Published in final edited form as:

J Am Coll Surg. 2019 January ; 228(1): 44–53. doi:10.1016/j.jamcollsurg.2018.10.002.

Evidence-Based Bundled Quality Improvement Intervention for Reducing Surgical Site Infection in Lower Extremity Vascular Bypass Procedures

Katherine E Hekman, MD, PhD^a, Eriberto Michel, MD^b, Eddie Blay Jr, MD^c, Irene B Helenowski, PhD^d, and Andrew W Hoel, MD, FACS^a

^aDivision of Vascular Surgery, Department of Surgery, Northwestern University Feinberg School of Medicine, Northwestern Medicine, Chicago, IL

^bDivision of Cardiac Surgery, Department of Surgery, Northwestern University Feinberg School of Medicine, Northwestern Medicine, Chicago, IL

^cSurgical Outcomes and Quality Improvement Center (SOQIC), Department of Surgery, Northwestern University Feinberg School of Medicine, Northwestern Medicine, Chicago, IL

^dDepartment of Preventive Medicine, Northwestern University Feinberg School of Medicine, Northwestern Medicine, Chicago, IL

Abstract

Background: Surgical site infection (SSI) poses a significant burden to patients and healthcare resources. Vascular Quality Initiative (VQI) data identify a higher rate of SSI for lower extremity bypass surgery than other vascular procedures. Bundled interventions have successfully reduced SSI in other surgical procedures.

Study Design: We evaluated our institution-specific VQI data for modifiable risk factors associated with index hospitalization SSI from January 2012 through October 2015. We implemented an evidence-based lower extremity bypass surgery SSI reduction bundle (perioperative chlorhexidine showers and transverse groin incisions) and prospectively enrolled all patients who had lower extremity bypass procedures, with a target adherence rate of 50% per bundle component. Bundle adherence and SSI events were measured from March 2016 through August 2017. We carried out a pre-post evaluation of bundle effectiveness in reducing index hospitalization SSI.

Results: In the pre-intervention period, 43/234 patients (18%) had SSI events. The only risk factors associated with SSI (female sex, diabetes, overweight body mass index) were not readily

Corresponding author: Andrew W Hoel, MD, FACS, Division of Vascular Surgery, Department of Surgery, Northwestern University, 676 N St Clair St Ste 650, Chicago, IL 60611, andrew.hoel@nm.org, 312-695-6107.

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Disclosure Information: Nothing to disclose.

Presented at the American College of Surgeons 104th Annual Clinical Congress, Scientific Forum, Boston, MA, October 2018.

modifiable. In an 18-month period after introduction of our intervention, adherence rates to pre-operative chlorhexidine showers, a transverse incision and a post-operative chlorhexidine shower were 71% (52/73), 48% (24/50) and 88% (64/73), respectively. Compliance with all applicable bundle components was 36% (26/73). The SSI rate post-intervention decreased from 18% to 4% (3/73). Intention-to-treat multivariable analysis showed a 97% SSI risk reduction with the bundle ($p=0.002$). As-treated analysis identified an 85% ($p=0.02$) and 62% ($p=0.047$) SSI risk reduction from the pre-operative and post-operative chlorhexidine showers, respectively.

Conclusion: In this evaluation study of the effectiveness of a quality improvement intervention, SSIs were markedly decreased after implementation of our evidence-based bundle for lower extremity vascular bypass procedures.

Precis

Institution-level Vascular Quality Initiative data yielded a paucity of modifiable risk factors for surgical site infection (SSIs). An evidence-based bundled intervention including chlorhexidine showers and transverse groin incisions was systematically implemented and effectively reduced SSI in lower extremity vascular bypass patients.

Keywords

SSI; vascular bypass; bundled intervention; chlorhexidine showers

Introduction

Surgical site infection (SSI) poses a significant burden both to patients and healthcare resources. Among vascular surgery procedures, the lower extremity bypass has the highest rate of SSI, at approximately 10%.¹ These SSI events lead to prolonged hospital stays and greater resource utilization.² More importantly, in the setting of concomitant microvascular disease impeding wound healing and often the presence of an implanted prosthetic bypass conduit, SSI can have devastating consequences such as loss of limb or even loss of life.¹

Several risk factors contributing to SSI have been identified for lower extremity bypass patients, including female sex, diabetes, smoking, obesity, steroid use, and prosthetic bypass conduit.^{3–7} While many SSI risk factors are not readily amenable to modification, bundled interventions targeting modifiable risk factors have successfully reduced SSI in other surgical procedures.^{2,8,9} Despite the significant sequelae of SSI, a prospectively validated bundled intervention to reduce SSI for lower extremity vascular bypass surgery has yet to be described.

