Cost-utility analysis of the use of prophylactic mesh augmentation compared with primary fascial suture repair in patients at high risk for incisional hernia

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Background. *Although hernia repair with mesh can be successful, prophylactic mesh augmentation (PMA) represents a potentially useful preventative technique to mitigate incisional hernia risk in select high-risk patients. The efficacy, cost-benefit, and societal value of such an intervention are not known. The aim of this study was to determine the cost-utility of using prophylactic mesh to augment fascial incisions.*
Methods. *A decision tree model was employed to evaluate the cost-utility of using PMA relative to primary suture closure (PSC) after elective laparotomy. The authors adopted the societal perspective for cost and utility estimates. A systematic review of the literature on PMA was performed. The costs in this study included direct hospital costs and indirect costs to society, and utilities were obtained through a survey of 300 English-speaking members of the general public evaluating 14 health state scenarios relating to ventral hernia.*
Results. *PSC without mesh demonstrated an expected average cost of $17,182 (average quality-adjusted life-year [QALY] of 21.17) compared with $15,450 (expected QALY was 21.21) for PMA. PSC was associated with an incremental cost-efficacy ratio (ICER) of −$42,444/QALY compared with PMA such that PMA was more effective and less costly. Monte Carlo sensitivity analysis was performed demonstrating more simulations resulting in ICERs for PSC above the willingness-to-pay threshold of $50,000/QALY, supporting the finding that PMA is superior.*
Conclusion. *Cost-utility analysis of PSC compared to PMA for abdominal laparotomy closure demonstrates PMA to be more effective, less costly, and overall more cost-effective than PSC. (Surgery 2015;158:700-11.)*

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Incisional hernia (IH) is a common and costly complication after operative interventions requiring abdominal fascia incisions, with an incidence approaching 70% in high-risk patients[1] and an annual cost upwards of $3.2 billion dollars in the United States alone.[2] Hernia decreases quality of life, impairs function, and causes pain, imparting added morbidity and mortality for patients.[3] Additionally, IH represents a financial loss for institutions,[4] and with each recurrence, successful repair becomes less likely and more costly.[5] Owing to the significant incidence, cost, and impact on patients there is a continued need for prevention and mitigation of IH risk.

Despite advances in operative technique, hernia repair outcomes have unfortunately not improved significantly in recent years.[5] Mesh reinforcement can reduce long-term hernia recurrence, but the long-term overall incidence of recurrences still approaches nearly 1 in 3.[6,7] Despite established evidence regarding the benefits of mesh reinforcement, there are wide and continued variations in the use of mesh and overall practice patterns.[8] As with many other common health issues such as diabetes, hypertension, and cardiovascular disease, primary prevention may offer the most cost-effective strategy for addressing IH.[9-13]

Incisional access through the abdominal wall is the prime culprit of hernia, and its prevention can begin at the index operation with targeted use of mesh prophylaxis in high-risk patients. Such high-risk patients are generally considered to be those with multiple comorbidities, including morbid obesity, diabetes, and hypertension.[14-25] This may afford the most effective and cost-efficient strategy, however to date there is no such analysis comparing prophylactic mesh augmentation (PMA) to primary suture repair (PSC) alone from a cost-utility standpoint. Studies have demonstrated relative benefits of PMA in reducing hernia formation after laparotomy in select high-risk patients, particularly in overweight individuals, including recent metaanalyses.[20,21] Many of these studies have been smaller, randomized controlled trials and have demonstrated potential risk reduction with PMA.[22,23] The aim of this analysis is to perform a cost-utility analysis of PMA versus PSC without mesh.

METHODS

This study, which was exempt from institutional review board review, employed a decision tree model to evaluate the cost-utility of using PMA compared with PSC after elective laparotomy. A cost-utility analysis is composed of costs, probabilities, and utilities of various outcomes (health states) used to evaluate the cost effectiveness of a novel intervention relative to the standard of care. The decision to utilize PMA is conventionally surgeon preference; as such, we designed our decision model with no mesh/PSC as the "standard of care" compared with PMA. The cost-utility analysis was performed in the United States surgical sector using TreeAge Pro 2013 (Williamstown, MA) with methodology based on guidelines set forth by the United States Panel on Cost-Effectiveness in Health and Medicine.[26] Study time horizon was the average remaining life expectancy of subjects from our survey (30 years on average), assuming that the average patient undergoing ventral hernia repair is 50 years old with life expectancy of 78.3 years (assumed 80 years for ease of calculation).

Perspective. We adopted the societal perspective for cost and utility estimates, which incorporates direct costs related to management of complications from hospital/provider perspective, indirect costs to the patient (travel, costs of lost wages from recovery), and to society (productivity loss owing to employment absenteeism) for a given intervention. These indirect costs can either be modeled fiscally or included in utility estimates (as performed here).

