FiberWire vs FiberTape

Comparison of Bacterial Adherence in a Murine Air Pouch Wound Model

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Background: For high–tensile strength sutures, past research has largely focused on mechanical properties or bacterial adherence across various manufacturers.

Purpose: This study investigated high-tensile strength sutures with different shapes but otherwise identical composition. The purpose was to evaluate the differences between high–tensile strength suture wire and suture tape relative to bacterial adherence and bacterial retention after washout.

Study Design: Controlled laboratory study.

Methods: Sutures were implanted in dorsal air pouches of 72 BALB/cJ mice. Experimental pouches were inoculated with *Staphylococcus aureus*; no bacteria were used in the control conditions. The mice were randomized into 3 groups: group 1 underwent suture extraction 7 days after implantation; group 2 underwent an irrigation procedure, followed by immediate suture extraction on day 7; and group 3 underwent an irrigation procedure on day 7, with delayed suture extraction on day 14 after implantation. The sutures were evaluated using confocal microscopy; electron microscopy; and spectrophotometry, through which optical density, as measured by the amount of scattered light, is directly correlated with the number of bacteria. Histological assessment was performed on the pouches.

Results: Optical density (mean ± SD) was significantly higher for FiberTape sutures than for FiberWire sutures, respectively, at the 2-hour time point for all groups (group 1, 0.0550 ± 0.0081 vs 0.0162 ± 0.006 [$P = .0054$]; group 2, 0.0225 ± 0.0049 vs 0.0056 ± 0.0006 [$P = .0045$]; group 3, 0.055 ± 0.0222 vs 0.0043 ± 0.0005 [$P = .0103$]). Additionally, groups 2 and 3 showed statistically significant results at the 4-hour time points (group 2, 0.0384 ± 0.0087 vs 0.0145 ± 0.0042 [$P = .0280$]; group 3, 0.0532 ± 0.0159 vs 0.0101 ± 0.0025 [$P = .0058$]). The wash fluid also demonstrated significantly greater optical density for the FiberTape than the FiberWire sutures, respectively, at the 2-hour time point for all groups (group 1, 0.1657 ± 0.0319 vs 0.0317 ± 0.008 [$P = .0063$]; group 2, 0.0522 ± 0.0156 vs 0.0127 ± 0.0022 [$P = .0219$]; group 3, 0.1707 ± 0.0205 vs 0.0191 ± 0.0053 [$P < .0001$]). No bacterial growth occurred in the control conditions. Histological assessment revealed only mild inflammation in the control groups as compared with more severe responses in the experimental groups at all time points.

Conclusion: FiberTape was associated with increased bacterial adhesion as well as retention as compared with FiberWire in an in vivo murine wound model.

Clinical Relevance: This study demonstrates that suture design influences the occurrence of and ability to clear surgical infection and must be considered when selecting high-tensile strength sutures in a clinical setting.

Keywords: FiberWire; FiberTape; suture; bacterial adherence; murine

New suture designs are frequently introduced to advantage surgical procedures. As operative techniques change to improve patient outcomes and minimize complications, implants, such as suture, are redesigned to meet the demands. For the repair of soft tissue structures, high-tensile strength sutures are desired and commonly employed. The literature on high-tensile strength sutures has focused on material properties, such as strength, handling, and knot security.[2,3,9,10,11,15] While bacterial adherence has been assessed, no previous studies have evaluated this characteristic in high-tensile strength materials that differ only by structural design and profile, such as suture wire and suture tape.

FiberWire (Arthrex) was one of the earliest high–tensile strength sutures developed. It is widely utilized and has desirable handling properties. FiberWire consists of an

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ultrahigh molecular weight polyethylene core surrounded by braided polyester and a silicone coating. FiberTape (Arthrex) has an identical composition but with expanded braids of 2 mm throughout its working length. The suture tape products have gained popularity because of a theoretically improved suture-tissue interface. When compared with the more traditional high-strength suture products, the increased surface area of FiberTape provides a broader contact area footprint and a resultant increased tissue cut-through resistance.[5]

Biomechanical studies have also shown greater load to failure of suture tape versus suture wire.[1,9,11] These characteristics can be especially relevant in procedures, such as arthroscopic repair of the rotator cuff or other high-demand areas where an intimate relationship between suture implant and soft tissues exists.

In addition to construct strength and near-anatomic reconstruction, prevention of infection by reducing bacterial load after surgical soft tissue repair is critical to successful patient outcomes. The purpose of this study was to evaluate the differences between suture wire (FiberWire) and suture tape (FiberTape) relative to bacterial adherence as well as bacterial retention after washout. It was hypothesized that despite the identical composition of the materials, the shape difference and increased surface area of FiberTape would lead to higher bacterial adhesion and subsequent biofilm retention as compared with FiberWire.

