
Bacterial Adherence to Surgical Sutures: Can Antibacterial-Coated Sutures Reduce the Risk of Microbial Contamination?

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- BACKGROUND:** Surgical site infections are associated with severe morbidity and mortality. The role of surgical sutures in the etiology of surgical site infection has been the objective of discussion for decades. This study used a standardized in vitro microbiologic model to assess bacterial adherence and the antibacterial activity of a triclosan-coated polyglactin 910 (braided) suture against selected Gram-positive and Gram-negative clinical isolates that may infect surgical wounds.
- STUDY DESIGN:** Standardized cultures ($2.0 \log_{10}$ colony forming units/mL and $5.0 \log_{10}$ colony forming units/mL of three clinical strains, *Staphylococcus aureus* (methicillin-resistant *S aureus* [MRSA]), *S epidermidis* (biofilm-positive) and *Escherichia coli* (extended-spectrum beta-lactamase [ESBL]-producer) were inoculated to triclosan-coated and noncoated polyglactin 910 sutures to evaluate comparative adherence of bacterial isolates to the antibacterial coated and noncoated surgical sutures; to assess the impact of serum proteins (bovine serum albumin) on antibacterial activity of triclosan-coated suture; and to document the duration of antibacterial activity of the triclosan-coated material. Selected suture samples were prepared for scanning electron microscopy to demonstrate bacterial adherence.
- RESULTS:** Substantial ($p < 0.01$) reductions in both Gram-positive and Gram-negative bacterial adherence were observed on triclosan-coated sutures compared with noncoated material. Pretreatment of surgical sutures with 20% BSA did not diminish antibacterial activity of the triclosan-coated braided device compared with noncoated suture ($p < 0.01$), and antibacterial activity was documented to persist for at least 96 hours compared with controls ($p < 0.01$).
- CONCLUSIONS:** The in vitro model demonstrated a considerable reduction ($p < 0.01$) in Gram-positive and Gram-negative bacterial adherence to a triclosan-coated braided suture, which was associated with decreased microbial viability ($p < 0.001$). Because bacterial contamination of suture material within a surgical wound may increase the virulence of a surgical site infection, treating the suture with triclosan provides an effective strategy for reducing perioperative surgical morbidity. (J Am Coll Surg 2006;203:481–489. © 2006 by the American College of Surgeons)
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Surgical site infections are associated with severe morbidity and mortality, especially in high-risk patient populations.^{1,2} The probability of a postoperative surgical site infection developing in a patient is influenced by

selected intrinsic and extrinsic risk factors present at the time of operation.¹⁻⁴ It is estimated that 750,000 surgical site infections occur in the US each year, using 3.7 million extra hospital days and costing more than \$1.6 billion in excess hospital charges each year.⁵⁻⁷ The cornerstones for reducing the risk of surgical site infection include exquisite surgical technique, timely and appropriate antimicrobial prophylaxis, effective and persistent skin antisepsis, and identification of adjunctive strategies for reducing wound contamination and promoting wound healing.

The effective influences of technique, prophylaxis, and skin antisepsis in reducing risk have been well doc-

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Abbreviations and Acronyms

cfu	= colony forming units
3X	= three times
TSB	= tryptic soy broth

umented in the surgical literature. But within the past 10 years, surgeons have embraced adjunctive innovative technology to reduce the risk of health care-associated infections.^{8,9} Within the surgical arena, innovative intraoperative strategies such as continuous insulin infusion, hyperoxia, and continuous antibiotic infusion are recognized to mitigate the risk of infectious morbidity, improving patient outcomes.¹⁰⁻¹² Mechanistically, these select interventions improve wound healing and host defense posture within the surgical wound, creating an environmental inhospitable to wound contamination.