Health states and probabilities. Health states are equivalent to postoperative outcomes. The relevant surgical literature was reviewed to identify clinically relevant outcomes reported with consistent definitions, including primary hernia formation, infection, hematoma, seroma, wound dehiscence, small bowel obstruction requiring operation, and enterocutaneous fistula. Hernia was defined by clinical examination or an imaging study. Wound infection was classified as either superficial (outpatient antibiotics), infection requiring admission for intravenous antibiotics, or deep-space infection (operative). Successful repair was defined by the absence of postoperative complications.

A systematic literature review was conducted in MEDLINE and EMBASE using the search terms "laparotomy," "mesh," "prophylactic," "prophylaxis," "incisional hernia," "surgical complication," "hernia prevention," "surgical mesh," along with Boolean operators "AND"/"OR" to determine health state probabilities for PSC and PMA for English articles published after 1995 with the following inclusion criteria:

a) cohort design of patients undergoing open midline laparotomy for any indication;
b) directly compared PSC and PMA; and
c) adequate reporting of operative technique and outcomes.

Case series describing only PSC or PMA and those involving laparoscopic surgical approaches were excluded. "High-risk patients" were considered to be adults undergoing abdominal surgery at higher risk for IH owing to the presence of comorbidities including being obese (body mass index >30 kg/m^2), hypertension, and diabetes. Pertinent data was extracted, pooled, and weighted relative to individual study sample size. The I^2 statistic, an estimate of heterogeneity, was judged low for an I^2 of <50%, borderline heterogeneous 50–75%, and unacceptable >75%. All analyses were conducted in Stata IC 13.1 (StataCorp 2013. Stata Statistical Software:

Release 13. College Station, TX; StataCorp LP) and RevMan 5.2 (The Cochrane Collaboration, Copenhagen, Denmark).[27]

Costs. Indirect costs to society were built into utility estimates. Technical (direct costs) were based on diagnosis-related group (DRG) classification obtained from publically available files from the Centers for Medicare and Medicaid Services for 2013, and represent the national average cost.[28] Nondiscounted costs were used for synthetic mesh (10×25 cm^2 piece) according to Lifecell's 2014 retail catalogue based upon the average mesh size in the systematic review (242 cm^2, rounded to 250 cm^2). Costs of mesh were added to base rates for all health states, and permanent mesh was chosen because the majority of patients in the review had synthetic PMA. Because the majority of included studies involved either bariatric or small/large bowel procedures, costs were derived by averaging 2 DRG codes: DRG-328 (stomach, esophageal, and duodenal procedures without complication) and DRG-331 (major small and large bowel procedures without complication). DRG-354 (hernia repair with complication/comorbidity) was used for less severe complications (seroma, nonoperative infection), whereas DRG-353 (hernia repair with major comorbidity/complication) was used for more severe complications (hematoma, infection requiring reoperation). Separate DRG codes (908 and 388) were used for enterocutaneous fistula and small bowel obstruction requiring surgery. For recurring complications, DRG costs were repeated,[28] and costs for each health state involved the cost of a successful surgery and its complications.

Costs for procedures and the associated quality-adjusted life-years (QALYs) were discounted at a standard rate of 3% per year to account for the time value of both money and quality of life. The United States Panel on Cost-Effectiveness in Health and Medicine has recommended using a standard discount rate of 3% annually in cost-utility analyses involving operative interventions.[29,30]

Utilities. The utilities used in this study were obtained through a survey of the general public evaluating 14 health states (outcomes) relating to ventral hernia. We used the consulting firm GfK (Palo Alto, CA) to distribute the web-based survey to derive utility using visual analog scale and time trade-off methodologies. This design is among the most comprehensive and thorough to date, has demonstrated a successful track record, and is one of few utility surveys in the literature in accordance with published guidelines.[31-37]

We recruited 300 participants to obtain a cohort representative of 97% of the English-speaking US population.[38] Sampling weights based on demographics were provided as a base weight, followed by post-stratification weighting to ensure cohort generalizability.[37] We believed that abdominal hernia could affect anyone in the general population and thus a survey of the general population would be the most appropriate method to assess patient utility.

Subjects were presented identical scenarios and asked to rank their preferences for each health state on a visual analog scale composed of a horizontal ladder of 10 cm in length ascending from a score of 0 (death) to 100 (perfect health) with literature-derived values filled in for other conditions as reference. Additionally, subjects were asked how many remaining years of life they would sacrifice to avoid a given health state (time trade-off). The overall utility of each health state was the average of individual opinion.

