decision analysis Economic analysis	30 d	Utility Cost QALY ICUR	(1) Single-stage, implant-based immediate breast reconstruction using acellular dermal matrix (2) Single-stage, implant-based immediate breast reconstruction using an autologous dermal flap	USD	- Medicare reimbursement CPT costs - Retail costs (Alloderm)	Multivariate	12
Implant-based and acellular dermal matrix/surgical technique	United States	Krishnan et al[38]	- Surgeon - Government	Decision analysis Economic analysis	30–34 mo	Utility QALY Cost/QALY Cost	(1) 2-stage, expander-implant immediate breast reconstruction with acellular dermal matrix (2) 2-stage, expander-implant immediate breast reconstruction without acellular dermal matrix	USD	- Medicare reimbursement CPT costs - Retail costs (Alloderm)	Univariate	12
TRAM flap and DIEP flap/autologous	United States	Krishnan et al[32]	- Third-party payers - Society	Decision analysis Economic analysis	30 d (mentions 3 mo and 1 y)	Utility Cost QALY ICUR	(1) DIEP flap (2) TRAM flap	USD	- Medicare reimbursement CPT codes - DRG codes	2-way	12
Implant-based and single/2-stage reconstruction/surgical technique	United States	Krishnan et al[36]	- Third-party payer (Medicare) - Patient	Decision analysis Economic analysis	30 d	Utility Cost QALY ICUR	(1) 2-stage (expander-implant) breast reconstruction (2) Single-stage (direct-to-implant) breast reconstruction	USD	- Medicare reimbursement CPT costs - Estimated national billing charges and out-of-pocket costs for patients with and without insurance	Multivariate	12
Implant-based and DIEP flap/type comparison	Canada	Matros et al[43]	- Payer	Decision analysis Economic analysis	36 y	Cost Breast-Q QALY (breast health-related QALYs) ICER	(1) DIEP flap reconstruction (2) Implant-based reconstruction	/	- 2010 Nationwide Inpatient Sample Database	1-way	12
Perioperative Angiography/Adjunct	United States	Offodile et al[25]	- Hospital - Surgeon	Decision analysis Economic analysis	/	Utility Cost QALY ICUR	(1) CTA (2) Doppler ultrasonography	USD	- Medicare reimbursement CPT codes - DRG codes	1-way	12
BRECONDA decision aid/adjunct	Australia	Parkinson et al[27]	- Healthcare	Decision analysis Economic analysis	6 mo	Utility Cost QALY ICER	(1) Use of BRECONDA decision aid (2) No use of BRECONDA decision aid	AUD	- Australian Public Hospitals Cost Report 2013 to 2014 and the Medicare Benefits Schedule	Yes, but type not specified	10

(*Continued*)

Table 2. (*Continued*)

Aspect(s) / Category	Country	Reference	Target	Model	Time Horizon	Outcome Measure	Strategies	Currency	Costing Data	Sensitivity Analysis	Quality Score
Single/2-stage reconstruction/ surgical technique	Colombia	Perea and Rosselli[40]	- Third-party payer - Columbian health system	Decision analysis Economic analysis	1 y	Utility Cost QALY Cost/ QALY (ICER)	(1) Immediate reconstruction (2) Delayed reconstruction	COP	- Colombian Instituto de Seguros Sociales 2001 IETS - Billing model of the Centro Javeriano de Oncología at the Hospital Universitario San Ignacio	Univariate and probabilistic	12
Implant-based and TRAM flap and free/pedicled flap/type comparison	United States	Preminger et al[23]	- Patients - Surgeons	Decision analysis Economic analysis	Lifetime	Utility Cost Cost/ QALY (ICER)	(1) Implant-based reconstruction (2) Free TRAM flap reconstruction	USD	- Healthcare Cost and Utilization Project based on International Classification of Diseases	1-way	12
Implant-based and single/2-stage reconstruction/ type comparison	United States	Razdan et al[45]	- Payer	Decision analysis Economic analysis	7 y	Cost Breast-Q QALY (breast QALY) Cost/ QALY (ICER)	(1) Immediate tissue expander placement followed by exchange to permanent implant with subsequent PMRT (2) Mastectomy followed by PMRT with delayed autologous reconstruction (3) Mastectomy (do-nothing option)	USD	- Nationwide Inpatient Sample 2010 database	1-way	12
Implant-based/ implants	United States	Siotos et al[35]	- Patients - Surgeons	Decision analysis Economic analysis	1 y	Cost Breast-Q QALY (breast health-related QALYs) Cost/ QALY (ICER)	(1) Silicone implant-based breast reconstruction (2) Saline implant-based breast reconstruction	USD	- Center for Medicare and Medicaid Services - Physician fee schedule/hospital costs	1-way	12
Implant-based and TRAM flap/type comparison	United States	Spear et al[42]	- Hospital	Economic analysis	7 y	Cost	(1) Implant-based breast reconstruction (2) TRAM flap breast reconstruction	USD	- Hospital based	/	9*
TRAM flap and DIEP flap and free/pedicled flap/autologous	Canada	Tan et al[33]	/	Decision analysis Economic analysis	2 y	Breast-Q Cost ICER	(1) DIEP flap (2) Free MS-TRAM flap	CAD	- UHN case costing system	/	9
TRAM flap and free/pedicled flap/autologous	Canada	Thoma et al[30]	- Ministry of Health	Decision analysis Economic analysis	/	Utility Cost QALY ICUR	(1) Free TRAM flap (2) Unipedicled TRAM flap	CAD	- Ontario Ministry of Health Schedule of Benefits - Budgeting Services at St. Joseph's Healthcare	1-way	12