Although the role of suture material as a nidus for wound contamination and infection has been the subject of speculation for more than 30 years, our findings suggest that as a biomedical device, surgical sutures exhibit an affinity for microbial adherence and colonization similar to that of other synthetic, implantable medical devices. Early studies demonstrated that adherence of microbial populations to suture material is highly variable, dependent on the specific microbial species, suture structure, and chemical composition of the device.^{13,14} Braided sutures have been shown to have a higher affinity for microbial colonization compared with nylon devices.¹⁵ A recent study using an animal model demonstrated that wounds closed with buried absorbable subcutaneous sutures (subcuticular) were more susceptible to infection after *Staphylococcus aureus* contamination than was transdermal closure, regardless of copious saline irrigation.¹⁶

The operating room environment poses a selected risk for intraoperative wound contamination. Recent studies challenged the expected source of wound contamination, usually attributed to the patient or a break in surgical technique, suggesting that the surgical wound can be seeded by exogenous flora from members of the operative team. The source of this flora has been identified as nasopharyngeal (shedding), and the causal linkage is based on intraoperative air sampling and molecular studies using pulse-field gel electrophoresis.¹⁷⁻¹⁹ An inoculum challenge of 5.0 log₁₀ cfu/g of tissue has been traditionally viewed as the intrinsic threshold value re-

quired for development of a tissue-based wound infection. This value, however, is currently under challenge for several reasons: the threshold inoculum for a biomedical device-associated infection is notably less (< 100 colony forming units [cfu]); intrinsic patient risk factors lower the threshold for infection; and the emergence of highly virulent, multidrug resistant pathogens alter wound pathogenicity.²⁰⁻²²

Various bacteria may contaminate not only the tissue in a surgical wound, but the actual suture material. Development of a triclosan-coated polyglactin 910 suture represents a recent effort aimed at reducing postoperative surgical site infections by preventing contamination of surgical suture within the operative wound. The model for this study was designed to provide an in vitro evaluation of contaminated suture material in an environment mimicking the physiologic conditions within the surgical wound. After insertion or implantation of a biomedical device, the inert surface is rapidly coated with tissue proteins, including fibrinogen, fibronectin, collagen, and other soluble substrates, all of which function as adhesins for microbial attachment. The study compared microbial adherence of selected Gram-positive and Gram-negative clinical isolates to triclosan-coated and noncoated braided surgical sutures, evaluating the impact of 20% on the antiseptic activity of the triclosan-coated device, in addition to measuring the duration of antiseptic activity.

METHODS**Suture material and microbial isolates**

The devices used in the study were 3-0 coated (triclosan) and uncoated polyglactin 910 braided surgical sutures (Ethicon Inc). The sutures were cut aseptically into 1-cm lengths and stored at room temperature until use. Three clinical strains were chosen for study: *Staphylococcus aureus* (SA-235-02), *Staphylococcus epidermidis* (RP-62A), and *Escherichia coli* (12GYN-99). All clinical isolates, with the exception of RP-62A, were recovered from superficial incisional site infections and expressed selected patterns of multidrug resistance: SA-235-02, methicillin-resistant *S aureus* (MRSA); 12GYN-99, extended-spectrum β -lactamase (ESBL). RP-62A, a clinical strain derived from a catheter-related blood stream infection, produces a copious exopolysaccharide biofilm.²³ All strains were incubated overnight on trypticase blood agar at 35° C. Broth cultures were prepared by inoculating fresh colonies to 20-mL of tryptic soy broth (TSB) and incubating the tubes for 18 hours at

35° C. Broth cultures were centrifuged (10 minutes, 3,000 rpm, at 22° C) and adjusted spectrophotometrically to provide a standard inoculum for experimental studies.

Comparative adherence and viability studies

Two standardized inocula, 2.0 log₁₀ and 5.0 log₁₀ cfu, were prepared in 0.85% PBS with 0.50% dextrose, and agglutinated cells of RP-62A were disrupted by serial passages through a 25-gauge needle and vortexed for 30 seconds before dilution. Individual suture segments were placed in 5-mL tubes, exposed to the diluted inoculum for 5 seconds or 2 minutes. The standardized inoculate was verified by serial plate count. After exposure to test strains, suture segments were gently washed (three times [3X]) in PBS to remove nonadherent cells and incubated for 24 hours at 35° C in 1 mL of PBS with 0.50% dextrose. At 24 hours, suture segments were removed, washed (3X), and sonicated in 1 mL PBS at 20 kHz for 2 minutes. The suture sonicate was serially diluted in PBS before plating to TSB and incubated for 48 hours at 35° C. Microbial recovery was expressed as log₁₀ cfu/cm suture segment. Ten suture segments were evaluated per inoculum challenge.