The utilities were converted to QALYs by multiplying the utility of a specific health state by the expected duration of that health state, in years, and adding that to the remaining life years multiplied by the utility of a successful operation. An example, for seroma, which assumes duration of 14 days (0.038 years), average utility for experiencing a seroma of 0.65, and the utility of a successful surgery without complication is 0.694, is demonstrated below:

$$\begin{aligned}\text{QALY} =&\left(\text{utility}_{(\text{health state})}\right)\times\left(\text{duration}_{(\text{health state})}\right)\\&+\left(\text{utility}_{(\text{successful repair})}\right)\\&\times(\text{remaining life}-\text{years})\end{aligned}$$

$$\begin{aligned}\text{QALY}_{\text{Seroma}} &= (0.65)\times(0.038)+(0.69)\times(30-0.038)\\&=20.82\ \text{QALY}\end{aligned}$$

Analysis. A decision tree with 2 branches, PSC and PMA, was created (Fig 1). Costs and QALYs were incorporated into this model with health state probabilities. Expected values for costs and outcomes were derived by multiplying the probability of a health state by its cost and QALY. These expected values were summed for both arms using the rollback method to derive the overall expected cost and utility (QALY) for laparotomy with and without synthetic mesh. The incremental cost-efficacy ratio (ICER) was calculated using the formula:

$$\begin{aligned}\text{ICER} =&(\text{Exp.Cost PMA}-\text{Exp.Cost PSC})/\\&(\text{Exp.QALY PMA}-\text{Exp.QALY PSC})\end{aligned}$$

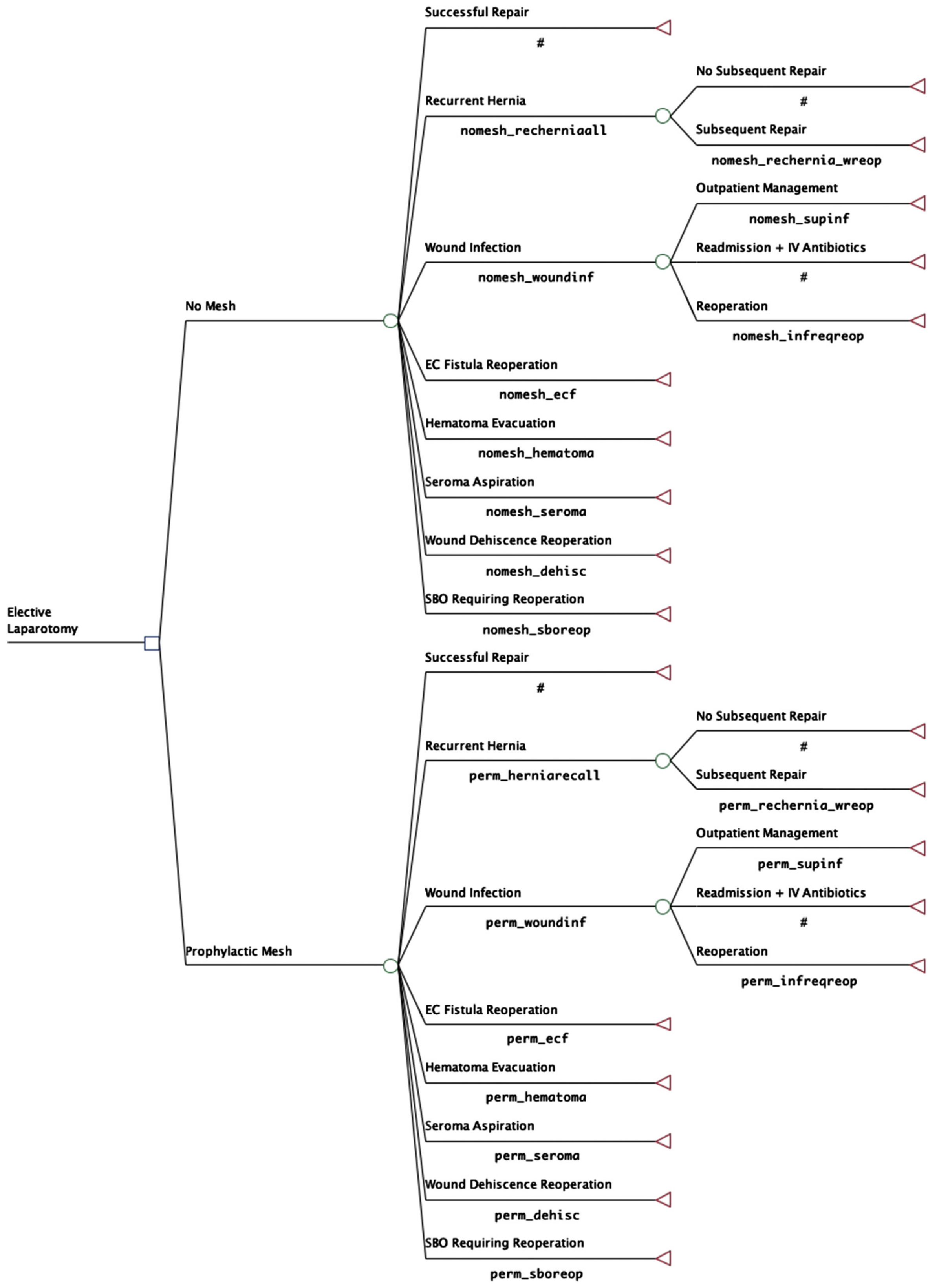


Fig 1. Decision tree of primary suture closure versus prophylactic mesh augmentation of the laparotomy.

