ORIGINAL CONTRIBUTION

Assessment of the Risk and Economic Burden of Surgical Site Infection Following Colorectal Surgery Using a US Longitudinal Database: Is There a Role for Innovative Antimicrobial Wound Closure Technology to Reduce the Risk of Infection?

David J. Leaper, D.Sc., M.D.[1] • Chantal E. Holy, M.Sc., Ph.D.[2] • Maureen Spencer, M.Ed.[3]
Abhishek Chitnis, Ph.D.[2] • Andrew Hogan, M.Sc.[4] • George W.J. Wright, Ph.D.[4]
Brian Po-Han Chen, Sc.M.[5] • Charles E. Edmiston, Jr, Ph.D.[6]

1 Emeritus Professor of Surgery, University of Newcastle; Emeritus Professor of Clinical Sciences, University of Huddersfield, United Kingdom
2 Medical Devices Epidemiology, Real-World Data Sciences, Johnson & Johnson, New Brunswick, New Jersey
3 Infection Prevention Consultants, Boston, Massachusetts
4 CRG-EVERSANA Canada Inc (formerly Cornerstone Research Group Inc), Burlington, ON, Canada
5 Ethicon, Inc, a Johnson & Johnson Company, Somerville, New Jersey
6 Emeritus Professor of Surgery, Department of Surgery, Medical College of Wisconsin, Milwaukee, Wisconsin

BACKGROUND: Colorectal surgical procedures place substantial burden on health care systems because of the high complication risk, of surgical site infections in particular. The risk of surgical site infection after colorectal surgery is one of the highest of any surgical specialty.

OBJECTIVE: The purpose of this study was to determine the incidence, cost of infections after colorectal surgery, and potential economic benefit of using antimicrobial wound closure to improve patient outcomes.

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Correspondence: Charles E. Edmiston, Jr., Ph.D., Department of Surgery, Medical College of Wisconsin, 8701 Watertown Plank Rd, Milwaukee, WI 53226. E-mail: edmiston@mcw.edu

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DESIGN: Retrospective observational cohort analysis and probabilistic cost analysis were performed.

SETTINGS: The analysis utilized a database for colorectal patients in the United States between 2014 and 2018.

PATIENTS: A total of 107,665 patients who underwent colorectal surgery were included in the analysis.

MAIN OUTCOME MEASURES: Rate of infection was together with identified between 3 and 180 days postoperatively, infection risk factors, infection costs over 24 months postoperatively by payer type (commercial payers and Medicare), and potential costs avoided per patient by using an evidence-based innovative wound closure technology.

RESULTS: Surgical site infections were diagnosed postoperatively in 23.9% of patients (4.0% superficial incisional and 19.9% deep incisional/organ space). Risk factors significantly increased risk of deep incisional/organ-space infection and included several patient comorbidities, age, payer type, and admission type. After 12 months, adjusted increased costs associated with infections ranged from $36,429 to $144,809 for commercial payers and $17,551 to $102,280 for Medicare, depending on surgical site infection type. Adjusted incremental costs continued to increase over a 24-month study period for both payers. Use of antimicrobial wound closure for colorectal surgery is projected to significantly reduce median payer costs by $809 to $1170 per patient compared with traditional wound closure.

LIMITATIONS: The inherent biases associated with retrospective databases limited this study.

CONCLUSIONS: Surgical site infection cost burden was found to be higher than previously reported, with payer costs escalating over a 24-month postoperative period. Cost analysis results for adopting antimicrobial wound closure aligns with previous evidence-based studies, suggesting a fiscal benefit for its use as a component of a comprehensive evidence-based surgical care bundle for reducing the risk of infection. See **Video Abstract** at http://links.lww.com/DCR/B358.

EVALUACIÓN DEL RIESGO Y LA CARGA ECONÓMICA DE LA INFECCIÓN DEL SITIO QUIRÚRGICO DESPUÉS DE UNA CIRUGÍA COLORRECTAL UTILIZANDO UNA BASE DE DATOS LONGITUDINAL DE EE.UU.: ¿EXISTE UN PAPEL PARA LA TECNOLOGÍA INNOVADORA DE CIERRE DE HERIDAS ANTIMICROBIANAS PARA REDUCIR EL RIESGO DE INFECCIÓN?

ANTECEDENTES: Los procedimientos quirúrgicos colorrectales suponen una carga considerable para los sistemas de salud debido al alto riesgo de complicaciones, particularmente las infecciones del sitio quirúrgico. El riesgo de infección posoperatoria del sitio quirúrgico colorrectal es uno de los más altos de cualquier especialidad quirúrgica.

OBJETIVO: El propósito de este estudio fue determinar la incidencia, el costo de las infecciones después de la cirugía colorrectal y el beneficio económico potencial del uso del cierre de la herida con antimicrobianos para mejorar los resultados de los pacientes.

DISEÑO: Análisis retrospectivo de cohorte observacional y análisis de costo probabilístico.

AJUSTES: El análisis utilizó la base de datos para pacientes colorrectales en los Estados Unidos entre 2014 y 2018.

PACIENTES: Un total de 107,665 pacientes sometidos a cirugía colorrectal.

PRINCIPALES MEDIDAS DE RESULTADO: Se identificó una tasa de infección entre 3 y 180 días después de la operación, los factores de riesgo de infección, los costos de infección durante 24 meses posteriores a la operación por tipo de pagador (pagadores comerciales y Medicare), y los costos potenciales evitados por paciente utilizando una tecnología innovadora de cierre de heridas basada en evidencias.