Our hypothesis was that a bundled intervention could be used to target modifiable risk factors for SSI in lower extremity bypass patients and be implemented successfully, reducing SSI events. Our goal in the present study was threefold: First, we aimed to utilize the Vascular Quality Initiative (VQI) data from our institution to identify risk factors for SSI in our lower extremity bypass patients, and to use these data along with existing literature to generate a bundled intervention targeting modifiable risk factors for SSI. Our second goal was to successfully implement a bundled intervention based on these findings. Third, we aimed to evaluate the efficacy of this bundled intervention in reducing SSI events.

Methods

Study Design

This retrospective and prospective chart review was reviewed and deemed exempt by the Institutional Review Board at Northwestern University. Institutional VQI data were utilized to identify pre-intervention patients who underwent lower extremity bypass surgery from January 1, 2012, through October 15, 2015. Inclusion criteria were the same as for inclusion into the VQI lower extremity bypass module. Institutional VQI data were pulled every 6 months after implementation of the bundle to track outcomes from March 1, 2016, through August 31, 2017. Patient demographics, comorbidities, intraoperative factors, and SSIs during the index hospitalization were drawn from the VQI data. SSI was defined as per the VQI criteria: the presence of a positive culture or the use of antibiotics during the index hospitalization. Bundle compliance was monitored through supplemental chart review.

SSI bundle

The SSI bundle was developed through the input of a multidisciplinary team, including surgeons, house staff, clinic nurses, Advanced Practice Providers (APPs), unit nurses and patient care technicians. The bundle implementation was coordinated by the lead author (K.E.H.) who met with the study stakeholders regularly to discuss bundle compliance and SSI outcomes, and to address any barriers to bundle implementation.

The bundle was devised using evidence-based factors and practical suggestions from the multidisciplinary team. The final bundle included pre-operative chlorhexidine showers, one the night before surgery and one the morning of surgery; a transverse groin incision when clinically applicable; and a chlorhexidine shower within two post-operative days, when the dressings were removed. All study stakeholders were educated on the importance of preventing SSI and on the bundle components. This was conducted through division quality improvement meetings for surgeons, house staff and inpatient APPs; through meetings with clinic APPs and with unit nursing leadership; and during morning huddles for unit nurses and patient care technicians.

For the pre-operative chlorhexidine showers, patients were provided chlorhexidine soap and written instructions at the time of their clinic visit, following Edmiston, et al.¹⁰ The scheduling coordinator called all patients the day before surgery to remind them of the details for their surgery, including the need to complete the pre-operative showers. For inpatient showers, chlorhexidine soap was routinely stocked on the units of our institution prior to bundle implementation. Inpatients were also provided a laminated placard in their room to check off completion of their shower tasks, before and after surgery. In circumstances where patients had significantly impaired mobility, particularly in the post-operative period, a “bed-bath” was substituted for a full shower.

Groin incision type and post-operative shower during hospitalization were routinely documented in the electronic medical record prior to implementation of the bundle. The pre-operative history and physical form was modified to include a check box for compliance with the pre-operative chlorhexidine shower regimen. Target compliance was set at 50% per component.

Statistical Analysis

VQI data are reported to the institution without risk adjustment. To adjust for covariates, a pre-post-intervention “intention-to-treat” analysis was performed to assess the effect of the bundle on SSI outcomes, in which a multivariable logistic regression model for SSI was used that included the pre-specified covariates and also an indicator variable for the intervention period [post-intervention vs. pre-intervention (reference)] as a covariable in the model. A secondary analysis using the bundle components as-treated was done to test the effect of the various components of the bundle on SSI outcomes. Patients with missing values for covariates were excluded from the analyses by Stata. Distributions of demographic and baseline characteristics were compared with a Fisher’s exact test. Odds ratios were generated in a univariate analysis to identify risk factors associated with SSI in our pre-intervention group. Pre- and post-intervention hospital length of stay were compared with a two-sided Student’s t-test.