Table I. Summary of included study characteristics

Author	*Year*	*Design*	*Indication*	*N PSC*	*N PMA*	*Mesh*	*Technique*	*Size**	*Follow-Up**	*Age (y)**	*BMI (kg/m²)**	*HTN (%)*	*DM (%)*
El-Khadrawy[19]	2009	RCT	Multiple	20	20	Polypropylene	Underlay	—	37	47.7	—	20	20
Gutierrez[24]	2003	RCT	Cancer	44	44	Polypropylene	Onlay	—	36	64.3	—	—	—
Curro[17]	2012	P-COH	Bariatric	50	45	Polypropylene	Underlay	25×10 (250 cm^2)	18	38.5	45.5	27	22
Strzelczyk[22]	2006	RCT	Bariatric	38	36	Polypropylene	Underlay	22×8 (176 cm^2)	28	39	46.5	68	21
Llaguna[15]	2011	P-COH	Bariatric	75	59	ADM	Underlay	16×6 (96 cm^2)	17	41	51.5	45	33
Pans[25]	1998	RCT	Bariatric	144	144	Vicryl	Underlay	26×21 (594 cm^2)	29	36.5	43.8	—	13
Total	—	—	—	371	348	—	—	11×22 (242 cm^2)	26.5	41.9	46.2	42	20

*Represents average.

ADM, Acellular dermal matrix; *BMI*, body mass index; *DM*, diabetes; *HTN*, hypertension; *P-COH*, prospective cohort; *PSC*, primary suture closure; *PMA*, prophylactic mesh augmentation; *RCT*, randomized control trial.

An intervention is "cost effective" if the ICER is >0 and less than the "willingness to pay" (WTP), which is the maximum amount of money society is willing to spend on an item for an added year of perfect health. We use the empirically accepted and previously published conservative WTP threshold of $50,000/QALY.

Sensitivity analysis. Sensitivity analyses were conducted for a range of different values for each probability, utility, and cost parameter. One-way and 2-way analyses were performed varying each parameter by ±15% in the base case settings. A Monte Carlo probabilistic uncertainty analysis was performed with 10,000 simulated iterations as a multivariate sensitivity analysis, which varies each probability, utility, and cost parameter simultaneously.

RESULTS

Characteristics of included studies. The systematic review included 6 studies, 4 of which were randomized control trials and 2 prospective cohorts (Table I). The average age of patients ranged from 36.5 to 64.3 years, body mass index ranged from 43.8 to 51.5 kg/m^2, and average follow up ranged from 17 to 37 months across all studies. Mesh placement was in an intraperitoneal or retrorectus underlay for all but 1 study, and average mesh size was 242 cm^2.

Base case results. Base case results for the strategy PSC without mesh demonstrated an expected average cost of $17,182 and was associated with an expected average QALY of 21.17 (Tables II–IV). For PMA, expected cost was $15,450; expected QALY was 21.21. PSC was associated with an ICER of −$42,444/QALY compared with prophylactic mesh augmentation; thus, assuming a WTP threshold of $50,000/QALY, a typical threshold for the United States, PMA was found to be more effective, less costly, and overall a dominant strategy relative to PSC (Fig 2). Additionally, base rate analysis with an absolute reduction in hernia recurrence rate of 15% for PMA demonstrated that mesh could cost a maximum of $3,700 and still be cost effective (Table IV).

Sensitivity analyses. One-way sensitivity analysis was conducted for all probability parameters, as demonstrated in the Tornado diagram (Appendix 1); in this plot, the ICER for PMA versus PSC is plotted for each outcome probability across its distribution parameters, with the most influential outcomes at the top and the least influential at the bottom. The outcome with the greatest influence, wound dehiscence with PSC, demonstrated an ICER of −$21,000/QALY at the lowest probability

Table II. Health state probabilities and relevant literature – prophylactic mesh augmentation versus primary suture closure