RESULTADOS: Infecciones del sitio quirúrgico, diagnosticadas postoperatoriamente en el 23,9% de los pacientes (4,0% incisional superficial y 19,9% incisional profunda / espacio orgánico). Los factores de riesgo aumentaron significativamente el riesgo de infección profunda por incisión / espacio orgánico e incluyeron comorbilidades selectivas del paciente, edad, tipo de pagador y tipo de admisión. Después de 12 meses, el aumento de los costos asociados con las infecciones varió de $ 36,429 a $ 144,809 para los pagadores comerciales y de $ 17,551 a $ 102,280 para Medicare, según el tipo de infección del sitio quirúrgico. Los costos incrementales ajustados continuaron aumentando durante un período de estudio de 24 meses para ambos pagadores. Se prevé que el uso del cierre antimicrobiano de la herida para la cirugía colorrectal reducirá significativamente los costos medios del pagador en $ 809- $ 1,170 por paciente en comparación con el cierre tradicional de la herida.

LIMITACIONES: Los sesgos inherentes asociados a las bases de datos retrospectivas limitaron este estudio.

CONCLUSIONES: Se encontró que la carga del costo de la infección del sitio quirúrgico es mayor que la reportada previamente, y los costos del pagador aumentaron durante un período postoperatorio de 24 meses. Los resultados del análisis de costos para la adopción del cierre de heridas antimicrobianas se alinean con estudios previos basados en evidencia, lo que sugiere un beneficio fiscal para su uso como componente de un paquete integral de atención quirúrgica basada en evidencia para reducir el riesgo de infección. Consulte **Video Resumen** en http://links.lww.com/DCR/B358. *(Traducción—Dr. Gonzalo Hagerman)*

KEY WORDS: Antimicrobial sutures; Colorectal surgery; Deep incisional infection; IBM MarketScan; Organ-space infection; Superficial incisional infection; Surgical care bundles; Surgical site infection.

In the United States, elective colorectal surgery ranks in the top 10 of operating room procedures, with over 300,000 procedures reported in 2012.[1] This presents a high cost to health care systems, in part relating to increased length of hospital stay and the high risk of managing postoperative complications, including surgical site infection (SSI).[2] The rate of SSI after colorectal surgery is one of the highest of any surgical specialty, with a reported incidence ranging from 9% to 41%.[2–4] Patient comorbidities related to this group of patients further increase the risk of SSI.[5,6] In addition, SSIs are associated with prolonged hospital and intensive care unit stays, increased readmission to the hospital, and additional community care.[3,7–9] In the United States, SSIs have been reported to account for $3.2 billion in attributable cost per year to acute care hospital budgets.[10,11] More accurate understanding of the epidemiology of infection and the associated patient comorbid risk factors are important considerations in the effort to mitigate their occurrence and provide patients with appropriate interventional care.

Evidence-based surgical care bundles have been devised to reduce the incidence of SSI after selective surgical procedures and improve patient outcomes. Components of these care bundles have included interventions such as weight-based, antibiotic prophylaxis; antiseptic skin preparation; appropriate hair removal; maintenance of normothermia; and glycemic control.[3,12] A meta-analysis of 13 studies involving 8515 patients has documented that the use of evidence-based care bundles can significantly lower SSI rates after open, elective, colorectal surgery compared with standard management: 7.0% compared with 15.1% (relative risk, 0.55; 95% CI, 0.39–0.77).[3] A subsequent analysis of 35 randomized controlled trials (RCTs) published in 2017 involving 17,557 patients documented a 40% reduction ($p < 0.001$) of SSIs following colorectal surgery when a care-bundle strategy was implemented.[12] In this meta-analysis, only 1 study included the analysis of antimicrobial suture (triclosan) wound closure used in its care bundle. Although antimicrobial wound closure is not documented in many of the systematic reviews and meta-analyses of surgical care bundles, the use of antimicrobial wound closure, using triclosan-coated or -impregnated sutures, is supported by level 1A clinical evidence to reduce the risk of SSIs following selective (clean, clean-contaminated, and contaminated) surgical procedures.[13–19]

The objective of the current study using a nationwide longitudinal database was to accurately assess the true incidence and actual costs associated with SSIs following colorectal procedures in the United States. The findings of this analysis suggest a potential economic and clinical outcome benefit for the inclusion of antimicrobial wound closure technology as a sentinel component of an evidence-based colorectal surgical care bundle.

MATERIALS AND METHODS

Database Analysis

A retrospective observational cohort analysis using the IBM MarketScan Commercial, Multi-State Medicaid and Medicare Supplemental databases was conducted to evaluate adult patients (≥18 years) undergoing colorectal surgery in the United States between 2014 and 2018. Colorectal surgery was defined as the index procedure using the *International Classification of Diseases*, *9th* and *10th Revision*, *Clinical Modification* (ICD-9-CM and ICD-10-CM) procedure codes and *Current Procedural Terminology* codes (Supplemental Table 1 http://links.lww.com/DCR/B355). All patients were required to have continuous enrollment for ≥12 months before and 6 months after each colorectal surgical procedure. Patients were categorized by demographic and clinical comorbidities using the 31 domains of the Elixhauser Comorbidity Index.

The following outcomes were evaluated: the rate of SSI (using diagnostic codes for superficial or deep incisional infections) identified from the 3rd to the 180th postoperative day, risk factors associated with deep incisional/organ-space SSI, and costs of infection over a 24-month follow-up period by payer type (commercial payers and Medicare). Infections identified within the first 2 days after surgery were not included because they may have been present on admission. The time from index operative procedure to any identified SSI was recorded. The full list of diagnostic codes used to inform superficial and deep incisional/organ-space infections are available in Supplemental Table 2 http://links.lww.com/DCR/B356 and Supplemental Table 3 http://links.lww.com/DCR/B357.