Impact of 20% BSA on antiseptic activity and microbial adherence/viability

To evaluate the impact of protein-coated braided suture material on bacterial adherence and cell viability, before microbial challenge, triclosan-coated and noncoated polyglactin 910 suture segments (1-cm) were preconditioned with 20% BSA (Sigma Chemical Co) for 30 minutes. The segments were then transferred to a 5-mL tube and exposed to either SA-235-02 (*S aureus*) or 12GYN-99 (*E coli*) at a concentration of 5.0 log₁₀ cfu/mL for 2 minutes, gently washed (3X) in PBS, and incubated for 24 hours at 35° C in PBS with 0.50% dextrose. At 24 hours, individual segments were removed, washed (3X), and sonicated in 1 mL PBS at 20 kHz for 2 minutes. The suture sonicate was serially diluted in PBS before plating to TSB, and it was incubated for 48 hours at 35° C. Before discarding the PBS (with 0.5% dextrose) culture medium, 0.5 mL was transferred to a sterile tube containing 0.5 mL PBS (total volume 1 mL), vortexed, serially diluted, plated to TSB, and incubated for 48 hours at 35° C to determine cell viability. Microbial recovery was expressed as log₁₀ cfu/mL or cm suture segment. A total of 10 replicate suture segments were evaluated per isolate.

Duration of antiseptic activity

BSA-preconditioned, triclosan-coated polyglactin 910 sutures were placed (individually) in 5 mL of PBS. On a daily schedule, PBS was aspirated from the tube and replaced with fresh PBS. At 24, 48, 72, and 96 hours, individual suture segments were removed, washed (3X) and exposed to *S aureus* or *S epidermidis* (log₁₀ cfu/mL) for 2 minutes, followed by a second wash (3X), and reincubated in PBS with 0.50% dextrose for 24 hours at 35° C. After incubation, suture segments were washed (3X), sonicated, serially diluted, plated to trypticase blood agar, and incubated for 48 hours at 35° C. Microbial recovery was expressed as log₁₀ cfu/cm suture segment. Ten replicates were evaluated per isolate and time interval. A noncoated *S aureus* and *S epidermidis* suture control was prepared, and microbial recovery was evaluated at 24 hours for comparison with the antiseptic-impregnated devices.

Scanning electron microscopy

Selected noncoated and coated suture segments were removed from the culture medium, washed 3× with PBS, and prefixed overnight in 1% glutaraldehyde containing 100 mmol/L of sodium cacodylate. Samples were postfixed in osmium tetroxide for 4 hours, washed 3X, serially dehydrated in ethanol, critical point dried, and sputter coated with gold and palladium. Samples were observed at an accelerating voltage of 25 kV with a spot size of 8 nm.

Statistical analysis

Differences in mean microbial recovery were analyzed by the two-sample *t*-test using the MINITAB-Release 13, Statistical Program (MINITAB Inc).

RESULTS

A considerable difference was observed in the mean microbial recovery of Gram-positive and Gram-negative microbial isolates adherent to noncoated versus triclosan-coated braided devices at both 5-second and 2-minute inoculum exposures (Figs. 1A, and 1B). The scanning electron micrograph (Figs. 2A, 2B) documents the impact of triclosan coating on reducing microbial adherence of MRSA (Fig. 2B) compared with that on the noncoated substrate (Fig. 2A). Interestingly, RP-62A a highly adherent biofilm-forming strain, was recovered in lower numbers than *S aureus* (SA-235-02) from the surface of noncoated suture material. But the adherence of both staphylococcal strains was substantially ($p <$