Author	N	*Recurrence*	*Recur, no reoperation*	*Any infection*	*deep infection*	*Superficial infection*	*Infection requiring reoperation*	*ECF*	*Seroma*	*Hematoma*	*Dehiscence*	*SBO*
Prophylactic mesh augmentation												
El-Khadrawy[19]	20	1	0	2	0	2	0	0	4	0	0	0
Gutierrez[24]	44	0	—	1	0	1	0	1	1	3	—	—
Curro[17]	45	2	0	1	0	1	0	—	7	0	—	—
Strzelczyk[22]	36	0	—	0	0	0	0	—	5	—	—	—
Llaguna[15]	59	1	0	4	—	4	—	—	6	—	—	—
Pans[25]	144	33	—	6	1	4	1	—	—	—	1	1
Total	348	37	0	14	1	12	1	1	23	3	1	1
Incidence (range)	n/a	5.5% (4.7–6.3%)	0.9% (0.8–1.0%)	4.5% (3.8–5.2%)	0.9% (0.8–1.0%)	2.7% (2.3–3.1%)	0.9% (0.8–1.0%)	1.3% (1.1–1.5%)	7.8% (6.6–9.0%)	2.0% (1.7–2.3%)	0.8% (0.7–0.9%)	0.8% (0.7–0.9%)
I^2		74%	0%	0%	0%	0%	0%	0%	65%	0%	0%	0%
Primary suture closure												
El-Khadrawy	20	3	—	4	0	4	0	1	3	0	1	0
Gutierrez	44	5	—	1	0	1	0	0	3	2	—	—
Curro	50	15	0	3	0	3	0	—	7	1	—	—
Strzelczyk	38	8	—	0	0	0	0	—	4	—	—	—
Llaguna	75	11	3	1	0	1	0	—	1	—	—	—
Pans	144	41	—	4	0	4	0	—	—	—	0	0
Total	371	83	3	13	0	13	0	1	18	3	1	0
Incidence (range)	n/a	20.1% (17.1–23.1%)	2.0% (1.7–2.3%)	3.6% (3.1–4.1%)	0.6% (0.5–0.7%)	2.4% (2.0–2.8%)	0.6% (0.5–0.7%)	1.3% (1.1–1.5%)	7.9% (6.7–9.1%)	2.7% (2.3–3.1%)	1.7% (1.4–2.0%)	0.4% (0.3–0.5%)
I^2		61%	23%	4%	0%	18%	0%	0%	67%	0%	0%	0%

ECF, Enterocutaneous fistula; I^2, heterogeneity (0–50% = no heterogeneity; 50–75% = some heterogeneity; >75% = high heterogeneity); *SBO*, small bowel obstruction requiring operation.

Table III. Health state visual assessment scale scores, utilities, and costs for primary suture closure (PSC) and prophylactic mesh augmentation (PMA)

	Utility parameters			*PSC*		*PMA ($268.22)*	
Health state	*VAS*	*QALY*	*Range*	*Base Rate*	*Range*	*Base Rate*	*Range*
Initial successful hernia repair	75	21.2250	18.0413–24.4088	$13,935	$11,845–16,025	$14,203	$12,073–16,334
Recurrent hernia no treatment	49.5	14.0085	11.9072–16.1098	$13,935	$11,845–16,025	$14,203	$12,073–16,334
Recurrent hernia with successful repair	52.8	21.1155	17.9482–24.2828	$37,503	$31,877–43,128	$37,771	$32,105–43,436
Superficial wound infection (cellulitis)	70.7	21.2215	18.0382–24.4047	$13,975	$11,878–16,071	$14,243	$12,106–16,379
Wound infection-readmit no op	55.8	21.2092	18.0278–24.3906	$20,114	$17,096–23,130	$20,382	$17,324–23,438
Wound infection-reoperation	45.9	21.1532	17.9803–24.3262	$26,481	$22,508–30,452	$26,749	$22,736–30,760
Enterocutaneous fistula	45.1	21.1513	17.9786–24.324	$28,673	$24,372–32,973	$28,941	$24,599–33,282
Hematoma	56.2	21.2095	18.0281–24.391	$28,673	$24,372–32,973	$28,941	$24,599–33,282
Seroma	67.4	21.2188	18.0359–24.4016	$26,481	$22,508–30,452	$26,749	$22,736–30,760
Wound dehiscence	53.2	21.2071	18.026–24.3881	$28,874	$24,542–33,205	$29,142	$24,770–33,513
Initial hernia no treatment	49.1	13.8953	11.811–15.9796	$32,353	$27,499–37,205	$32,621	$27,727–37,513

QALY, Quality-adjusted life-years; *VAS,* visual analog scale.

Table IV. Base case and threshold analysis of each strategy for laparotomy closure

Analysis	*Strategy*	*Cost*	*Efficacy (QALY)*	*ICER ($/QALY)*	*Cost of mesh*
Base case	Prophylactic mesh	$15,450	21.21	0	$268
	No mesh	$17,182	21.17	−42,444	
Threshold	Prophylactic mesh	$19,182	21.21	50,000	$3,732

ICER, Incremental cost-efficacy ratio; *QALY,* quality-adjusted life-years.

estimate and still favors PMA. No outcome resulted in an ICER of $50,000/QALY or greater for PMA in 1-way sensitivity analysis.