Statistical analyses were performed fitting the data with logistic regression models to evaluate which variables were associated with a deep incisional/organ-space SSI. Generalized linear regression models with log-link and gamma distribution were used to evaluate the adjusted total payments for patients with and without SSI. The adjusted incremental cost of each infection was calculated using least-squares means over 24 months after the index procedure. To obtain the accurate costs associated with each infection type, the IBM MarketScan database was reviewed to break down deep incisional/organ-space infections. In cases where patients had multiple readmissions throughout the study period, resulting in codes for both infection types being used, the category of both combined was retained. All payments were adjusted to a 2018 consumer price index. All regression analyses were conducted using SAS 9.0.

Cost Analysis

An exploratory cost analysis utilizing data extracted from the retrospective observational cohort, in combination with publicly available literature, was created to evaluate the potential economic impact of introducing antimicrobial wound closure after colorectal surgery to commercial payers and Medicare. A decision tree was designed and run as a Monte Carlo simulation to compare colorectal procedures in a current treatment practice with where antimicrobial suture wound closure was utilized in future practice (Fig. 1).

Key variables for each of the model branches included the differential cost of antimicrobial wound closure compared with traditional suture technology, the probability of developing an SSI with antimicrobial sutures compared to traditional sutures, and the inpatient cost of SSI. The probability of SSI with traditional sutures was assumed to be equal to the rate calculated from the retrospective observational database cohort. Because antimicrobial sutures are not likely to impact organ-space infection rates, the cost analysis was performed on superficial and deep incisional SSIs only. The SSI risk reduction with antimicrobial wound closure was taken from available publications on contaminated and dirty (class 3 or class 4) wound types.[20] Costs of SSI were taken from the 12-month adjusted cost for superficial incisional and deep SSIs from

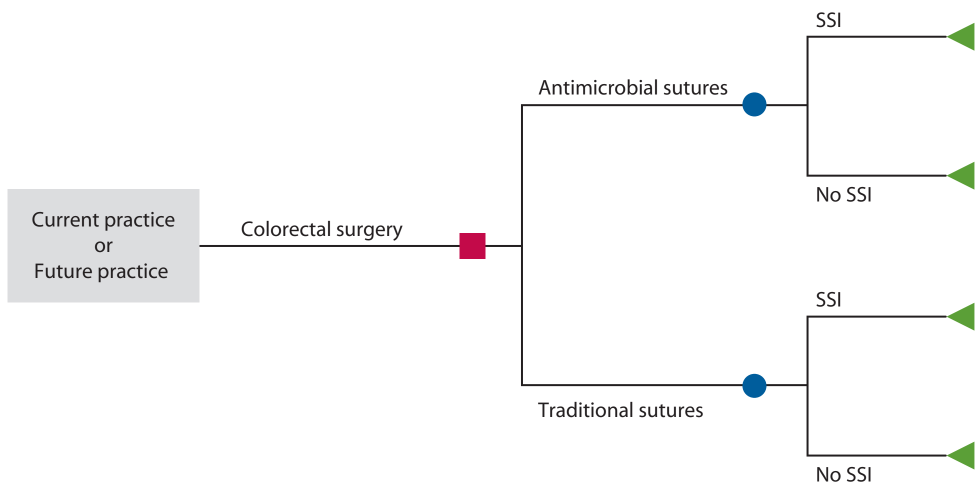

FIGURE 1. Basic structure of decision-tree cost model. The model was run for each type of payer and infection evaluated. SSI = surgical site infection.

the retrospective observational database cohort. The unit costs of traditional sutures and antimicrobial sutures were obtained from the vendor. With the probabilistic analysis, the increased incremental cost associated with antimicrobial sutures was assumed to be approximately $0.48 (USD) per suture strand, with a log-logistic distribution.

Results of the model consisted of a primary analysis that examined the incremental costs per patient over the first postoperative 12 months for superficial and deep incisional SSI. A secondary analysis, removing superficial infection rates and costs, was performed to examine the impact of deep incisional SSI only. To address uncertainty in input parameters, the results of the primary and secondary analyses were conducted probabilistically.

RESULTS

Database Analysis

A total of 107,665 patients undergoing colorectal surgery between 2014 and 2018 were included in the analysis (Fig. 2). The demographics and clinical presentation of patients at the time of their index surgery are shown in Table 1. Within 6 months of the postindex procedure, 23.9% of patients had a diagnosis of SSI after colorectal surgery. The majority of infections were classified as deep incisional/organ-space infections, accounting for 19.9% of infections; whereas the remaining 4.0% were superficial incisional infections. Differences in the risk of infection were noted for a few key populations. For example, emergency procedures had a higher risk of deep incisional/organ-space infections (29.1% vs 17.4%) and superficial incisional infections (5.2% vs 3.7%) compared with nonemergency procedures. For open versus laparoscopic procedures, deep incisional/organ-space infection rates were 25.2% and 12.7%, and superficial incisional SSI rates were 4.8% and 2.7%. For unspecified approach procedures (n = 21,015, 19.5% of total patients), the deep incisional/organ-space SSI rate was 21.1% and the superficial SSI rate was 4.4%, similar to the rates for open procedures (Table 1). Most infections, diagnosed postprocedure, occurred within 3 to 25 days (50%) and, by 2 months, 75% had been identified. A summary of patient baseline comorbidities relative to infection status at 6 months is summarized in Table 2. When analyzing the risk factors associated with deep incisional/organ-space SSIs, regression analysis found certain patient comorbidities, age, payer type, and admission type to be associated with adverse outcome (Fig. 3).