Results

Patient population

During the pre-intervention period examined, 234 patients underwent lower extremity bypass surgery. In our post-intervention period, 73 patients underwent lower extremity bypass surgery. Patient demographic and baseline characteristics for the pre- and post-intervention arms are represented in Table 1. The difference in sex distribution between our pre- and post-intervention cohorts was not statistically significant (60.7% vs 72.6% males, $p = 0.07$). The groups did not differ significantly in percentage of diabetes (45.7% vs 47.2%), past or current smokers (78.2% vs 81.9%), patients with prior lower extremity bypass surgery (37.2% vs 34.7%), or the urgency of the index case (73.5% vs 75.3% elective). The groups did differ in the distribution of body mass index (BMI) quartiles, as the post-intervention group had fewer patients in the highest and lowest BMI quartiles (46% vs 71% in the middle quartiles, $p = 0.002$ for distribution amongst all quartiles). The groups also differed in the distribution of indications for bypass surgery. The post-intervention group had a lower frequency of rest pain and a higher frequency of acute ischemia as compared with the pre-intervention group (post- vs pre-intervention 19.2% vs 37.6% for rest pain, and 31.5 vs 12.8% for acute ischemia, $p = 0.001$).

We evaluated our pre-intervention arm for risk factors associated with SSI in a univariate analysis. Diabetes (OR 2.59; 95% CI:1.29, 5.18; $p = 0.007$) and female sex (OR 2.17; 95% CI: 1.11, 4.27; $p = 0.02$) were associated with SSI (Table 2).

Bundle compliance

Bundle compliance rates over an 18-month period after implementation are shown in Figure 1. Both pre- and post-operative shower components achieved 71% ($N=52/73$) and 88% ($N=64/73$) compliance, meeting the target rate of 50% compliance. The transverse incision component achieved 48% ($N=24/50$) compliance, just below the target compliance rate, but 3-fold higher than pre-intervention. Of note, only 35.6% ($N=26/73$) of patients received all relevant components of the bundle (pre-operative showers with transverse groin incision and

post-operative shower for patients with a groin incision; pre- and post-operative showers for patients without a groin incision).

SSI Outcome

In our pre-intervention period, there were 43 SSI events, representing an SSI rate of 18.4%. In our post-intervention group, there were 3 SSI events, representing an SSI rate of 4.1% (Figure 1). An “intention-to-treat” multivariable analysis was carried out to evaluate the effect of the bundle while adjusting for covariates: sex, BMI quartile (derived from the entire cohort), history of smoking, diabetes, dialysis, pre-operative hemoglobin, history of a prior bypass, indication for bypass, type of conduit, and type of groin incision (when applicable). This multivariable analysis showed a 97% SSI risk reduction with the bundle ($p=0.002$) (Table 3). Additional variables emerged as risk factors for SSI in our multivariable model, including the third BMI quartile (OR 5.08; 95% CI: 1.59, 16.23; $p = 0.008$) and female sex (OR 3.09; 95% CI: 1.34, 7.12; $p = 0.008$). Since the main outcome was SSI during the index hospitalization, we compared the average length of stay pre- and post-intervention. For patients without SSI, there was no significant difference in the post-operative length of stay between pre- and post-intervention cohorts (mean + standard deviation, $7.94 + 8.32$ days vs $7.67 + 6.24$ days, $p=0.80$). The occurrence of SSI, however, was significantly associated with an extended post-operative length of stay across the entire cohort (mean + standard deviation, with SSI $11.78 + 6.01$ vs without SSI $7.87 + 7.81$, $p=0.0014$.)