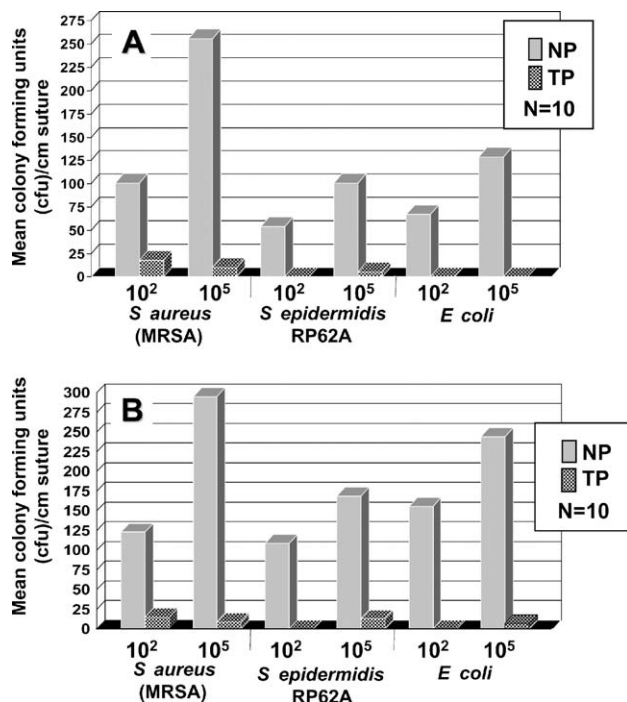


Figure 1. (A) Mean microbial recovery from noncoated and triclosan-coated polyglactin 910 surgical sutures exposed to bacterial inoculum for 5 seconds, $p < 0.01$. (B) Mean microbial recovery from noncoated and triclosan-coated polyglactin 910 surgical sutures exposed to bacterial inoculum for 2 minutes, $p < 0.01$. MRSA, methicillin-resistant *Staphylococcus aureus*; NP, noncoated polyglactin 910; TP, triclosan-coated polyglactin 910.

0.01) reduced on the surface of the triclosan-coated device compared with the noncoated suture material. *E coli* was also observed to adhere to the surface of the braided suture in numbers similar to the staphylococcal isolates and likewise, was substantially ($p < 0.01$) reduced in the presence of triclosan. Although increasing the time of inoculum exposure from 5 seconds to 2 minutes resulted in a slight increase in microbial adherence to the surface of the noncoated and triclosan-coated devices, the results were not statistically significant.

For the suture material preconditioned in BSA, compared with nonconditioned suture material, there was approximately a 35% to 40% increase in staphylococcal and *E coli* adherence to the surface of both noncoated and triclosan-coated polyglactin 910 sutures. But, the BSA conditioning did not diminish the antiseptic activity of triclosan-coated sutures compared with the noncoated devices (Fig. 3, $p < 0.01$). In addition to inhibiting microbial adherence to the surface of braided sutures, the triclosan-coated devices demonstrated a bactericidal activity against both Gram-positive and Gram-

negative clinical isolates in the presence and absence of BSA (Table 1, $p < 0.001$).

No marked difference was observed in mean microbial recovery from triclosan-coated suture segments previously incubated in PBS for 24, 48, 72, and 96 hours, suggesting that effective antiseptic (triclosan) activity was present for at least 4 days (Fig. 4) compared with noncoated polyglactin 910 sutures. Figures 2C and 2D are scanning electron micrographs obtained from the same series of experiments. Figure 2C is from a section of noncoated suture material that was inoculated with 100,000 cfu of *S epidermidis* (RP-62A), demonstrating a copious exopolysaccharide biofilm; Figure 2D is the same microbial strain inoculated to a triclosan-coated suture that was previously incubated 96 hours in PBS. These initial studies suggest that triclosan-coated sutures were highly effective in reducing the microbial adherence of both biofilm-forming and nonbiofilm-forming staphylococcal isolates to the surface of braided surgical sutures.