For more accurate costs associated with SSIs, deep incisional/organ-space infections were broken down into separate categories. Rates of deep incisional, organ-space, and combined deep incisional/organ-space infections were 10.6%, 4.8%, and 4.5% (Fig. 4). For the commercial payer population, after adjusting for patient demo-

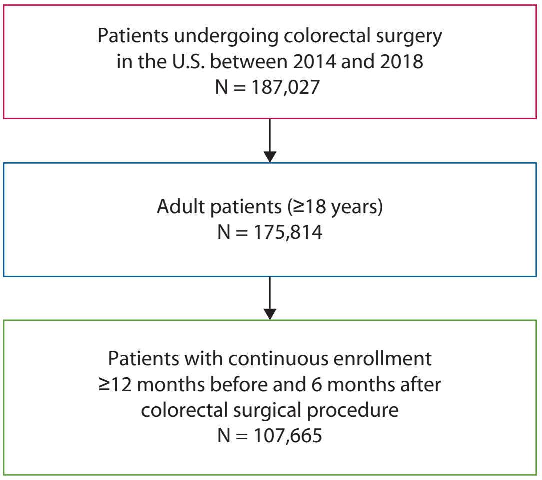

FIGURE 2. Flow diagram for included patients undergoing colorectal surgery.

TABLE 1. Demographics and clinical presentation of study patients at time of index surgery

Data categories	Overall (n = 107,665)		Deep incisional/organ-space SSI (n = 21,441)		Superficial SSI (n = 4292)		No infection (n = 81,932)	
	n	%	n	%	n	%	n	%
Male sex	50,246	46.7	9919	46.3	1997	46.5	38,330	46.8
Years								
2014	27,970	26.0	5754	26.8	1268	29.5	20,948	25.6
2015	23,110	21.5	4832	22.5	921	21.5	17,357	21.2
2016	21,725	20.2	4499	21.0	801	18.7	16,425	20.1
2017	18,714	17.4	3584	16.7	691	16.1	14,439	17.6
2018	16,146	15.0	2772	12.9	611	14.2	12,763	15.6
Age category								
18–24	3290	3.1	845	3.9	102	2.4	2343	2.9
25–34	6196	5.8	1541	7.2	268	6.2	4387	5.4
35–44	12,763	11.9	2733	12.8	500	11.7	9530	11.6
45–54	26,966	25.1	5064	23.6	1054	24.6	20,848	25.5
55–64	36,257	33.7	6840	31.9	1415	33.0	28,002	34.2
65–74	10,507	9.8	2048	9.6	420	9.8	8039	9.8
75+	11,686	10.9	2370	11.1	533	12.4	8783	10.7
Site of care								
Outpatient	5076	4.7	658	3.1	153	3.6	4265	5.2
Inpatient	102,589	95.3	20,783	96.9	4139	96.4	77,667	94.8
Admission type								
Nonemergency	84,805	78.8	14,784	69.0	3109	72.4	66,912	81.7
Emergency	22,860	21.2	6657	31.1	1183	27.6	15,020	18.3
Surgical approach								
Open	48,144	44.7	12,127	56.6	2322	54.1	33,695	41.1
Laparoscopic	38,506	35.8	4889	22.8	1042	24.3	32,575	39.8
Unspecified	21,015	19.5	4425	20.6	928	21.6	15,662	19.1
Database indicator								
Commercial	70,243	65.2	12,605	58.8	2530	59.0	55,108	67.3
Medicaid	15,690	14.6	4542	21.2	827	19.3	10,321	12.6
Medicare	21,732	20.2	4294	20.0	935	21.8	16,503	20.1
Charlson Comorbidity Index								
0	39,743	36.9	7255	33.8	1348	31.4	31,140	38.0
1–2	36,333	33.8	6909	32.2	1463	34.1	27,961	34.1
3–4	16,971	15.8	3530	16.5	753	17.5	12,688	15.5
+5	14,618	13.6	3747	17.5	728	17.0	10,143	12.4
Functional Comorbidity Index								
0	20,225	18.8	3627	16.9	649	15.1	15,949	19.5
1–2	40,003	37.2	6864	32.0	1336	31.1	31,803	38.8
3–4	28,270	26.3	5693	26.6	1181	27.5	21,396	26.1
+5	19,167	17.8	5257	24.5	1126	26.2	12,784	15.6
Elixhauser Comorbidity Index								
0	17,730	16.5	3180	14.8	556	13.0	13,994	17.1
1–2	38,363	35.6	6365	29.7	1293	30.1	30,705	37.5
3–4	27,666	25.7	5294	24.7	1139	26.5	21,233	25.9
+5	23,906	22.2	6602	30.8	1304	30.4	16,000	19.5

SSI = surgical site infection.

graphic and clinical characteristics, the incremental costs of superficial incisional SSIs were $28,866 at 6 months, $36,429 at 12 months, and $44,281 at 24 months after the index surgery. The adjusted incremental costs for deep incisional, organ-space, and combined deep incisional/organ-space SSIs ranged from $43,490 to $122,177 at 6 months, $52,628 to $144,809 at 12 months, and $64,563 to $164,471 at 24 months after the index surgery. For the Medicare population, the incremental costs for superficial SSIs were $16,026 at 6 months, $17,551 at 12 months, and $20,758 at 24 months after the index surgery. The adjusted incremental costs for deep incisional, organ-space, and combined deep incisional/organ-space SSIs ranged from $25,387 to 84,067 at 6 months, $32,456 to $102,280 at 12 months, and $45,771 to $121,274 at 24 months after the index surgery. Across the study time horizon, superficial incisional SSIs were associated with the lowest cost to payers and combined deep incisional/organ-space infections were associated with the highest cost (Table 3). The longitudinal analysis found that the cost associated with all SSI types can be substantial and increase out to 24 months after surgery.