We next ran our multivariable model, using the same covariates as above, with each of the three individual bundle components as-treated. In the as-treated analysis for the pre-operative chlorhexidine showers alone, the showers conferred an 85% SSI risk reduction (OR 0.15; 95% CI: 0.03, 0.70; $p = 0.02$) (Table 4). In this pre-operative shower multivariable model, female sex (OR 3.07; 95% CI: 1.40, 6.72; $p = 0.005$) and the third BMI quartile (OR 2.96; 95% CI: 1.03, 8.54; $p = 0.04$) remained significant risk factors for SSI. This individual as-treated analysis for the post-operative chlorhexidine shower element also found female sex to be a risk factor for SSI, and showed a 62% SSI risk reduction from the post-operative chlorhexidine showers (OR 0.38; 95% CI: 0.15, 0.99; $p = 0.047$). Finally, the model examining the transverse incision by itself did not find this element to be associated with a significant risk reduction. However, this transverse incision multivariable model additionally found diabetes to be associated with SSI (OR 2.75; 95% CI: 1.06, 7.10; $p = 0.04$), while current/prior smoking (OR 0.29; 95% CI: 0.11, 0.82; $p = 0.02$) and non-autogenous conduit (OR 0.37; 95% CI: 0.14, 0.93; $p = 0.03$) were found to be protective against SSI.

Discussion

In this analysis we showed 1) a paucity of modifiable risk factors for SSI in our patient cohort, 2) successful implementation of a bundled SSI reduction intervention based on prior literature, and 3) SSI risk reduction in our patients with implementation of this intervention.

Our analysis of the pre-intervention cohort did not reveal any readily modifiable risk factors for inclusion in our bundled intervention. In the univariate analysis of our pre-intervention cohort, only female sex and diabetes were associated with SSI, whereas the multivariable analysis, adjusting for covariates of the entire cohort, additionally found BMI to be

associated with SSI. We did, however, identify from the literature that chlorhexidine showers and transverse groin incisions reduced SSI in other, similar patient cohorts. Our evidence-based bundle, therefore, was based on the existing literature.

Implementation of the bundled intervention to reduce SSI met our target rate of compliance for the pre- and post-operative chlorhexidine showers, likely due in part to the ongoing feedback of compliance rates communicated through regular meetings with stakeholders. Transverse groins incisions, when a groin incision was used, fell short of the target compliance rate likely due to inadequate anatomic exposure for certain types of procedures. Overall compliance with all applicable bundle components was 35.6%, limited primarily by the low adherence to the transverse groin incision component. The SSI rates in our cohort fell from 18.4% to 4.1% after 18 months of bundle implementation. “Intention-to-treat” analysis adjusting for covariates showed a 97% SSI risk reduction with the bundle. The as-treated analysis for each bundle component individually suggested that the pre-operative and post-operative showers drove the index hospitalization SSI reduction effect of the bundle. Given the nature of the quality improvement process, the stakeholder investment required to implement an initiative may have contributed to improved awareness and engagement of the treatment team regarding SSI prevention. This may have contributed non-measurable effects on the SSI reduction seen here. Nonetheless, these results showed significant SSI risk reduction after implementation of our evidence-based bundle in our lower extremity vascular bypass patient population.

The SSI risk factors in our population, female sex, diabetes and BMI, agree with previously published studies.^{3–5,7} However, our analysis did not find significant association between SSI other commonly cited risk factors in lower extremity bypass patients, such as smoking, dialysis or procedure indication. These prior studies, however, examined 30-day infection rates, and there may be a different subset of risk factors for SSI events that occur during the index hospitalization versus within 30 days of the operation. Furthermore, several of these studies examined only subsets of lower extremity bypass patients undergoing specific approaches, and reported 30-day SSI risk factors including critical limb ischemia, prior bypass operation, use of non-autogenous grafts, the in situ autogenous technique and location of distal bypass target (anterior tibial or dorsalis pedis arteries).^{3,5,6,11,12} This may reflect a difference due to the inclusion of different technical approaches aside from the in-situ approach in our cohort.

In a larger study looking at index hospitalization SSI, Kalish, et al, utilized the VQI database to analyze risk factors in 7,908 lower extremity bypass cases across 45 states. In univariate analysis, they found an association between SSI and obesity, dialysis, pre-operative tissue loss and vein graft conduit.⁷ While prior reports conflict on the positive versus negative association between SSI and non-autogenous bypass conduit, our as-treated results corroborate the findings of Kalish, et al,^{5–7,13} that non-autogenous conduit does not significantly affect SSI risk. However, we found no association with dialysis and pre-operative tissue loss. This unique set of risk factors for SSI may be a consequence of the smaller sample size in our study. These differences could also relate to regional variation in demographics and risk factors, as our study is limited to a single institution.