METHODS

Approval was obtained from our Institutional Animal Care and Use Committee, and a validated air pouch model was used to carry out the experimental protocol.[7,14] Seventy-two BALB/cJ mice were injected with 1.5 mL of air subcutaneously on their dorsal surface. The air pouches were maintained by injecting 0.5 mL of air 3 days after the initial injection. After 1 week of pouch maturation, the mice were anesthetized via intraperitoneal ketamine (120 mg/kg) and xylazine (10 mg/kg) in preparation for suture implantation. Once properly anesthetized, the mice were transferred to the operative table, and the dorsal skin was prepared using povidone-iodine and 70% ethyl alcohol. A 1-cm segment of suture was implanted in each pouch through a 5-mm skin incision. The sutures used in this study included No. 2 FiberWire and FiberTape. Manufacturer-specific shears were utilized to minimize fraying of the suture segment ends. Closure of the dorsal incision was performed using skin glue (Vetbond; 3M).

The mice were randomized into 3 groups, with 4 conditions for each group: 1 experimental condition with bacteria and 1 control condition for each of the 2 suture types (Table 1). After suture implantation, the experimental pouches were inoculated with 0.5 mL of kanamycin-resistant *Staphylococcus aureus* (lux) (Xenogen 29; Caliper Life Science) dosed at 1×10^8 colony-forming units per pouch using a 26-gauge needle. No bacteria were included in the control conditions. Group 1 was defined by suture extraction 7 days after implantation. Group 2 underwent an irrigation procedure 7 days after implantation, followed by immediate suture extraction. Group 3 underwent an irrigation procedure on day 7 and had the sutures extracted 1 week later on day 14 after implantation. The washout procedure performed on groups 2 and 3 consisted of flushing 2 mL of sterile saline into the pouch using a syringe and subsequent removal of the fluid using bulb suction. The animals were euthanized via hypercarbia at each endpoint before suture extraction. The extracted sutures were kept in 1 mL of broth at 4°C until analysis.

TABLE 1
Summary of Assignments

	Group 1[a]	Group 2[b]	Group 3[c]
Control suture, No.			
FiberWire	4	4	4
FiberTape	4	4	4
Experimental suture, No.			
FiberWire	8	8	8
FiberTape	8	8	8

[a]Extract day 7.
[b]Washout day 7, extract day 7.
[c]Washout day 7, extract day 14.

Gross tissue appearance before and after suture removal was documented photographically to record qualitative differences among groups. After suture extraction, the entire air pouch was removed and fixed in 10% neutral buffered formalin for histological assessment. After 48 hours of fixation, the pouches were washed briefly with deionized water before being transferred to 70% ethanol and processed for paraffin imbedding. Tissue sections (5 μm) were stained with hematoxylin and eosin and images of stained sections were digitally captured using a Zeiss light microscope (Carl Zeiss Microscopy, LLC).

One suture from each condition was imaged using confocal microscopy, followed by environmental scanning electron microscopy (ESEM). Sutures assigned for confocal microscopy were stored in 1 mL of broth at 4°C after extraction. On the day of imaging, the sutures were stained with Alexa Fluor 488 with excitation and emission maxima of 495/519 nm (Invitrogen; Thermo Fisher Scientific) to differentiate the biofilm on the suture materials. Confocal

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Ethical approval for this study was obtained from St John Providence Health System (project 104-17).

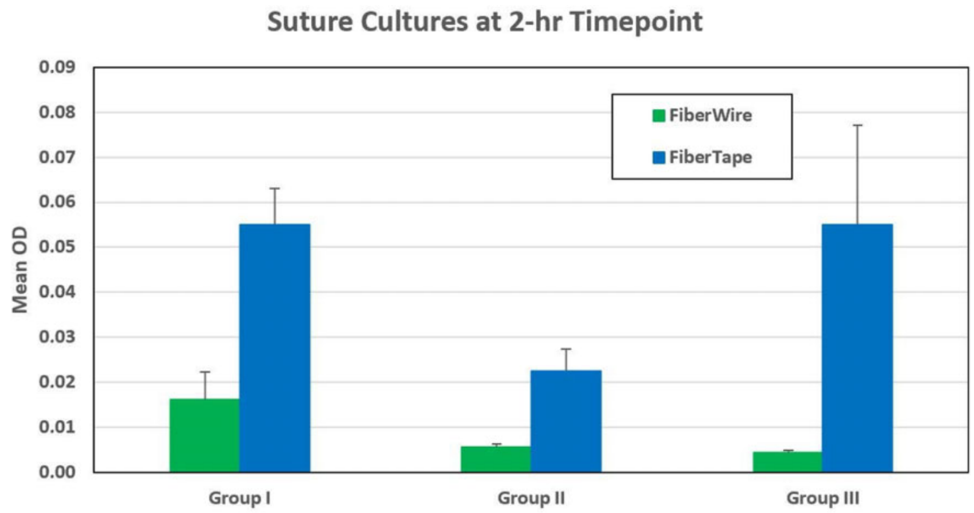

Figure 1. Mean optical density (OD) of suture cultures with statistically significant differences between FiberWire and FiberTape at the 2-hour time point measurements for each group. Error bars indicate SD.