TABLE 2. Key comorbidities of patients included in the study, at study start and based on infection status at 6 months after the index surgery

	Overall (n = 107,665)		Infection (n = 25,733)		No infection (n = 81,932)	
Elixhauser comorbidity	n	%	n	%	n	%
Hypertension, uncomplicated	50,553	47.0	12,981	50.4	37,572	45.9
Solid tumor without metastasis	32,289	30.0	6934	26.9	25,355	30.9
Chronic pulmonary disease	19,544	18.2	5813	22.6	13,731	16.8
Fluid and electrolyte disorders	18,722	17.4	6456	25.1	12,266	15.0
Cardiac arrhythmias	18,710	17.4	5559	21.6	13,151	16.1
Diabetes mellitus, uncomplicated	18,253	17.0	5234	20.3	13,019	15.9
Depression	17,380	16.1	5334	20.7	12,046	14.7
Obesity	16,865	15.7	4773	18.5	12,092	14.8
Liver disease	15,363	14.3	3867	15.0	11,496	14.0
Hypothyroidism	13,678	12.7	3482	13.5	10,196	12.4
Deficiency anemia	13,520	12.6	3743	14.5	9777	11.9
Weight loss	9990	9.3	3437	13.4	6553	8.0
Peripheral vascular disorders	9446	8.8	2846	11.1	6600	8.1
Diabetes mellitus, complicated	8360	7.8	2692	10.5	5668	6.9
Valvular disease	8186	7.6	2328	9.0	5858	7.1
Metastatic cancer	7327	6.8	2024	7.9	5303	6.5
Renal failure	6811	6.3	2213	8.6	4598	5.6
Congestive heart failure	6608	6.1	2268	8.8	4340	5.3
Hypertension, complicated	6335	5.9	1977	7.7	4358	5.3
Rheumatoid arthritis/collagen vascular diseases	5343	5.0	1660	6.5	3683	4.5
Other neurological disorders	5052	4.7	1865	7.2	3187	3.9
Blood loss anemia	4820	4.5	1311	5.1	3509	4.3
Coagulopathy	3979	3.7	1308	5.1	2671	3.3
Drug abuse	3559	3.3	1362	5.3	2197	2.7
Alcohol abuse	3248	3.0	1042	4.0	2206	2.7
Pulmonary circulation disorders	2895	2.7	1041	4.0	1854	2.3
Peptic ulcer disease	2447	2.3	715	2.8	1732	2.1
Psychoses	1665	1.5	640	2.5	1025	1.3
Paralysis	1625	1.5	847	3.3	778	0.9
Lymphoma	1103	1.0	311	1.2	792	1.0
AIDS/HIV	524	0.5	127	0.5	397	0.5

Cost Analysis

Results of the primary cost analysis suggest that the use of antimicrobial wound (fascial and incisional) closure would result in a statistically significant cost avoidance for superficial and deep incisional SSIs at 12 months compared to the current practice for both Medicare and commercial payers. Median costs avoided per patient for commercial payers and Medicare were $1170 (95% CI, $146–$4884) and $1036 (95% CI, $111–$4823) (Fig. 5). In the secondary analysis of deep incisional SSIs only, incremental costs avoided per patient were similarly reduced, with commercial payers and Medicare predicting avoidance of $809 (95% CI, $26–$4481) and $870 (95% CI, $33–$4624) per patient for antimicrobial suture wound closure (Fig. 6).

DISCUSSION

The IBM MarketScan Commercial, Multi-State Medicaid and Medicare Supplemental database is a unique, observational, cohort database study that highlights the true cost and accurate economic burden of SSIs following colorectal surgery. With over 1 in 5 patients at risk to experience an SSI within 6 months after colorectal surgery, and the cost burden of each episode ranging from $16,026 to $144,809 over 6 to 12 months, the cost of SSIs to the US health care system is substantial. These results demonstrate the importance of minimizing SSI-related costs by using evidence-based care bundles.

All surgical wounds are contaminated to some degree at closure; the primary determinant of whether the contamination is implicated in establishing a surgical infection is dependent on patient comorbid risk factors, degree of wound contamination, and immune-host tissue competency at the time of closure.[21] At first incision, sebaceous glands and hair follicles are transected, allowing skin-colonizing bacteria to contaminate the surgical wound. The intrinsic virulence of the skin flora combined with the level of contaminating bioburden can be the nidus for infection in a susceptible host. Furthermore, the rate of SSI for colorectal procedures is significantly influenced by the "layering-effect" of multiple, comorbid risk factors such as obesity, diabetes mellitus, low serum albumin, alcohol consumption, cigarette smoking, extended operative times, and anesthetic time.[22]