(*Continued*)

Table 2. (*Continued*)

Aspect(s) / Category	Country	Reference	Target	Model	Time Horizon	Outcome Measure	Strategies	Currency	Costing Data	Sensitivity Analysis	Quality Score
TRAM flap and DIEP flap and free/pedicled flap/autologous	Canada	Thoma et al[31]	- Ministry of Health for Ontario	Decision analysis Economic analysis	Lifetime	Utility Cost QALY ICUR	(1) DIEP flap (2) TRAM flap	CAD	- Ontario Ministry of Health Schedule of Benefits - St. Joseph's Healthcare	Yes, but type not specified	12
DIEP flap and SIEA flap/autologous	Canada	Thoma (2008)[34]	- Ontario Ministry of Health	Decision analysis Economic analysis	/	Utility Cost QALY ICUR	(1) SIEA flap (2) DIEP flap	CAD	- Schedule of Benefits: Physician Services Under the Health Insurance Act (25) - Hospital (St Joseph's Healthcare) cost (OR) - Mentor Canada (material)	1-way	12
Implant-based and DIEP flap and Single/2-stage reconstruction and acellular dermal matrix/ type comparison	United States	Tran et al[44]	/	Economic analysis	/	Cost	(1) 2-staged implant reconstruction using tissue expander and acellular dermal matrix (2) DIEP flap	USD	- Medicare	/	10*

*Scored out of 11 as nonapplicable utility evaluation.

AUD, Australian dollar; BRECONDA, Breast Reconstruction Decision Aid; CAD, Canadian dollar; ciNPT, closed-incision negative pressure therapy; COP, Columbian Peso; CPT, Current Procedure Terminology; CTA, computed tomographic angiography; DRG, diagnosis-related groups; EUR, Euro; ICER, incremental cost-effectiveness ratio; ICUR, incremental cost–utility ratio; IETS, Instituto de Evaluación Tecnológica en Salud; MS, Muscle Sparing; PMRT, Post-Mastectomy Radiation Therapy; OR, Operating Room; SIEA, superficial inferior epigastric artery; SOC, standard of care; UHN, University Health Network; USD, US dollar.

/ indicates data not available.

Surgical Technique

Several techniques employed in breast reconstruction have also been subject of comparison (n = 6). Considering the advent of acellular dermal matrix (ADM), now making single-stage reconstruction more feasible, single- and 2-stage reconstruction have been compared by 2 articles: first by Krishnan et al[36] by analyzing utility, cost, QALY, and cost per QALY, and by Jansen et al[37] by looking specifically at the cost of direct-to-implant with AlloDerm (LifeCell Corp., Branchburg, N.J.) compared with 2-stage non-AlloDerm reconstruction. Of note, Krishnan et al[38] also specifically evaluated the cost-effectiveness of using ADM through cost per QALY gained. With the recent push for increasing prepectoral reconstructions, Cattelani et al[39] conducted an economic analysis discussing prepectoral and subpectoral reconstructions. To address the variability of cost across the globe, Perea and Rosselli[40] contrasted immediate and delayed reconstruction techniques, specifically in Columbia. In terms of newer surgical techniques, Asban et al[41] compared large volume displacement oncoplastic surgery with a single-stage implant technique through decision and economic analyses, as its cost-effectiveness has yet to be affirmed.