Our study is also the first to report efficacy of chlorhexidine showers for reducing SSI in vascular patients, although it has been shown to be an effective component of *Staphylococcus aureus* decolonization prior to certain orthopedic procedures.^{14–16} Most studies evaluating chlorhexidine showering across diverse populations of surgical patients have not identified a significant SSI risk reduction.¹⁵ This may have been due a lower baseline rate of SSI, a lack of an optimized showering regimen, differences in patient populations, heterogeneity of procedures to which the showers were applied, or that the pre-operative shower was not used in conjunction with routine post-operative showering as in our bundled approach.¹⁰

There are several limitations to our study. These include being a single center study and the small sample size. The small sample size impacted our study in two ways. First, it likely impaired our ability to identify SSI risk factors specific to our patient population. Second, with only 3 SSI events in the post-intervention period, this low rate of SSI significantly limited our ability to apply and interpret conventional parametric statistical evaluations. Furthermore, our pre- and post-intervention cohorts were not identical with significant differences in the distributions of BMI and in indication for surgery. As for BMI, the third quartile was associated with SSI, and the post-intervention population had a higher percentage of patients in this quartile, suggesting this difference would be unlikely to skew our post-intervention SSI rate down. As for indication for surgery, there was a trend towards fewer patients with rest pain and more with acute ischemia in the post-intervention period. It is difficult to interpret the impact this shift may have had on the SSI rate, as our study did not identify an association between any indication category and SSI. Prior studies identified tissue loss or limb salvage as risk factors, but this category remained steady between pre- and post-intervention cohorts. Lastly, the VQI SSI metric is defined as an SSI that occurs during the index hospitalization, which does not capture all clinically significant SSI and renders comparison of our findings to the existing literature more difficult. The index hospitalization SSI metric, however, is uniformly captured, facilitating more reliable analyses. With no significant difference in the post-operative length of stay before and after our intervention, this metric captured the same SSI risk window pre- and post-intervention. Furthermore, in our cohort of 307 patients, only 185 had 30-day SSI outcomes in the VQI database, impeding meaningful analysis. This was, in part, because the 30-day outcome metric in VQI was initiated midway through our evaluation period. Analyzing the index hospitalization SSI rate allowed us to accurately track our target outcome throughout the duration of our evaluation period.

Conclusion

Our study represents a successful systematic implementation of an evidence-based SSI reduction bundled intervention. Furthermore, our results suggest that pre- and post-operative chlorhexidine showers can be employed to lower surgical site infections in lower extremity bypass patients. Importantly, these findings also show that institution level quality improvement data can be evaluated for risk factors, and that a bundled intervention can be successfully implemented to lower SSI in vascular bypass patients.

Acknowledgement

The authors would like to acknowledge Dr. Anthony Yang and Jeanette Chung, PhD, for their support and intellectual contributions to the design of this study. The authors would also like to acknowledge Dr. Mark Eskandari for his support of this project, and the team of Vascular Surgery Advanced Practice Providers who worked diligently to implement the bundle – Rita Herm-Barabasz, PhD, Rebekkah Sobolewski, Kathryn Carey, Jennifer Schroeder, Jo-Anna McGrath, Lauren Broucek, Matthew Meador and Kara Easton.

Support: Dr Hekman is supported by NIH grant 1F32HL137292 and Dr Blay is supported by NIH grant 5T32HL094293.