DISCUSSION

Microbial adherence to the surface of surgical sutures has been reported in the surgical literature for more than 30 years.^{19-22,24} It has been demonstrated that once suture material, especially braided sutures, becomes contaminated, local mechanisms of wound decontamination mediated by granulocytic cell populations become ineffective.^{25,26} Gristina and colleagues²⁷ reported that percutaneous sutures approximating skin edges were often colonized from the body surface into the wound track by strains of *S epidermidis* capable of producing an amorphous extracellular matrix (biofilm), protecting the microbial populations from host defense factors. Suture structural composition and tissue reactivity have also been shown to influence infectivity, with braided suture material more vulnerable to microbial contamination than monofilament devices.²⁸⁻³⁰ Braided suture provides a large surface area with a three-dimensional architectural matrix that is highly complex relative to a monofilament device, entrapping bacteria and increasing the risk of contamination. This risk would be decreased by creating an antibacterial environment within and immediately adjacent to the suture infrastructure.

Development of an antibacterial surgical suture has been under consideration since the early 1980s.^{25,31-34} Experimental findings have been intriguing, but development of an FDA-approved surgical suture has been slow, in part because of technical issues involving product safety, stabil-

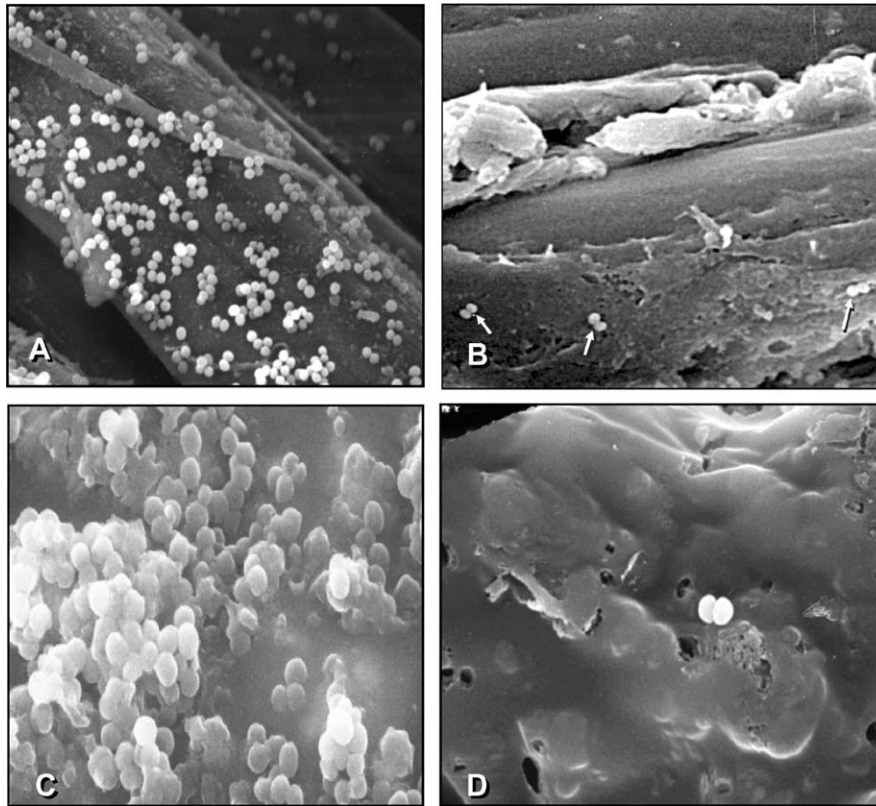


Figure 2. (A) Adherence of methicillin-resistant *Staphylococcus aureus* (MRSA) to noncoated polyglactin 910 braided suture, magnification, $\times 5,400$. (B) Few MRSA cells (arrows) present on surface of triclosan-coated braided device, magnification, $\times 5,260$. (C) RP-62A, biofilm-producing strain on surface of noncoated polyglactin 910 suture, magnification, $\times 12,600$. (D) Scanning electron micrograph documenting a substantial reduction in adherence of RP-62A to surface of triclosan-coated polyglactin suture incubated in PBS for 96 hours before microbial challenge, magnification, $\times 11,200$.

ity, and standardization. The decision to adopt this technology within the current patient care environment may be guided by concerns of perceived benefit versus economic considerations. A study conducted by Storch and colleagues,³⁵ using standard laboratory reference strains of *S aureus* and *S epidermidis*, demonstrated that triclosan-coated polyglactin 910 sutures exhibit an antibacterial activity sufficient to prevent in vivo bacterial colonization in a guinea pig model. Although this model cannot be viewed as a definitive surrogate of an in situ wound infection, the guinea pig model is an appropriate laboratory test vehicle for evaluating the impact of a triclosan-coated device (suture) on microbial colonization.