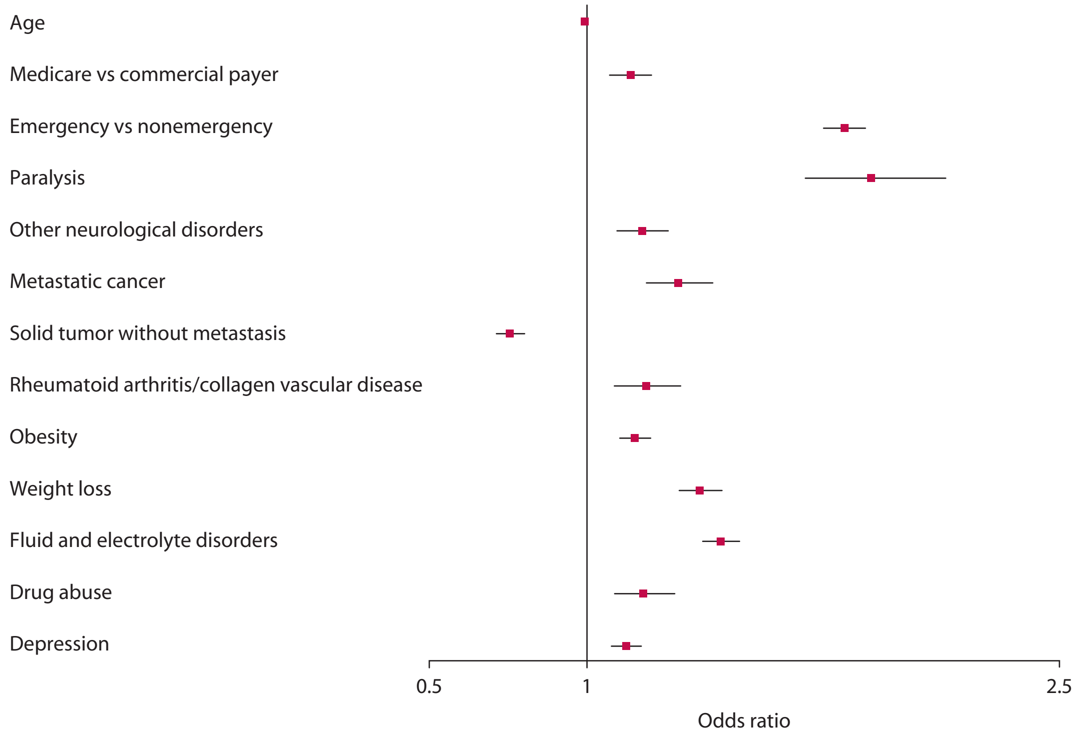

FIGURE 3. Risk factors significantly associated with deep incisional/organ-space SSI ($p < 0.001$). SSI = surgical site infection.

Several recent studies, meta-analyses, and systematic reviews have documented the beneficial role of an evidence-based surgical care bundle.[12,13,23–25] Although in most published care bundles the inclusion of antimicrobial sutures is absent from consideration, the intrinsic mechanistic benefit of antimicrobial wound closure for fascia and subcuticular closure relates to documented antimicrobial activity against both Gram-positive and Gram-negative surgical wound pathogens.[26,27]

When considering the benefits of an antimicrobial wound closure, 2 questions need answering. First, are the sutures placed in the surgical wound a potential nidus for infection? A study published in 2013 documented that traditional (nonantimicrobial) braided or monofilament sutures, excised from the infected wounds of surgical patients, demonstrated an established microbial biofilm in 100% of cases, clearly suggesting that an implanted suture, like other biomedical devices, is at high risk for early, microbial biofilm formation, and subsequent risk of SSI, when implanted within a contaminated field.[28] Second, does the level of evidence for antimicrobial sutures justify their inclusion in current, evidence-based colorectal surgical care bundles? Numerous RCTs, including multi-

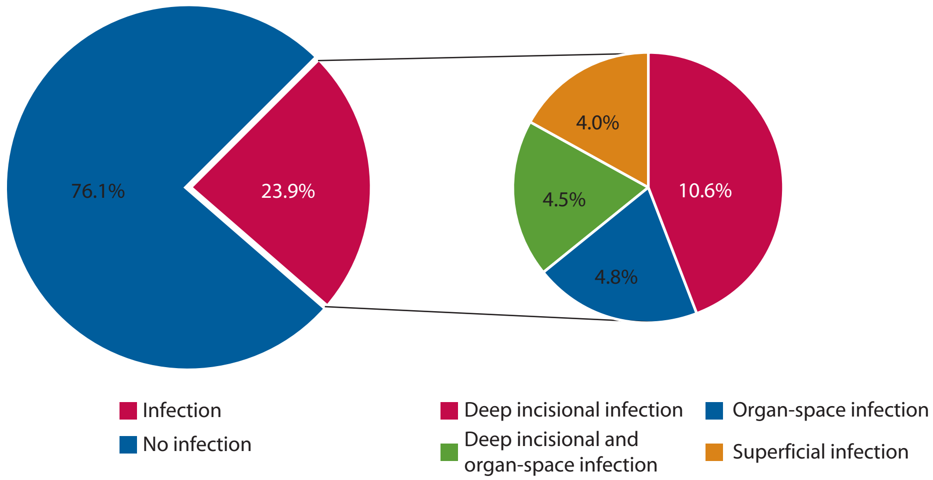

FIGURE 4. Surgical site infection rate at 6 months after the index colorectal surgery by infection type.