Type Comparison

Determining the difference between specific types of reconstructive options was the goal of 7 articles. In terms of comparing autologous and implant-based reconstructions, a contrast with TRAM flaps was carried out by Spear et al[42] through an economic analysis. This is useful because it has been suggested that when carried out well, implant-based reconstruction can have as good an aesthetic result as autologous tissue reconstruction, and this without the donor-site morbidity.[42] A similar comparison was done by Preminger et al[23] who looked at the utility, cost, QALY, and cost per QALY. Matros et al[43] discussed the contrast between DIEP and implant-based reconstruction to determine which one would be more cost-effective, considering the premise that autologous reconstruction is suggested to be more expensive. Similarly, Tran et al[44] compared the DIEP flap to 2-staged implant reconstruction using tissue expander and ADM through a cost analysis. Razdan et al[45] compared autologous and implant-based reconstructive options in the light of postmastectomy radiation therapy, through cost, QALY, and cost per QALY modalities, to contribute to the debate as to which of the 2 is more advantageous. When focusing on solely implant-based type comparisons, using ADM was contrasted to using an autologous dermal flap by Krishnan et al[46] to determine the most cost-effective of the 2, specifically taking into account the cost savings of not using an ADM. Finally, Grover et al[47] compares 5 different types of either autologous or implant-based reconstructive options in decision and economic analyses to determine the most effective method of 5 standard procedures. To better understand the debate between autologous and implant-based reconstruction, a direct comparison of the conclusions of these studies, among other data, can be found in Table 6.

Table 3. Aspects of Breast Reconstruction Discussed in the Decision Analysis Models

Aspect	No. Studies
Implant based[23,35–39,41–47]	13
TRAM flap[23,29–33,42]	7
DIEP flap[31–34,43,44]	6
Single/2-stage reconstruction[36,37,40,44,45,47]	6
Free/pedicled flaps[23,30,31,33,47]	5
Acellular dermal matrix[37,38,44,46]	4
Perioperative angiography[21,22,24,25]	4
Closed-incision negative pressure therapy[26]	1
BRECONDA decision aid tool[27]	1
Histologic analysis of the mastectomy scar[28]	1
SIEA flap[34]	1
Pre-/subpectoral reconstruction[39]	1
Large volume displacement oncoplastic surgery[41]	1
Latissimus dorsi flap[47]	1
Autologous dermal flap[46]	1

BRECONDA, Breast Reconstruction Decision Aid; SIEA, superficial inferior epigastric artery.

Table 4. Outcome Measured in the Decision Analysis Models

Outcome Measure	No. Studies
Cost[21–47]	27
QALY (including breast health-related QALY)[21,22,25,27,29–32,34–36,38,40,41,43,45–47]	18
Cost/QALY (including ICUR and ICER)[21,23,25,27,30–36,38,40,41,43,45–47]	18
Utility[21,22,25,27,29–32,36,38,40,41,45,46]	14
Breast-Q[33,35,39,43,45]	5

ICER, incremental cost-effectiveness ratio; ICUR, incremental cost–utility ratio.

Table 5. Costing Sources Included in the Decision Analysis Models

Costing Source	No. Studies
Individual hospital financial departments[22,24,28–31,34,35,37,39,40,42]	12
Medicare[21,24,25,32,35,36,38,41,44,46,47]	11
Company based[21,24,34,38,46]	5
DRG codes[25,32,41]	3
The HCUP Nationwide Inpatient Sample[23,43,45]	3
Ontario Ministry of Health Schedule of Benefits[30,31,34]	3
Australia Medicare Benefits Schedule and Australian Public Hospitals Cost Report[27]	1
MarketScan Commercial Claims and Encounters database[26]	1
Estimated national billing charges and out-of-pocket costs for patients with and without insurance[36]	1
Ministry of Health in British Columbia and Medical Services Plan for British Columbia[37]	1
Literature search[22]	1
Colombian Instituto de Seguros Sociales 2001 and IETS[40]	1
University Health Network Case Costing system (Toronto, Canada)[33]	1

DRG, diagnosis-related groups; HCUP, Healthcare Cost and Utilization Project; IETS, Instituto de Evaluación Tecnológica en Salud.