Tissue-based studies in an animal model suggest that triclosan-coated braided sutures exhibit no adverse effect on wound healing.³⁶ Similar findings have been observed in pediatric patients. Ford and associates³⁷ reported in 2005 that triclosan-coated polyglactin 910 did not adversely effect wound healing in pediatric patients

undergoing general surgical procedures. Although the study was not sufficiently powered to measure infectious outcomes, the authors did observe decreased incidence of incisional pain ($p < 0.01$) and diminished edema with the triclosan-coated sutures compared with the standard polyglactin 910 (noncoated) suture study group. It is important, however, to point out that although these findings are interesting, subjective pain studies in the pediatric populations may be influenced by other moderating factors.

Triclosan is a broad-spectrum antiseptic with documented safety and efficacy against selected Gram-positive and Gram-negative bacteria.³⁸ Incorporation of agents such as triclosan in commercial products is not without some controversy. Levy³⁹ hypothesized that widespread use of these antibacterial agents may lead to diminished activity against clinically significant microbial pathogens or selection of bacterial strains with increased resistance (decreased therapeutic efficacy) to

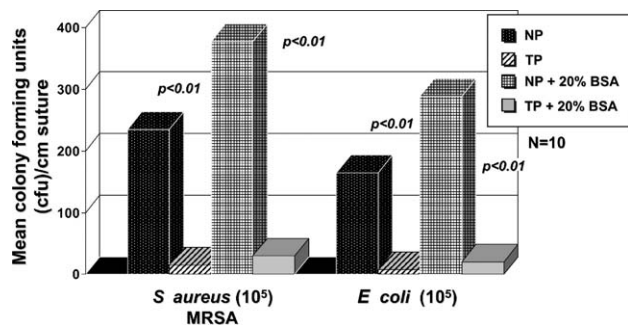


Figure 3. Impact of 20% BSA on Gram-positive and Gram-negative mean microbial recovery from noncoated versus triclosan-coated polyglactin 910 braided sutures. MRSA, methicillin-resistant *Staphylococcus aureus*; TP, triclosan-coated polyglactin 910.

Table 1. Microbial Cell Viability at 24 Hours in Culture Supernatant of Triclosan-Coated and Noncoated Polyglactin 910 Braided Surgical Sutures in the Presence and Absence of 20% Bovine Serum Albumin

Initial inoculum	Mean log ₁₀ cfu/mL (n=10)			
	10 ⁵		10 ⁵ + 20% BSA	
Organism	NC	C	NC	C
<i>S aureus</i> (MRSA)*	3.4	ND	3.9	0.3
<i>E coli</i> (ESBL) [†]	2.6	ND	3.1	0.1
p Value	< 0.001		< 0.001	

*Strain # SA-235-01 methicillin-resistant (MRSA).

[†]Strain # 12GYN-99 extended-spectrum β -lactamase resistance (ESBL).

C, triclosan-coated polyglactin braided suture; cfu, colony forming units; NC, noncoated polyglactin 910 braided suture; ND, no organisms detected.

commonly used antimicrobial agents. But two recent studies suggested that subinhibitory or long-term exposure to triclosan is not associated with diminished triclosan activity or increased antimicrobial resistance, as measured by minimal inhibitory concentrations.^{40,41} Although these two studies suggest that the acquisition of microbial resistance to triclosan appears to be very low based on minimal inhibitory concentration data, we should not forget that selected microbial populations (ie, *Pseudomonas aeruginosa*) have been found to be resistant to various antiseptic agents, including triclosan, so the potential risk of encountering a clinical strain resistant to triclosan is unlikely to be zero.