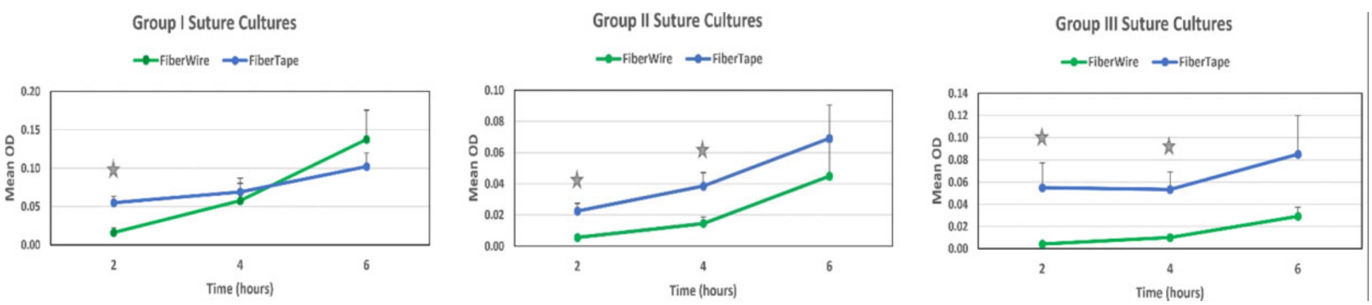

Figure 2. Mean optical density (OD) of suture cultures for each group across all measured time points. Significant values are marked by a star. Error bars indicate SD.

imaging was then performed using an LMS 800 confocal microscope. After confocal imaging, the sutures were air-dried and sputter-coated with gold, and their surface morphology was evaluated using ESEM.

The remaining sutures from each condition were lightly washed, sonicated, and cultured. Washing was performed twice using phosphate buffer saline; the suture was placed in 0.5 mL of phosphate buffer saline and spun at 100 rpm for 10 seconds. The supernatant with bacteria that eluted from the sutures (wash fluid) was collected for culturing. After the light wash, the sutures were placed in 1 mL of broth containing kanamycin and subjected to sonication at 55 kHz (UL1 71310 Sonicator; Ultronics) for 10 minutes to remove adherent bacteria and disrupt the biofilm. The sonication fluid was then collected for culture. After sonication, the sutures were placed in fresh broth in preparation for culturing. The cultured suture therefore represented the bacteria that were strongly adherent or contained in residual biofilm. The wash fluid, sonicate fluid, and sutures were individually cultured in a shaker at 37°C at 225 rpm for 6 hours. Optical density (OD) readings were taken at 600 nm every 2 hours for the wash fluid, sonication fluid, and sutures using a Nanodrop 2000 spectrophotometer (Thermo Fisher Scientific), as previously described.[12] For OD, the amount of scattered light is directly correlated with the number of bacteria in the solution.

Statistical analysis for the OD measurements was performed using a paired 2-tailed t test with equal variance among the groups at 3 time points: without irrigation (day 7), after irrigation (day 7), and the 14-day endpoint (day 14). All analyses were performed using SPSS Version 23.0 (IBM Corp) with an alpha level of 0.05.

RESULTS

OD measurements did not show any bacterial growth for the control conditions of either suture type. In the experimental conditions exposed to bacteria, quantitative microbiology demonstrated statistically significant differences across all groups. Specifically, the suture cultures of FiberTape had statistically significant greater mean OD readings than did FiberWire at the 2-hour time points for each group (Figure 1). The FiberTape suture cultures were also significantly higher at the 4-hour time points for groups 2 and 3, which underwent the irrigation procedures. The suture cultures for each group across all time points are illustrated in Figure 2. Statistically significant results were also demonstrated in the wash fluid in all groups and in the sonicate for groups 1 and 3 (Table 2).

TABLE 2
FiberTape vs FiberWire in the Experimental Conditions

	P Value[a]		
Hour	Group 1	Group 2	Group 3
Wash			
2	.0063[b]	.0219[b]	<.0001[b]
4	.0908	.1109	.0007[b]
6	.1677	.4733	.1580
Sonicate			
2	.0089[b]	.1330	.0033[b]
4	.2305	.1116	.0156[b]
6	.3462	.3326	.8455
Suture			
2	.0054[b]	.0045[b]	.0103[b]
4	.7067	.0280[b]	.0058[b]
6	.3729	.4521	.0672

[a]Based on *t* test.
[b]Statistically significant.

ESEM images were unremarkable for the control sutures across all groups (Figure 3). Group 1 ESEM images demonstrated bacterial adhesion and biofilm formation on the surfaces and between the fibers for both experimental suture types (Figure 4). In group 2, ESEM images exhibited smaller and more dispersed areas occupied by biofilms on the FiberWire (Figure 5, A and B) versus the FiberTape (Figure 5, C and D). For group 3, ESEM images showed persistent biofilm presence on both suture types, which appeared more concentrated at the junction of the fiber bundles on the FiberTape (Figure 6, C and D) and more dispersed on the FiberWire (Figure 6, A and B). Confocal microscopy images showed the presence of biofilm on both types of experimental sutures. A greater qualitative appearance of biofilm remained on the FiberTape sutures after the irrigation procedures in groups 2 and 3 than on the FiberWire sutures (Figure 7).