Table 6. Comparison of Autologous versus Implant-based Reconstruction, from Articles Included in the Study

Title	First Author	Goal(s)	Comparison	Data/Analysis	Conclusion(s)
Resource Cost Comparison of Implant-Based Breast Reconstruction versus TRAM Flap Breast Reconstruction	Spear et al[42]	Compare the resource costs of TRAM flap and prosthetic reconstruction	TRAM flap versus implant	Cost: $USD	- The average cost of TRAM flap reconstructions was $19,607 compared with $15,497 for prosthetic reconstructions - Prosthetic breast reconstruction is significantly less expensive and uses fewer resources than the TRAM flap alternative
How Should Quality-of-Life Data Be Incorporated into a Cost Analysis of Breast Reconstruction? A Consideration of Implant versus Free TRAM Flap Procedures	Preminger et al[23]	Compare implant and free TRAM flap breast mound reconstruction in a cost–utility analysis	Free TRAM flap versus implant	Cost: $USD Probabilities: literature review Markov model	- Mean lifetime cost was $14,080 for a free TRAM flap and $16,940 for an implant according to the sensitivity analysis, the older the patient, the more the costs converge - Even a slight increase in utility of implants over that of free TRAM flaps makes implants a cost-effective option - The added cost of implant reconstruction decreases with age and that even a marginal increase in utility of implants over TRAM flaps makes implants a cost-effective option for reconstruction. For young patients, TRAM flaps offer a reasonable alternative to implants from a cost perspective.
Cost-Effectiveness Analysis of Implants versus Autologous Perforator Flaps Using the BREAST-Q	Matros et al[43]	Determine if autologous tissue reconstructions are cost-effective compared with prosthetic techniques when health-related quality of life and patient satisfaction are considered	DIEP flap versus implant	Cost:$USD Probabilities: literature review Effectiveness measure: BREAST-Q 1-way sensitivity analysis	- The incremental cost of a DIEP flap compared with implants was $21,613 for unilateral reconstructions and $19,052 for bilateral procedures. - For unilateral reconstructions, breast health-related quality-adjusted life years were 19.5 for DIEP flaps and 17.7 for implants, whereas for bilateral reconstructions, these were 19.7 for DIEP flaps and 19.0 for implants. - The additional cost for obtaining 1 y of perfect breast-related health for a unilateral DIEP flap compared with implant reconstruction was $11,941. For bilateral DIEP flaps, the additional cost was $28,017. - DIEP flaps are cost-effective compared with implants, especially for unilateral reconstructions.
Cost Analysis of Postmastectomy Reconstruction: A Comparison of Two Staged Implant Reconstruction Using Tissue Expander and Acellular Dermal Matrix With Abdominal-based Perforator Free Flaps	Tran et al[44]	Perform a comprehensive cost analysis to compare TE/I + ADM and DIEP flap	DIEP flap versus 2-staged TE/I with ADM	Cost:$USD Probabilities: literature review	- Average actual cost for successful TE/I + ADM was $13,304.55 and for DIEP flaps was $10,237.13. - Incorporating complication data resulted in an increase in cost to $13,963.46 for TE/I + ADM and $12,624.29 for DIEP flap - DIEP flap breast reconstruction incurs lower costs compared with TE/I + ADM

(*Continued*)

Table 6. (*Continued*)

Title	First Author	Goal(s)	Comparison	Data/Analysis	Conclusion(s)
Cost-Effectiveness Analysis of Breast Reconstruction Options in the Setting of Postmastectomy Radiotherapy Using the BREAST-Q	Razdan et al[45]	Develop a cost-effectiveness model for women undergoing breast reconstruction in the setting of postmastectomy radiotherapy using BREAST-Q scores as the principal outcome measure	Autologous reconstruction versus implant (2-stage immediate)	Cost: $USD Effectiveness measure: BREAST-Q 1-way sensitivity analysis	- Compared with mastectomy alone, the incremental cost of immediate tissue expander/implant was $38,218, whereas the incremental cost for delayed autologous reconstruction was $77,907 - The incremental breast quality-adjusted life-year values of an immediate tissue expander/implant were 0.66, whereas delayed autologous was 0.76. - The cost for each additional breast quality-adjusted life year gained with an immediate tissue expander/implant is $57,906, and for delayed autologous reconstruction is $102,509. - For patients with advanced breast cancer who require postmastectomy radiotherapy, immediate prosthetic-based breast reconstruction is a cost-effective approach.
A Comparison of Acellular Dermal Matrix to Autologous Dermal Flaps in Single-Stage, Implant-based Immediate Breast Reconstruction: A Cost-Effectiveness Analysis	Krishnan et al[46]	Determine if the added procedural cost for acellular dermal matrix is cost-effective relative to using an autologous dermal flap in single-stage immediate breast reconstruction following mastectomy	Autologous dermal flap versus ADM in the context of 1-stage implant reconstruction	Cost: $USD Probabilities: literature review Utilities: survey of experts 1-way sensitivity analysis	- There is a cost difference of $261.72 and a 0.001 increase in the quality-adjusted life years when using acellular dermal matrix, yielding an incremental cost–utility ratio of $261,720 per quality-adjusted life year. - Acellular dermal matrix is not a cost-effective technology in patients who can have an autologous dermal flap in single-stage immediate breast reconstruction.
Comparing Five Alternative Methods of Breast Reconstruction Surgery: A Cost-Effectiveness Analysis	Grover et al[47]	To assess the cost-effectiveness of 5 standardized procedures for breast reconstruction to delineate the best reconstructive approach in postmastectomy patients in the settings of nonirradiated and irradiated chest walls	Autologous flaps with pedicled tissue versus autologous flaps with free tissue versus latissimus dorsi flaps with breast implants versus expanders with implant exchange versus immediate implant placement	Cost: $USD Probabilities: literature review Utilities: survey of experts Univariate sensitivity analyses and Bayesian multivariate probabilistic sensitivity analysis	- Pedicled autologous tissue and free autologous tissue reconstruction were cost-effective compared with the do-nothing alternative, with pedicled being slightly more cost-effective. - Autologous tissue reconstruction is the most cost-effective approach in irradiated and nonirradiated patients.