The use of antibacterial-coated (or -impregnated) medical devices has become widespread within the health care environment. Numerous biomedical devices including urologic and central venous catheters, and orthopaedic, vascular, and cardiothoracic implants are commercially available with antibacterial impregnating or surface coatings. This in vitro study clearly demon-

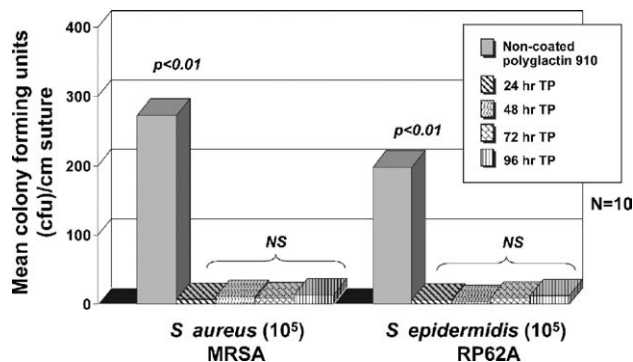


Figure 4. Duration of antibacterial activity of triclosan-coated polyglactin 910 braided suture material. MRSA, methicillin-resistant *Staphylococcus aureus*; TP, triclosan-coated polyglactin 910.

strated that triclosan-coated sutures were highly effective in reducing the adherence of selective clinical Gram-positive, Gram-negative, drug-resistant, and biofilm-forming strains to the surface of a widely used braided surgical suture (polyglactin 910). When evaluating the efficacy of these devices based on clinical or in vitro data, does it make any difference if the antibacterial device features an active or passive component? Figure 5A is a low power scanning electron micrograph of a braided polyglactin 910 suture, demonstrating a tightly woven structure, in which bacterial cells are easily sequestered. Figure 5B and 5C demonstrate two common surgical sutures: the braided material (TP) is coated with triclosan and the monofilament (TM) actually has triclosan incorporated within the structure of the polymer. Both images demonstrate a zone of inhibition surrounding the suture samples, in which the active agent (triclosan) is eluded into the surrounded media seeded with MRSA or ESBL-producing *E coli*, inhibiting bacterial growth. This study also suggested that in addition to inhibiting the adherence of selected Gram-positive and Gram-negative clinical isolates to the surface of the braided device, exposure to triclosan-coated sutures results in microbial cell death, as evidenced by the results presented in Table 1.

If the surgical suture is implicated as the cause of a wound infection (as would occur if the suture material became contaminated from contact with residual bacteria from patients' skin or from intraoperative aerosols), then an antibacterial coating should nearly eliminate the possibility of the suture material becoming a vector of infection. In a different clinical scenario, if the surgical wound becomes contaminated from failure of wound closure, from technical or ischemic complications, or