At the end of the experiment and after removal of the sutures, the pouches were collected and processed for histology. Hematoxylin- and eosin–stained sections were analyzed for differences in tissue reaction to the sutures. As expected, both suture types had a mild inflammatory response in the control pouches, as noted by the presence of few granulocytes in the pouch tissue. This response was aggravated for both experimental infected sutures in all 3 groups. Representative images are shown in Figures 8 to 10.

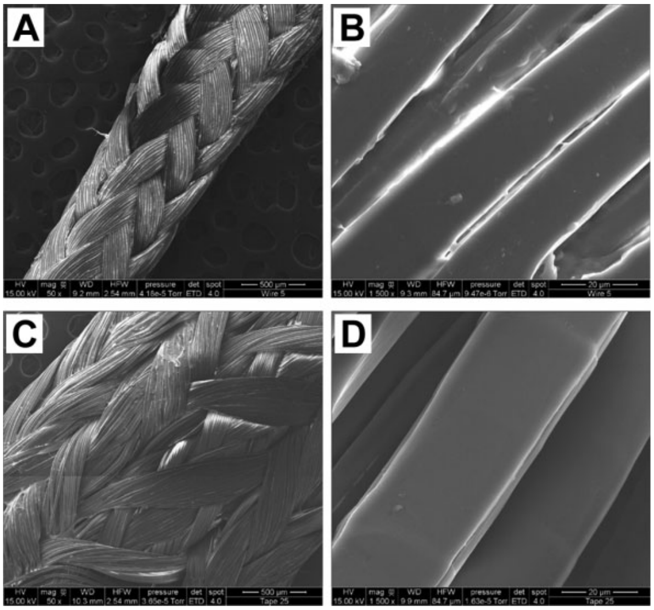

Figure 3. Environmental scanning electron microscopy images of control sutures for (A, B) FiberWire and (C, D) FiberTape at 50× and 1500× magnifications. Note the presence of some tissues around the fibers but no presence of bacteria.

DISCUSSION

To our knowledge, this is the first study to compare FiberWire and FiberTape with regard to bacterial adherence and retention. The purpose was to evaluate the effects of the suture design and surface area as they relate to bacterial adhesion, biofilm formation, and the potential to harbor infection in a simulation washout. This in vivo murine wound model demonstrated significantly greater bacterial adherence to the FiberTape sutures in the experimental conditions across all groups. The FiberTape sutures retained more bacteria natively and despite an irrigation procedure. Statistically significant bacterial counts were also demonstrated in the wash fluid across all groups as well as in the sonicate fluid for groups 1 and 3, suggesting that the FiberTape initially harbored more bacteria than did the FiberWire in addition to those that remained adherent.

Group 3—which underwent an irrigation procedure on day 7, followed by delayed pouch extraction on day 14—showed statistically significant results for the 2- and 4-hour time points across all sample types (wash fluid, sonicate fluid, and suture cultures). Because this group represented the clinical scenario of a washout procedure in the presence of surgical infection and subsequent implant retention, it is important to note that the FiberTape continued to retain higher bacterial counts on the sutures in addition to releasing more bacteria into the wash fluid and the sonicate fluid. This suggests that even after an irrigation procedure, FiberTape has increased bacterial attraction, adherence, and retention as compared with FiberWire.

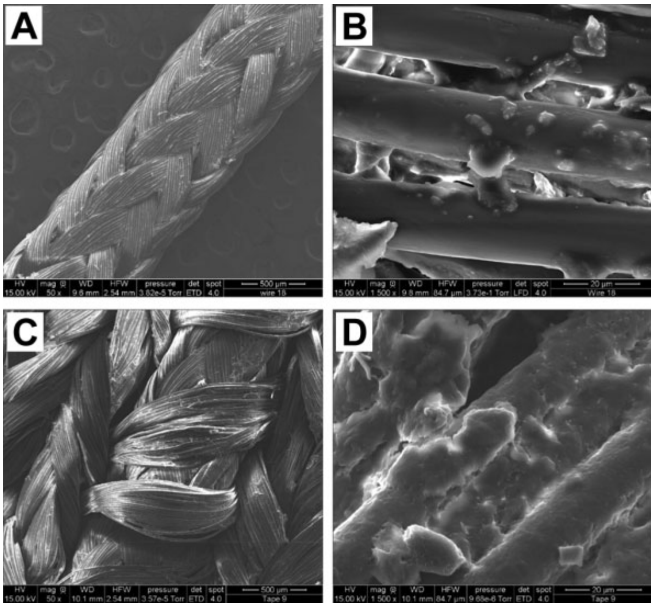

Figure 4. Group 1 environmental scanning electron microscopy images for infected (A, B) FiberWire and (C, D) FiberTape at 50× and 1500× magnifications. Biofilm is apparent on and between the fibers of both suture types.