Monte Carlo sensitivity analysis was performed varying all parameters simultaneously. Figure 3 demonstrates the ICER plot for 1,000 simulations (all 10,000 simulations not pictured to optimize image clarity). Each dot represents 1 simulation and the resulting ICER of PSC relative to PMA (dot assumed to be at the origin of the plot). Quadrant II dots are less effective and more costly, quadrant IV dots are more effective and less costly, and quadrants I and III represent intermediate values. Relative to PMA, PSC was more costly and less efficacious (dominated, quadrant II) in 38% of simulations and less costly and more efficacious (superior, quadrant IV) in only 12% of simulations. Overall, more simulations resulted in ICERs for PSC above the WTP threshold of $50,000/QALY, supporting the finding that prophylactic mesh augmentation has greater cost utility.

WTP threshold was varied from 0 to $100,000/QALY and it was found that prophylactic mesh augmentation was most commonly the optimal strategy across all WTP thresholds (Appendix 2). Additionally, when varying the absolute reduction in hernia recurrence rate for PMA compared with PSC, the maximum cost of mesh for WTP of $100,000/QALY and $150,000 was $5,500 and $7,600, respectively (Appendix 3).

DISCUSSION

There is a growing body of evidence demonstrating favorable risk reduction with the use of PMA in patients undergoing laparotomies. As increasing stock is placed in the cost efficacy of medical interventions rather than just their medical efficacy, the ability to understand in numerical terms the effect of an intervention will be increasingly important in medical decision making from both the patient and societal perspective. The goal of this work was to evaluate the cost utility of PMA

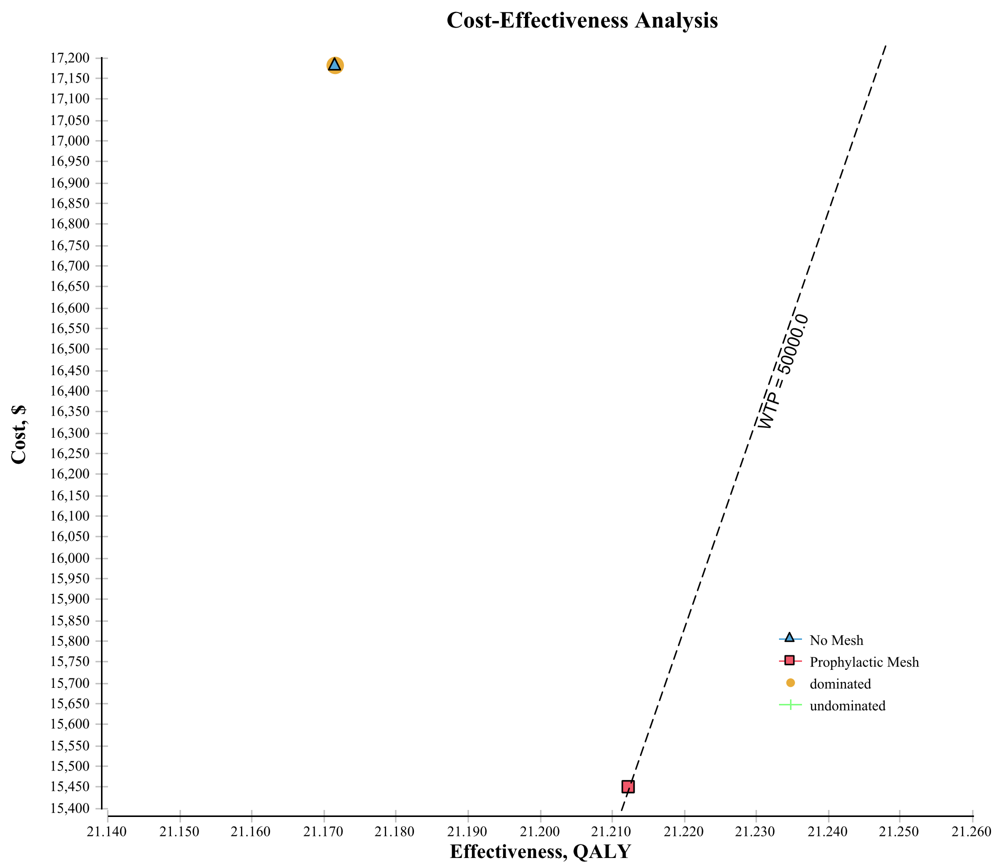


Fig 2. Cost-utility plot.

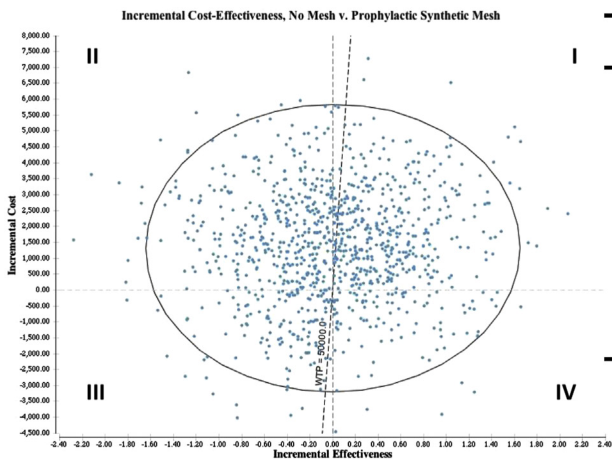
relative to PSC without mesh when closing incisional laparotomies.