TABLE 3. Summary of SSI costs from the database analysis by infection type, payer, and time point

	Mean SSI cost (95% CI)			
Payers	*Deep incisional and organ-space*	*Deep incisional*	*Organ-space*	*Superficial*
Commercial payers				
6 months	$122,117 ($117,490–$127,007)	$43,490 ($42,120–$44,888)	$71,324 ($67,859–$74,904)	$28,866 ($26,690–$31,115)
12 months	$144,809 ($137,819–$152,062)	$52,628 ($50,633–$54,670)	$85,079 ($79,641–$90,747)	$36,429 ($33,085–$39,910)
24 months	$164,471 ($152,816–$176,759)	$64,563 ($61,143–$68,097)	$96,910 ($87,550–$106,844)	$44,281 ($38,538– $50,350)
Medicare				
6 months	$84,067 ($77,457–$91,069)	$25,387 ($22,884–$28,010)	$47,955 ($44,325–$51,764)	$16,026 ($12,884–$19,375)
12 months	$102,280 ($92,575–$112,670)	$32,456 ($28,832–$36,280)	$54,547 ($49,293–$60,111)	$17,551 ($13,040–$22,408)
24 months	$121,274 ($104,102–$140,169)	$45,771 ($38,679–$53,407)	$66,784 ($56,992–$77,402)	$20,758 ($12,538–$29,834)

SSI = surgical site infection.

ple systematic reviews and meta-analyses, have been conducted to compare antimicrobial sutures with traditional, nonantimicrobial sutures (braided or monofilament absorbable sutures) for closure of fascia and muscle, subcutaneous tissues, and skin. The use of antimicrobial sutures was found to be effective at significantly reducing the risk of SSI across different surgical procedures including colorectal.[19,29–34] A recent robust analysis evaluated 25 RCTs, representing 11,957 surgical patients, demonstrated that the use of antimicrobial sutures significantly reduced the risk of SSI at 30 days (relative risk, 0.73; 95% CI, 0.65–0.82). Sensitivity analysis also documented a significant SSI reduction benefit for clean, clean-contaminated, and contaminated surgical procedures.[35]

The findings of this current study are important because they not only confirm the financial burden of SSIs after colorectal procedures, which have been reported in published indirect estimates of cost, but also emphasize that the true economic burden is underrecognized. With the longitudinal nature of the database, a large cohort (n = 107,665) of "real-world" patient information was used to determine that the incidence of SSIs within 6 months of colorectal surgery was 23.9%, a finding similar to previously reported SSI rates. It is also clear that the incidence of SSI has not been underreported in the databases used in the present study, a reflection of accurate postdischarge surveillance, the accuracy of which is often marred in previous reports – a key finding that highlights the limitations of currently available literature in establishing the actual cost of SSIs after colorectal procedures over time, with the adjusted incremental cost to payers at 6 months ranging up to $122,177. In addition, the cost of SSIs to payers is not limited to the first 6 months postprocedure. Between 6 and 12 months and 12 and 24 months, costs continued to escalate for all SSI types and payers. These findings indicate that there is often a need for prolonged care for patients who experience an SSI following colorectal surgery, especially in the case of deep incisional infections or anastomotic leak (organ-space).

In this study, the costs of an SSI were found to be higher than those previously reported that have ranged from $11,778 to $42,177.[10,36] Recent National Institute of Health and Care Excellence guidelines on SSI prevention and treatment reported an average cost of managing a single patient with an SSI of £3122.86.[16] Estimated mean attributable cost of SSI treatment cited in the Centers for Disease Control and Prevention guidelines ranges from $10,443 (2005 US dollar (USD)) to $25,546 (2002 USD)

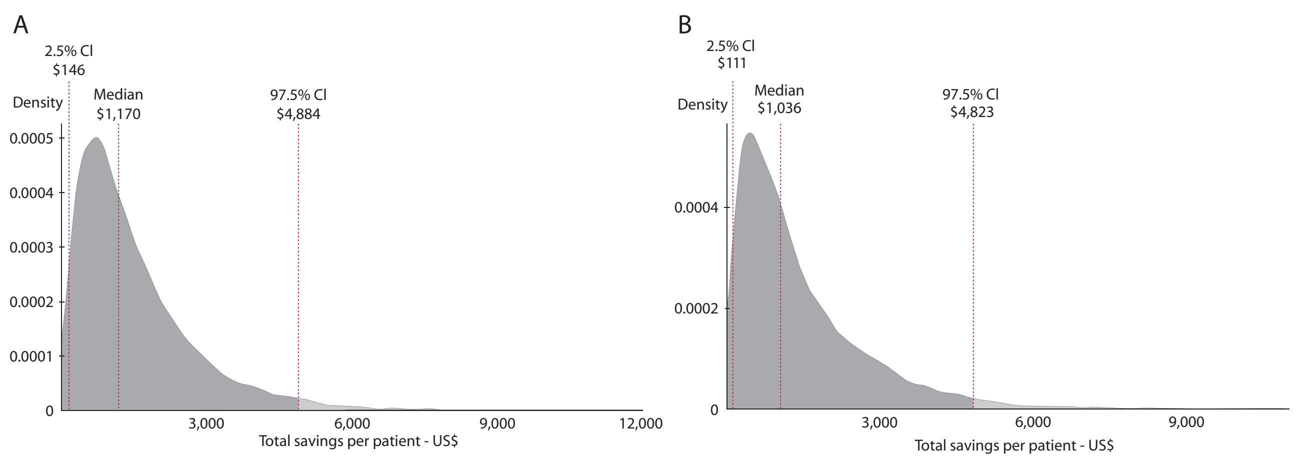

FIGURE 5. Primary cost analysis median, 95% CI, and distribution of savings per patient with antimicrobial sutures in the future practice over 12 months for deep incisional and superficial SSI: commercial payers (A) and Medicare (B). SSI = surgical site infection.