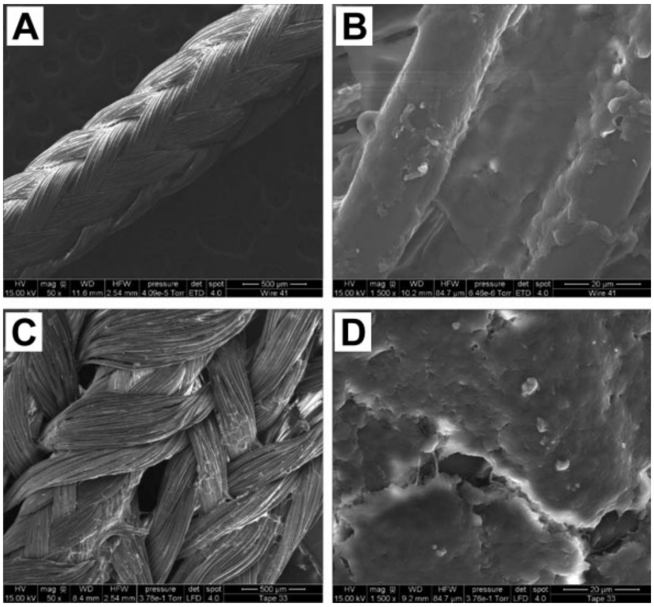

Figure 5. Group 2 environmental scanning electron microscopy images of infected sutures after irrigation with immediate extraction. The biofilms and single bacteria remain apparent on and between the suture fibers: (A, B) FiberWire and (C, D) FiberTape at 50× and 1500× magnifications.

A potential explanation for the findings may be the increased surface area of the FiberTape sutures. While this characteristic lends itself to an improved suture-tissue interface and pull-through resistance, the broadened shape

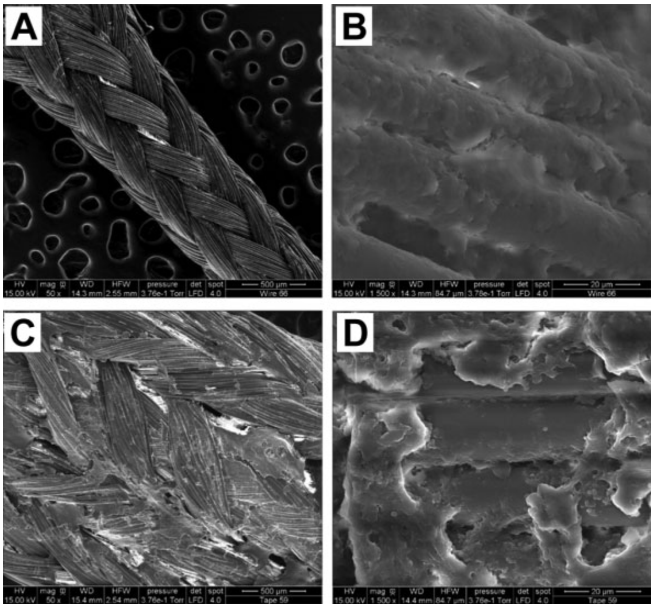

Figure 6. Group 3 environmental scanning electron microscopy images of infected sutures after irrigation and after being kept in the pouch for an additional week. The biofilms and single bacteria remain apparent on and between the suture fibers: (A, B) FiberWire and (C, D) FiberTape at 50× and 1500× magnifications.

and subsequent increased surface area of FiberTape may also portend increased surgical complications, such as infection. Previous studies have demonstrated the increased bacterial adherence of braided versus monofilament sutures,[6,14] and we have shown that this also applies to increased surface area of otherwise similarly composed high–tensile strength sutures. In addition to an increased risk of acquiring an infection in the presence of bacteria (group 1), our findings suggest that FiberTape has an increased risk of retaining infection even after simulated washout procedures (groups 2 and 3).

The 6-hour time points did not show statistically significant differences for any of the groups or sample types. This can be explained by the doubling time of the bacterial population. Over time, the differences between the suture types was negated by the bacterial generation time in the cultured samples. Apart from apparent outlier data for the suture cultures of group 1, the FiberTape continued to have higher OD measurements than did the FiberWire at 6 hours despite the lack of statistical significance at this time point (Figure 2).

Masini et al[13] utilized an in vitro method to evaluate bacterial adherence of high–tensile strength sutures from various companies and found that FiberWire had less bacterial adherence than did MaxBraid (Biomet) but greater bacterial adherence than did Orthocord (DePuy Mitek). The authors attributed their findings to the different materials composing the design of the sutures tested. Additional studies in rabbit models have assessed soft tissue reactions to nonabsorbable orthopaedic sutures.[4,8]