References

1. Bandyk DF. Vascular surgical site infection: risk factors and preventive measures. *Semin Vasc Surg* 2008;21:119–123. [PubMed: 18774446]
2. Keenan JE, Speicher PJ, Thacker JK et al. The preventive surgical site infection bundle in colorectal surgery: an effective approach to surgical site infection reduction and health care cost savings. *JAMA Surg* 2014;149:1045–1052. [PubMed: 25163027]
3. Wengrovitz M, Atnip RG, Gifford RRM et al. Wound complications of autogenous subcutaneous infrainguinal arterial bypass surgery: Predisposing factors and management. *J Vasc Surg* 1990;11:156–163. [PubMed: 2296096]
4. Neumayer L, Hosokawa P, Itani K et al. Multivariable predictors of postoperative surgical site infection after general and vascular surgery: results from the patient safety in surgery study. *J Am Coll Surg* 2007;204:1178–1187. [PubMed: 17544076]
5. Fischer JP, Nelson JA, Mirzabeigi MN et al. Prophylactic muscle flaps in vascular surgery. *J Vasc Surg* 2012;55:1081–1086. [PubMed: 22209610]
6. Johnson JAC TH; Strutt PJ; Gundersen AL Wound Complications after Infrainguinal Bypass. *Arch Surg* 1988;123:859–862. [PubMed: 3382352]
7. Kalish JA, Farber A, Homa K et al. Factors associated with surgical site infection after lower extremity bypass in the Society for Vascular Surgery (SVS) Vascular Quality Initiative (VQI). *J Vasc Surg* 2014;60:1238–1246. [PubMed: 24953898]
8. Johnson MP, Kim SJ, Langstraat CL et al. Using Bundled Interventions to Reduce Surgical Site Infection After Major Gynecologic Cancer Surgery. *Obstetrics and gynecology* 2016;127:1135–1144. [PubMed: 27159744]
9. Hewitt DB, Tannouri SS, Burkhart RA et al. Reducing colorectal surgical site infections: a novel, resident-driven, quality initiative. *Am J Surg* 2017;213:36–42. [PubMed: 27427296]
10. Edmiston CE Jr., Lee CJ, Krepel CJ et al. Evidence for a Standardized Preadmission Showering Regimen to Achieve Maximal Antiseptic Skin Surface Concentrations of Chlorhexidine Gluconate, 4%, in Surgical Patients. *JAMA Surg* 2015;150:1027–1033. [PubMed: 26308490]
11. Feigenbaum HS, Reifsnnyder TS, Bandyk DS, Seabrook GS and Kinney ES. Wound complications of the in situ saphenous vein bypass technique. *J Vasc Surg* 1992;15:0843–0850.
12. Schwartz MEH EB, Schanzer H Wound Complications after In Situ Bypass. *J Vasc Surg* 1988;7:802–807. [PubMed: 3373622]
13. Szilagyi DES RF; Elliott JP; Vrandecic MP Infection in Arterial Reconstruction with Synthetic Grafts. *Ann Surg* 1972;176.
14. Lynch W, Davey PG, Malek M, Byrne DJ and Napier A. Cost-effectiveness analysis of the use of chlorhexidine detergent in preoperative whole-body disinfection in wound infection prophylaxis. *J Hosp Infect* 1992;21:179–191. [PubMed: 1353510]
15. Webster J and Osborne S. Preoperative bathing or showering with skin antiseptics to prevent surgical site infection. *Cochrane Database Syst Rev* 2012:CD004985.
16. Chen AF, Wessel CB and Rao N. Staphylococcus aureus screening and decolonization in orthopaedic surgery and reduction of surgical site infections. *Clin Orthop Relat Res* 2013;471:2383–2399. [PubMed: 23463284]

Figure 1.

Surgical site infection reduction bundle results. Compliance with each component of the bundle 18 months after implementation showed a significant increase in utilization of the bundle components compared to pre-intervention ($p<0.0001$ for each component).

Compliance with all 3 bundle components was 35.6%. In-hospital surgical site infection rates in infrainguinal bypass surgeries fell from 18% to 4% after implementation of the surgical site infection reduction bundle ($p=0.002$).

Table 1:

Demographic and Baseline Characteristics, as well as SSI Outcome Events, of the Pre-Intervention (January 2012 through October 2015) and Post-Intervention (March 2016 through August 2017) Cohorts

Variable	Pre-intervention (N=234), n (%)	Post-intervention (N=73), n (%)	p Value
Factor			
Male sex	142 (60.7)	53 (72.6)	0.07
Diabetes	107 (45.7)	34/72 (47.2)	0.89
BMI quartile, kg/m ²			
23.5	62 (26.5)	10/72 (13.9)	0.002*
23.5<BMI 26.8	58 (24.8)	23/72 (31.9)	
26.8<BMI 31.5	49 (20.9)	28/72 (38.9)	
>31.5	65 (27.8)	11/72 (15.3)	
Prior bypass	87 (37.2)	25/72 (34.7)	0.78
Dialysis	20 (8.5)	6/71 (8.45)	0.99
Smoking	183 (78.2)	59/72 (81.9)	0.62
Indication			
Asymptomatic/claudication	47 (20.1)	15 (20.5)	0.001*
Rest pain	88 (37.6)	14 (19.2)	
Tissue loss	69 (29.5)	21 (28.8)	
Acute ischemia	30 (12.8)	23 (31.5)	
Preoperative hemoglobin, g/dL			
12	113 (48.3)	37 (50.7)	0.89
>12	118 (51.1)	36 (49.3)	
Urgency			
Elective	172 (73.5)	55 (75.3)	0.97
Urgent	51 (21.8)	15 (20.5)	
Emergent	11 (4.7)	3 (4.1)	
Non-autogenous conduit	120 (52.3)	38 (52.1)	1.0
Outcome			
Surgical site infection	43 (18.4)	3 (4.1)	0.002*

Smoking defined as past or current.