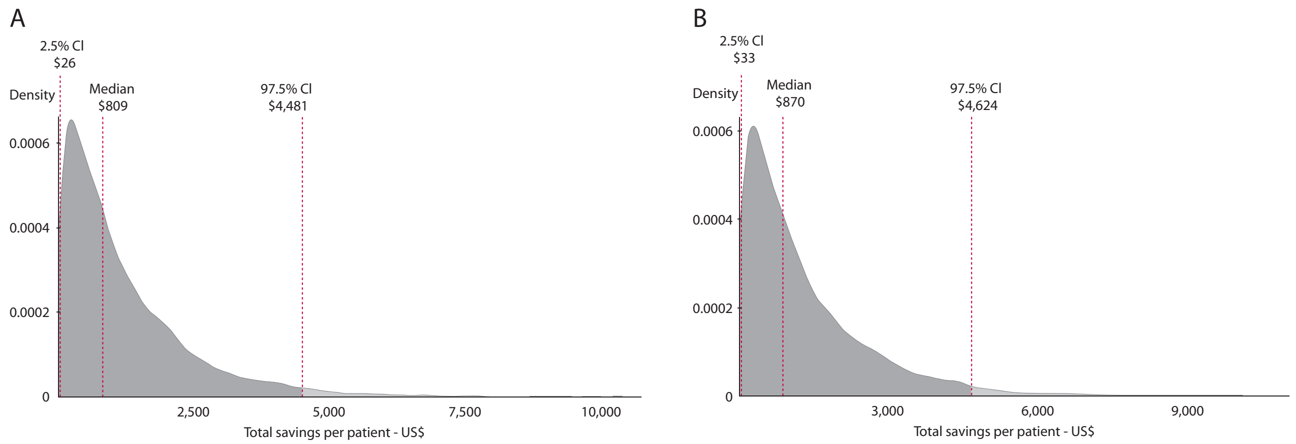

FIGURE 6. Secondary cost analysis median, 95% CI, and distribution of savings per patient with antimicrobial sutures in the future practice over 12 months for deep incisional SSI only: commercial payers (A) and Medicare (B). SSI = surgical site infection.

per SSI.[14] One reason for the disparity between these reported costs and those from this analysis, other than the extended level of postdischarge surveillance, is the increase in infection treatment costs to payers over time. Earlier reported costs were presented as 2002 to 2012 USD, whereas the costs in this study are reported in 2018 USD, although this is not likely to be the primary cause for the differences observed. In earlier publications, the most common definition for the cost of an SSI was the incremental costs to the hospital for the added inpatient stay attributable to the infection or following readmission.[36] In this analysis, costs of SSI after colorectal surgery reflect the overall cost to payers over time. These overall costs for patients provide a more accurate representation of the true cost of an SSI that has previously been underestimated by surrogate data rather than the "real world" data presented here.

Two studies involving the economic benefits associated with using an antimicrobial suture for wound closure have been recently published.[19,37] In the first study, published by Singh and colleagues,[37] the increased cost of antimicrobial sutures was minimal compared with the potential avoided costs of SSIs to third-party payers. Despite conclusions similar to the current study, there are several key differences between our analysis and those of Singh et al.[37] These differences included the population of interest (abdominal procedures), published sources for the risk and cost of infection, and the cost perspectives that were evaluated (hospital, third-party, and societal). The current analysis focuses solely on colorectal procedures using data from a large national database to inform baseline infection risk; the reduced risk of infection following the use of antimicrobial sutures, which was taken from a recent meta-analysis by Leaper and colleagues; and all the relevant costs of SSIs to different payers were captured during a 12-month period.[20] Singh et al used an overall SSI rate of 15% derived from the study of Alexander et al[38] in 2009, which evaluated morbidly obese patients. The superficial and deep incisional/organ-space SSI rates were calculated based on previously published estimates multiplied by 15%.[37] The current study utilized real-world data from over 100,000 patients to document the rates of 4.0% and 10.6% for superficial and deep incisional SSIs. Here costs avoided are presented per patient, whereas the costs from Singh et al were presented per SSI averted.[37] Compared to the recent meta-analysis and probabilistic cost analysis by Leaper et al,[20] the results presented here demonstrate that similar costs can be avoided when using antimicrobial sutures, although the magnitude of the results differ. In the United Kingdom, the costs of SSI derived from UK National Health Service sources are much lower, ranging from £3000 to £5000,[20] whereas the 12-month mean costs of an SSI used in the current study ranged from $36,429 to $52,628 for commercial payers and from $17,551 to $32,456 for Medicare for superficial and deep incisional SSIs.

The results of this study have some important limitations. As with all retrospective database observational studies, results are limited to the captured information. All information within the IBM MarketScan Commercial, Multi-State Medicaid and Medicare Supplemental databases is provided by individual health care settings and is subject to errors in incomplete hospital reporting, coding errors, or misclassification of patients; causality cannot be inferred. We were unable to control for potentially important factors including physical function, socioeconomic status, wound care, and nutritional status. The exclusion of these and other potential predictive factors could impair the accuracy of our model estimates. The occurrence of SSIs was identified based on ICD-9-CM and ICD-10-CM diagnosis codes, without the availability of laboratory confirmation, although the diagnosis of an SSI is primarily a clinical decision. Future prospective studies might be useful to supplement the results of the current analysis.

CONCLUSION

The results of this study highlight the substantial burden associated with SSI following colorectal surgery, and the potential economic benefit of including an antimicrobial suture for wound closure in an evidence-based surgical care bundle for colorectal surgery.

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