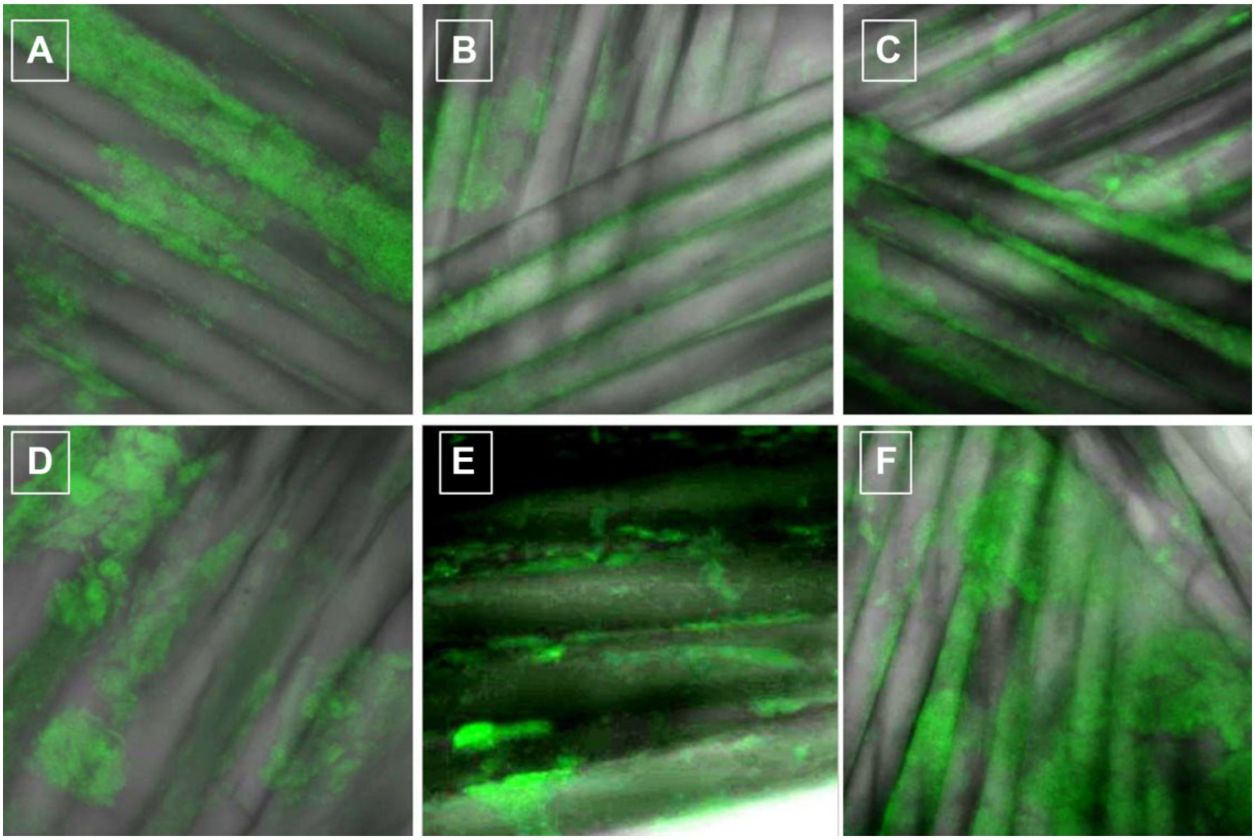

Figure 7. Confocal microscopy images at 40× magnification. (A-C) FiberWire and (D-F) FiberTape in groups 1, 2, and 3, respectively.

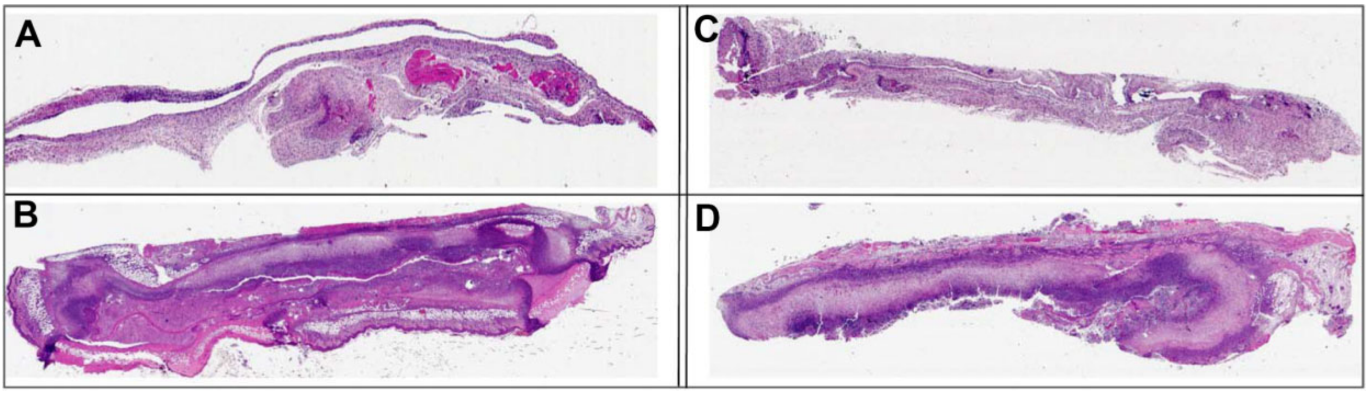

Figure 8. Group 1 hematoxylin- and eosin–stained pouch tissue after suture extraction at 40× magnification. FiberWire: (A) control and (B) experimental conditions. FiberTape: (C) control and (D) experimental conditions.