* Statistically significant

Table 2:

Results from univariate logistic regression models for surgical site infection (SSI) as outcome and selected risk factors as predictors in the pre-intervention study population. Ref = reference value

Factor, category	Odds ratio [95% CI]	p Value
Sex		
Male	Ref	
Female	2.17 [1.11, 4.27]	0.02 *
Diabetes		
None	Ref	
Managed with diet, non-insulin medication, or insulin	2.56 [1.29, 5.18]	0.007 *
BMI quartile, kg/m ²		
23.5	Ref	
23.5<BMI 26.8	1.47 [0.50, 4.37]	0.57
26.8<BMI 31.5	2.69 [0.97, 7.45]	0.16
>31.5	2.49 [0.94, 6.58]	0.22
Prior bypass		
No	Ref	
Yes	0.72 [0.35, 1.47]	0.37
Dialysis		
Never on dialysis/functioning transplant	Ref	
On dialysis	1.58 [0.54, 4.61]	0.41
Smoking		
Never	Ref	
Past or current	0.75 [0.35, 1.63]	0.47
Indication		
Asymptomatic/ Claudication	Ref	
Rest Pain	1.00 [0.39, 2.57]	0.53
Tissue Loss	0.73 [0.26, 2.06]	0.12
Acute Ischemia	2.71 [0.92, 8.01]	0.01
Preoperative hemoglobin, g/dL		
>12	Ref	
12	1.56 [0.79, 3.06]	0.21
Urgency		
Elective	Ref	
Urgent	1.32 [0.59, 2.95]	0.59
Emergent	2.94 [0.81, 10.71]	0.15
Non-autogenous conduit		
Autogenous vein	Ref	
Other	0.70 [0.37, 1.31]	0.26

* Statistically significant

Author Manuscript

Author Manuscript

Author Manuscript

Author Manuscript

Table 3:

Results from Multivariable Logistic Regression for Surgical Site Infection as Outcome with Selected Risk Factors and the “Intention-To-Treat” with the Bundled Intervention as an Indicator Covariable (N=295)

Factor, category	Odds ratio [95% CI]	p Value
Intention-to-treat		
Pre-intervention	Ref	
Post-intervention	0.032 [0.004, 0.277]	0.002 *
Sex		
Male	Ref	
Female	3.09 [1.34, 7.12]	0.008 *
Diabetes		
None	Ref	
Managed with diet, non-insulin medication, or insulin	1.92 [0.85, 4.34]	0.12
BMI quartile, kg/m ²		
BMI 23.5	Ref	
23.5<BMI 26.8	1.28 [0.39, 4.25]	0.21
26.8<BMI 31.5	5.08 [1.59, 16.23]	0.008 *
31.5<BMI	2.66 [0.88, 7.99]	0.40
Prior bypass		
No	Ref	
Yes	0.55 [0.23, 1.28]	0.17
Dialysis		
Never on dialysis/functioning transplant	Ref	
On dialysis	1.38 [0.73, 2.60]	0.32
Smoking		
Never	Ref	
Past or current	0.57 [0.24, 1.38]	0.21
Indication		
Asymptomatic/ Claudication	Ref	
Rest pain	0.63 [0.22, 1.82]	0.20
Tissue loss	0.48 [0.15, 1.58]	0.06
Acute ischemia	2.77 [0.68, 11.20]	0.02
Preop Hemoglobin, g/dL		
>12	Ref	
12	1.04 [0.47, 2.28]	0.93
Urgency		
Elective	Ref	
Urgent	1.09 [0.41, 2.90]	0.76
Emergent	1.71 [0.30, 9.57]	0.57