With the ongoing PRImary Mesh Closure of Abdominal Midline Wound (PRIMA) study, an international, multicenter, double-blinded, randomized, controlled trial comparing running slowly absorbable suture closure with the same closure augmented with mesh, considerable interest in the benefits and cost utility of such preventative strategies is needed.[39] A recent early analysis of complications from the PRIMA study has demonstrated no significant risk of added wound complications with PMA.[40] Despite this encouraging evidence that primary prevention using PMA might reduce risk, a more comprehensive analysis incorporating rates of complications associated with each modality, along with cost and utility, would assist in determining the overall societal value. This is particularly important in light of the Affordable Care Act, which places value in high-quality, low-cost, effective interventions. As the long-term data become available from the PRIMA study, such level I data will help to guide practice.

To build on this growing body of work, we performed a cost-utility analysis to better assess the true value of utilizing mesh prophylactically. Cost-utility studies represent a cornerstone of modern clinical effectiveness research, in which health state utilities, modern costs, and published probabilities are incorporated into decision analysis.

IH can impact as many of 70% of patients who are high-risk after laparotomy,[1] generating billions of dollars in annual healthcare expenditures[2] and creating significant impairments in the quality of life for patients.[3] Based upon the data from our systematic review, "high-risk" patients were generally morbidly obese and had a relatively high incidence of comorbidities associated with increased wound complications. The complications represent a fiscal strain on healthcare systems, and are themselves associated with frequent complications, including recurrence, and a vicious and rapid cycle of morbidity and cost.[4,5]

Our results demonstrated that PSC created an expected cost of $17,182 and QALY of 21.17, compared with a cost of $15, 450 with an expected



Quadrant	Relative Cost	Relative Efficacy	Relative ICER	Proportion
I	Greater	Greater	< $50,000/QALY	36.2%
I	Greater	Greater	> $50,000/QALY	2.0%
II (Dominated)	Greater	Less	> $50,000/QALY	37.8%
III	Less	Less	< $50,000/QALY	12.1%
III	Less	Less	> $50,000/QALY	0.3%
IV (Superior)	Less	Greater	< $50,000/QALY	11.5%

Proportion of Simulations By Scatter Plot Quadrant, No Mesh Relative to Prophylactic Mesh

Fig 3. Monte Carlo incremental cost-efficacy ratio (ICER) scatter plot and proportion of simulations by scatter plot quadrant.

QALY of 21.21 for PMA. PSC was associated with an ICER of -$42,444/QALY compared with PMA. Based on a WTP threshold of $50,000/QALY, PMA was more clinically effective, less costly, and overall a dominant strategy relative to PSC. Analysis with an absolute reduction in hernia recurrence rate of 15% for PMA demonstrated that mesh could cost a maximum of $3,700 and still be cost effective. For other levels of WTP and greater rates of reduction, costs of mesh and potentially devices for implantation could cost as much as $20,000 and still remain cost effective. These thresholds are important to note regarding mesh selection. As synthetic mesh, which costs $1–2 per cm^2 or $250–500 per sheet, is relatively inexpensive, it clearly is a cost-effective solution based on our results. However, biologic mesh remains significantly more expensive, with human-derived mesh ranging from $28 to 38/$cm^2$ ($7,000–9,000 per 250 cm^2 sheet), and porcine-derived mesh ranging from $16 to 24/$cm^2$ ($4,000–6,000 per 250 cm^2 sheet). Emerging mesh technologies such as less expensive but non-permanent bio-absorbable meshes which are not as costly as biologics, yet are non-permanent may offer greater benefits for PMA. Thus, it is likely that absolute hernia recurrence must be reduced by >15% with biologic mesh compared with primary suture repair for it to be a reliably more cost-effective option. These findings underscore the tremendous societal benefit of selective PMA in high-risk patients.

Our analysis was validated further using a Monte Carlo sensitivity analysis varying all parameters simultaneously, which demonstrated that significantly more simulations resulted in ICERs for PSC above the WTP threshold of $50,000/QALY, further lending strong support to the finding that PMA is the dominant choice and should be adopted.