Esenyel et al[8] found that when compared with Ethibond (Ethicon) and polypropylene (DemeTech), FiberWire produced the most severe inflammatory reaction in the joint capsule but the least severe reaction in the muscle and tendon in the first 3 weeks. Carr et al[4] assessed 8 high-strength sutures and found FiberWire's generalized inflammatory response to be in the lowest half at 30, 60, and 120 days. The authors again attributed their results to the various compositions of suture material, as well as braid characteristics.

One of the strengths of this study was the comparison of sutures that had the same composition and differed only in their physical design and surface area. This allowed minimization of extraneous variables and provided surgeons the opportunity to weigh a potentially increased risk of infection against an improved suture-tissue relationship within

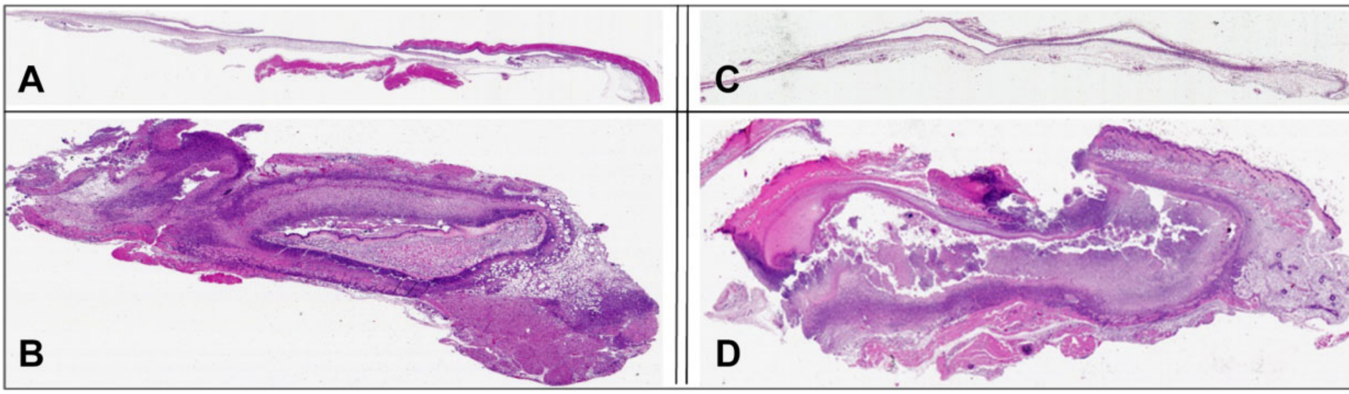

Figure 9. Group 2 hematoxylin- and eosin–stained pouch tissue after suture extraction at 40× magnification. FiberWire: (A) control and (B) experimental conditions. FiberTape: (C) control and (D) experimental conditions.

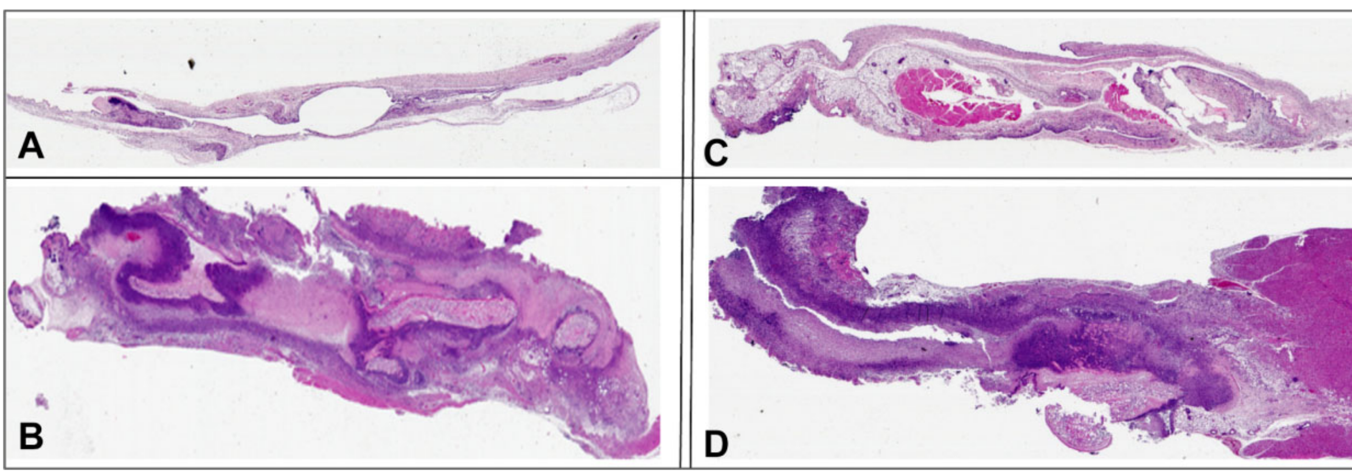

Figure 10. Group 3 hematoxylin- and eosin–stained pouch tissue after suture extraction at 40× magnification. FiberWire: (A) control and (B) experimental conditions. FiberTape: (C) control and (D) experimental conditions.

the same product line. Additionally, the use of an in vivo model and the simulated washout procedure helped to make our findings as clinically relevant as possible in a laboratory setting. Last, the lack of bacterial growth in our control conditions supported a controlled environment and subsequent conclusions of our results.