Factor, category	Odds ratio [95% CI]	p Value
Conduit		
Autogenous vein	Ref	
Other	0.66 [0.30, 1.44]	0.29
Groin incision		
None	Ref	
Vertical incision	0.81 [0.29, 2.26]	0.28
Transverse incision	1.58 [0.44, 5.76]	0.29

* Statistically significant

Results from Multivariable Logistic Regressions for Surgical Site Infection as Outcome with Selected Risk Factors and Each Bundle Element As-Treated as an Indicator Covariable

Table 4:

Factor, category	Odds ratio [95% CI]	p Value	Odds ratio [95% CI]	p Value	Odds ratio [95% CI]	p Value
As-treated						
Preop chlorhexidine shower (N=301)	0.15 [0.03, 0.70]	0.02 *				
Transverse vs vertical incision (N=229)			1.01 [0.37, 2.80]	0.98		
Postop chlorhexidine shower (N=301)					0.38 [0.15, 0.99]	0.047 *
Sex						
Male	Ref		Ref		Ref	
Female	3.07 [1.40, 6.72]	0.005 *	4.66 [1.81, 12.01]	0.002 *	2.87 [1.33, 6.19]	0.007 *
Diabetes						
None	Ref		Ref		Ref	
Managed with diet, non-insulin medication, or insulin	1.95 [0.89, 4.27]	0.10	2.75 [1.06, 7.10]	0.04 *	2.07 [0.94, 4.57]	0.07
BMI quartile, kg/m ²						
BMI 23.5	Ref		Ref		Ref	
23.5<BMI 26.8	0.86 [0.28, 2.61]	0.12	1.17 [0.30, 4.54]	0.39	0.88 [0.29, 2.63]	0.13
26.8<BMI 31.5	2.96 [1.03, 8.54]	0.04 *	4.01 [1.14, 14.14]	0.01 *	2.81 [0.97, 8.11]	0.048
31.5<BMI	1.97 [0.72, 5.41]	0.36	1.67 [0.45, 6.16]	1.00	1.98 [0.72, 5.44]	0.34
Prior bypass						
No	Ref		Ref		Ref	
Yes	0.53 [0.24, 1.18]	0.12	0.93 [0.36, 2.38]	0.88	0.51 [0.23, 1.14]	0.10
Dialysis						
Never on dialysis/functioning transplant	Ref		Ref		Ref	
On dialysis	1.32 [0.72, 2.44]	0.37	0.77 [0.33, 1.82]	0.55	1.27 [0.69, 2.32]	0.44
Smoking						
Never	Ref		Ref		Ref	
Past or current	0.54 [0.24, 1.23]	0.14	0.31 [0.12, 0.81]	0.02 *	0.60 [0.27, 1.35]	0.22
Indication						

Factor, category	Odds ratio [95% CI]	p Value	Odds ratio [95% CI]	p Value	Odds ratio [95% CI]	p Value
Asymptomatic/claudeication	Ref		Ref		Ref	
Rest pain	0.74 [0.27, 2.05]	0.53	0.98 [0.31, 3.16]	0.43	0.72 [0.26, 1.99]	0.56
Tissue loss	0.45 [0.14, 1.43]	0.04	0.33 [0.08, 1.36]	0.05	0.42 [0.13, 1.35]	0.04
Acute ischemia	1.99 [0.56, 7.01]	0.048	0.99 [0.22, 4.51]	0.56	1.81 [0.52, 6.25]	0.06
Preop hemoglobin, g/dL						
>12	Ref		Ref		Ref	
≤12	1.25 [0.58, 2.66]	0.57	1.14 [0.46, 2.79]	0.78	1.22 [0.57, 2.59]	0.61
Urgency						
Elective	Ref		Ref		Ref	
Urgent	1.15 [0.46, 2.85]	0.61	2.32 [0.81, 6.62]	0.96	1.21 [0.49, 2.99]	0.77
Emergent	2.27 [0.49, 10.54]	0.32	[‡]		1.98 [0.44, 8.97]	0.43
Conduit						
Autogenous vein	Ref		Ref		Ref	
Other	0.55 [0.26, 1.15]	0.11	0.41 [0.17, 0.98]	0.046 [*]	0.61 [0.30, 1.27]	0.19

^{*} Statistically significant

[‡] Unable to estimate