PMA has been shown to enhance fibroproliferation and angiogenesis within the repair site, which in turn creates added tensile strength when compared with PSC.[41] The concept of a load-sharing repair and the importance of mechanoconduction relate to the signal induction that mechanical strain across the repair induces to initiate proliferative, morphologic, and functional response in abdominal wall fibroblasts lost when the load force is removed. After laparotomy and hernia formation, the loss of wound edge tension may be a contributing factor.[42] PMA provides needed biomechanical integrity after laparotomy, which returns tensile strength of the abdominal wall to the pre-incised state in animal models.[18]

PMA relative to PSC, even when affixed with fibrin glue alone, has been demonstrated to significantly increase the tensile strength of repair in animal models.[43] PMA most likely creates a load-sharing interface with mesh to minimize hernia formation. One potential concern related to utilization of PMA may be that the use of mesh, particularly a synthetic mesh, in higher risk patients at risk for infection or wound complications; however, some encouraging data are being published that demonstrate relatively favorable outcomes with mesh in contaminated hernia repairs.[44]

The critical strength of this analysis and topic relate to the following. First, hernia is common and costly; thus, effective and, more important, cost-effective strategies are of considerable relevance to patients, society, and healthcare systems.

This decision analysis is applicable to a wide range of scenarios and patient characteristics, and our cost-utility model aids in elucidating the factors that contribute to optimal fascial closure after laparotomy. Our analysis therefore provides data for health systems, surgeons, and patients to tailor the use of this intervention to deliver the most cost-effective intervention. Furthermore, our analysis reveals that, depending on the WTP and the absolute risk reduction afforded by PMA, the cost-effective price of mesh varies, such that these data may assist in determining a suitable price for meshes and devices. Overall, these data will act to optimize patient care while minimizing patient costs. In brief, this model can be used to make individual decisions whereby a surgeon can account for both quality-of-life and costs, in formulating a decision.

Limitations and future directions. This study is not without limitations that merit further discussion; further, these limitations and our findings must be considered in the framework of our study assumptions and the limits of cost-utility analyses. Regarding the probabilities of each health state or outcome, our results are based on a systematic review of the literature. Limitations in our reported probabilities include the variations in patient populations and indications for laparotomy across each study. The patient populations tended to be considered "high risk," but no standardized definition exists for this group. In general, patients were obese across all studies and had ≥1 comorbidity that would place them at high risk for either short-term wound healing complications (diabetes, cardiovascular disease, advanced age) and/or longer term hernia complications (history of prior abdominal surgeries). We attempt to address this inter-study heterogeneity by only including studies with long-term follow up for hernia formation and only deriving probabilities for studies that report head-to-head cohort outcomes. Although 12-month follow-up will not capture all hernia complications, we believe it is sufficient for this analysis and that longer term results are not likely to alter our findings significantly. This limitation leads to another important observation to note; namely, that our results are not generalizable to all patients undergoing laparotomy. Because included studies report data on "high-risk" patients, the results of our analysis are best applied to similar patient populations and the reader must keep this in mind when interpreting our findings.

Another limitation of this study involves grouping distinct synthetic mesh types when deriving probabilities and cost data. Although there are certainly differences in the types of synthetic mesh we grouped together, current literature has failed to show significant differences in outcomes by mesh type.[45] Furthermore, prior cost-utility analyses have conventionally grouped different synthetic meshes as one.[46] Another consideration is that biologic mesh and Vicryl mesh were used infrequently in some studies. The vast majority of patients, however, underwent prophylactic mesh augmentation with an underlay synthetic mesh and, thus, we have extrapolated outcomes assuming no differences in outcomes when including additional types of mesh. This limitation was unavoidable, because the included studies did not report outcomes separately by mesh type when >1 type was used, and our results must be interpreted in light of this.

The cost data in this analysis are represented by Medicare Reimbursement rates for 2013 using DRG codes. Although we believe this design results in generally accurate procedural direct costs, it is unlikely that they are completely accurate and one must note that costs vary from hospital to hospital and by geographic region as well.

For this work, we used an Internet-based survey of the general population to attempt to understand the patient utility that is derived from a given health state. A limitation of this method is that it is difficult to assess to what extent our responders understood the study instructions and questions. A practice question was used to ensure that responders understood what they were asked to do and the standard deviation of our data suggests that all responders had a similar understanding of what was being asked. The weighting method used is generalizable to 97% percent of the English-speaking United States population, but our survey utility data are not valid for patients falling outside of these demographics.

Future directions must focus on the refinement of risk factors associated with IH formation, and eventually include prospectively and externally validated, procedure and specialty-specific risk models to guide the effective use of PMA. A more in-depth analysis of the biomechanical properties of mesh affixation comparing glued and more rigidly affixed mesh, as well as the benefits of tension/load sharing compared with rigid fixation is needed. The task of minimizing and eliminating IH is a daunting one, but the identification of effective, cost-conscious, proximate causes and targeting appropriate patients represents the state-of-the-art in IH prevention, which is germane to comprehensive hernia treatment.

In conclusion, cost-utility analysis demonstrates PMA in high-risk patients is more effective, less costly, and overall more cost effective than PSC. Further investigation of PMA is needed to define the ideal candidate, as well as the appropriate mesh and position of placement.

SUPPLEMENTARY DATA

Supplementary data related to this article can be found online at http://dx.doi.org/10.1016/j.surg.2015.02.030.

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