ADM, acellular dermal matrix; TE/I, tissue expander-implant; USD, US dollar.

DISCUSSION

This is the first systematic review to consolidate and appraise high-quality decision analysis models in breast reconstruction surgery. Many interesting points regarding the literature's landscape can be highlighted.

Although patient satisfaction with their reconstruction has brought on multiple validated questionnaires, the targeted audience was rarely patients (n = 3). Considering the limit in resources available, adopting a societal perspective in economic analyses is usually the most logical approach from a public health vantage. However, in the field of breast reconstruction, patient-reported outcomes are one of the most important measures of success. The analysis of this endpoint highlights that future research in decision analysis for breast reconstruction should be geared toward more patient-specific outcomes, to optimize strategies for individuals and not just from a public health standpoint.

Decision analysis models are often based on specific situations, outcomes, and populations, and, thus, generalizing their conclusions should be done with caution. Similar models could lead to different conclusions, depending on the data that are used and in which context. For example, Chatterjee et al[21] found that LAICGA was an overall cost-effective technology, whereas Kanuri et al[24] found that it was cost-effective only for high-risk patients, such as smokers, obese patients, and patients with large breasts.[21,24] This highlights the importance of being critical and meticulous when looking at a decision analysis and that certain conclusions are intrinsically dependent on the exact population studied and the data used to populate the model. Similarly, economic evaluations are highly dependent on the source of their costing data. In this review, it is noted that most of the costing data are from Medicare, which makes many of these conclusions limited to the American context. Parties should, therefore, always develop their own population and context-specific models to create relevant conclusions to their questions.

Models other than the simple decision tree were simply underutilized in the literature. Headroom, scenario, and threshold analyses and a Markov model were noted to being of mention. These more novel methods allow researchers to formulate more robust conclusions by considering potential scenarios or even the progression of an intervention over time, for example.[48] Considering that only 2 articles made mention of these, this consolidation demonstrates the need for future research to focus on such models in order to better the robustness of their conclusions and more accurately depict clinical situations.

The presence of sensitivity analyses was of importance when evaluating the quality of evidence.[49] Because statistical indicators such as the *P* value do not apply to decision analyses, one must rely on other methods, such as sensitivity analyses, to validate the model. The majority of articles (n = 18) included sensitivity analyses, with most (n = 10) being of the 1-way type. A model often relies on many assumptions, notably the accuracy of the data used to estimate probabilities, costs, and outcomes, which can thereafter affect the overall conclusion. The best way to then assess the reliability of a model is to vary these assumptions over a reasonable range and to see if the final interpretation of the analysis then differs, which is essentially a sensitivity analysis. The Canadian Coordinating Office for Health Technology Assessment recently published guidelines demonstrating the fundamental need for even more advanced sensitivity analyses to validate a model and affirm its robustness.[50] Decision analysis in breast reconstruction surgery should, in the future, conform to these guidelines to produce high-level quality evidence.

CONCLUSIONS

In conclusion, this systematic review highlights the growing literature concerning decision analyses in breast reconstruction surgery. These models allow surgeons, patients, and administrators to comparatively evaluate the quality of life and cost associated with different surgical strategies, management options, and novel adjuncts. However, this study also demonstrates several limitations uniformly present in the current evidence because more studies should focus on patient-centered perspectives and better sensitivity analysis practices. Due to their variable nature, decision analyses and economic evaluations presented cover a broad range of data for the endpoints that were studied. Nonetheless, certain features proved to be more common; the simple decision tree model was most frequently used, and implant-based reconstruction and TRAM flaps were the most commonly assessed topics.

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