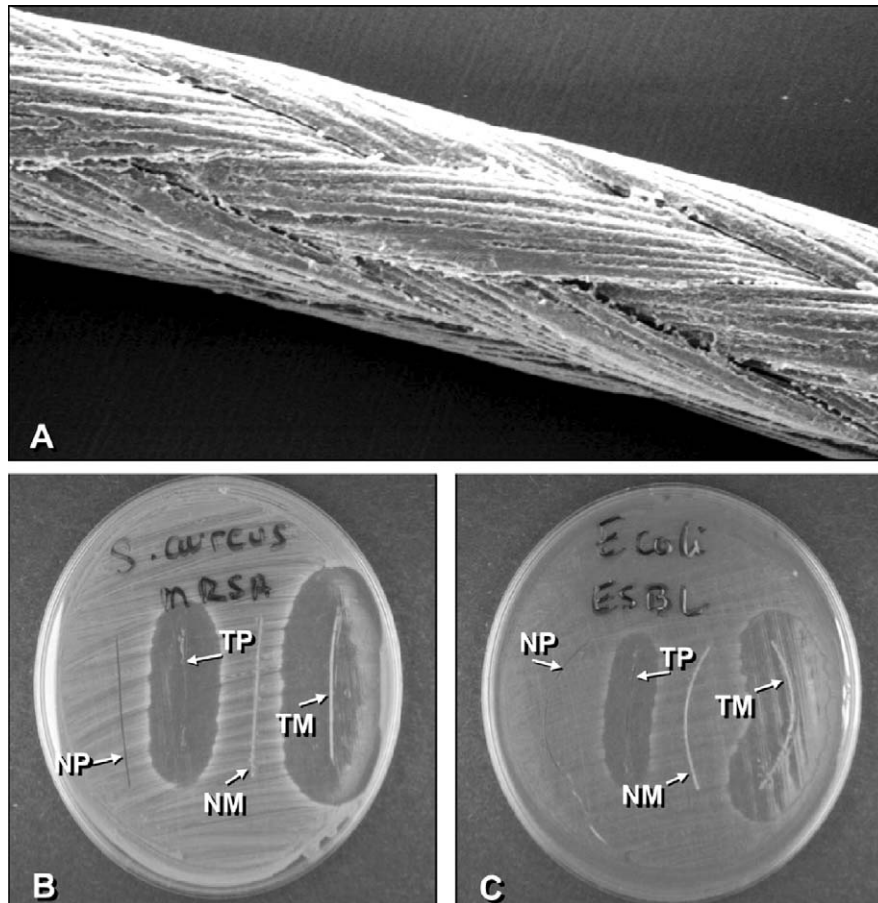


Figure 5. (A) Low magnification of polyglactin 910 suture, demonstrating braided structure of surgical device, magnification, $\times 420$. (B) Photomicrograph of triclosan-coated polyglactin 910 and triclosan-impregnated monofilament, documenting zone of inhibition against methicillin-resistant *Staphylococcus aureus*. (C) Photomicrograph of triclosan-coated polyglactin 910 and triclosan-impregnated monofilament, documenting zone of inhibition against extended-spectrum β -lactamase-producing *E. coli*. NM, nonimpregnated monofilament device; NP, noncoated polyglactin suture; TM, monofilament; TP, triclosan-coated polyglactin 910.

from an endogenous source such as lymphatic channels or systemic bacteremia, then deployment of an antibiotic-coated material in the surgical wound may be effective in arresting bacterial growth. In this setting, the suture material becomes an adjunctive component of the wound aseptic process.

Although recent reports³⁵⁻³⁷ documented the bactericidal activity of triclosan, this study provided evidence that coating surgical sutures with an antiseptic agent decreases bacterial adherence (and likely cell death), resulting in decreased suture contamination. Correlating the findings of serial dilution cultures and zone inhibition with scanning electron microscopy provides insight into the mechanism by which a wound would be protected by using a suture coated with a bactericidal agent

to close a surgical incision. In addition, this study demonstrated that the antimicrobial activity of triclosan was sustained, over a time frame when re-epithelialization should occur during the early postoperative period, and during the interval when a surgical wound is subject to microbial challenge from technical complications and lymphatic or hematogenous contamination. This study also documented that the antiseptic activity of triclosan was not diminished when the suture material was coated with biologic substrates, mimicking the tissue proteins recruited to the margins of a surgical wound.

The results of this study suggest that antibacterial-coated sutures exhibit an inhibitory or bactericidal activity against bacteria commonly cultured from surgical wounds; clinicians and hospitals will be challenged with the question as

to whether or not to invest in this type of innovative technology for routine surgical wound closure. The morbidity from surgical wounds is very expensive because of the associated treatment costs for antibiotics, wound care, prolonged hospitalization, and loss of patients' work productivity.^{2,6} So antibacterial-coated sutures may well prove cost effective in reducing morbidity (infection) in the surgical patient. Because surgical wound infection rates may be highly variable, particularly in routine, elective operations, where antiseptic coated sutures would be used in substantial volumes, the real efficacy of such products may be determined only with a large, multicenter, prospective, randomized, blinded study evaluating the clinical outcomes, microbiology, and economic benefits of these innovative devices.

Author Contributions

Study conception and design: Edmiston, Seabrook, Krepel

Acquisition of data: Edmiston, Goheen, Krepel

Analysis and interpretation of data: Edmiston, Seabrook, Johnson, Lewis, Brown, Towne

Drafting of manuscript: Edmiston, Seabrook, Johnson

Critical revision: Edmiston, Seabrook, Goheen, Krepel, Johnson, Lewis, Brown, Towne

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