This study was not without limitations. We were technologically unable to quantify biofilm formation between the suture types. As a result, the study relied on qualitative analysis for this finding. Additionally, no specific quantitative measurement of the surface area for each suture was determined; however, we concluded that any attempted measurement may inherently be flawed given the intricate nature of the woven suture materials. Last, a small percentage of the mice experienced more severe reactions and died before the end of the experiment. In some circumstances, the pouches and their sutures appeared to have been consumed by other mice in the same group. We subsequently held the mice in individual cages to thwart such occurrences in later groups. In other instances, the sutures were adhered to the pouch, which may have led to premature pouch rupture and potential increased risk of sepsis. This also illustrates the difference between colonization of the pouches and systemic infection. Mice that died were replaced accordingly.

For the repair of soft tissue structures, high–tensile strength sutures are preferred and commonly employed. While bacterial adherence has been evaluated among high-tensile strength sutures in the past, no previous studies have compared this characteristic in suture materials that differ only by structural design and profile, such as FiberWire and FiberTape. The in vivo murine air pouch wound model utilized in this study was a unique means of doing so. FiberWire and FiberTape have been proven to be strong and effective clinically; in the face of infection, however, bacterial adherence and retention after washout could lead to devastating results regardless of construct strength. One must therefore be mindful of the contribution of material and physical properties of sutures relative to biologic effect.

Future research may be devoted to evaluating inflammatory markers elicited by the sutures, bacterial adherence associated with suture knots, or the incidence of infection between FiberTape and FiberWire in human patients. On the basis of this study, surgeons should be particularly selective of the type of suture implant chosen for soft tissue repair in patient populations and surgical sites with a high risk or predisposition for bacterial contamination.

CONCLUSION

This study found significantly greater bacterial adhesion and retention with FiberTape than with FiberWire in an in vivo murine air pouch wound model. The clinical relevance of the findings relates to decreasing the occurrence of surgical infection as well as the ability to clear a surgical infection while retaining the suture construct.

REFERENCES

1. Bisson LJ, Manohar LM. A biomechanical comparison of the pull-out strength of No. 2 FiberWire suture and 2-mm FiberWire tape in bovine rotator cuff tendons. *Arthroscopy*. 2010;26(11):1463-1468.
2. Bisson LJ, Manohar LM, Wilkins RD, Gurske-Deperio J, Ehrensberger MT. Influence of suture material on the biomechanical behavior of suture-tendon specimens a controlled study in bovine rotator cuff. *Am J Sports Med*. 2008;36(5):907-912.
3. Burgess R, Elder S, McLaughlin R, Constable P. In vitro biomechanical evaluation and comparison of FiberWire, FiberTape, OrthoFiber, and nylon leader line for potential use during extraarticular stabilization of canine cruciate deficient stifles. *Vet Surg*. 2010;39(2):208-215.
4. Carr BJ, Ochoa L, Rankin D, Owens BD. Biologic response to orthopedic sutures: a histologic study in a rabbit model. *Orthopedics*. 2009;32(11):828-834.
5. Deranlot J, Maurel N, Diop A, et al. Abrasive properties of braided polyblend sutures in cuff tendon repair: an in vitro biomechanical study exploring regular and tape sutures. *Arthroscopy*. 2014;30(12):1569-1573.
6. Dhom J, Bloes DA, Peschel A, Hofmann UK. Bacterial adhesion to suture material in a contaminated wound model: comparison of monofilament, braided, and barbed sutures. *J Orthop Res*. 2017;35(4):925-933.
7. Edlich RF, Panek PH, Rodeheaver GT, Turnbull VG, Kurtz LD, Edgerton MT. Physical and chemical configuration of sutures in the development of surgical infection. *Ann Surg*. 1973;177(6):679-688.
8. Esenyel CZ, Demirhan M, Kilicoglu O, et al. Evaluation of soft tissue reactions to three nonabsorbable suture materials in a rabbit model. *Acta Orthop Traumatol Turc*. 2009;43(4):366-372.
9. Gnandt RJ, Smith JL, Nguyen-Ta K, McDonald L, Leclere LE. High-tensile strength tape versus high-tensile strength suture: a biomechanical study. *Arthroscopy*. 2016;32(2):356-363.
10. Ilahi OA, Younas SA, Ho DM, Noble PC. Security of knots tied with Ethibond, Fiberwire, Orthocord, or Ultrabraid. *Am J Sports Med*. 2008;36(12):2407-2414.
11. Liu RW, Lam PH, Shepherd HM, Murrell GAC. Tape versus suture in arthroscopic rotator cuff repair: biomechanical analysis and assessment of failure rates at 6 months. *Orthop J Sports Med*. 2017;5(4):2325967117701212.
12. Markel DC, Bergum C, Wu B, Bou-Akl T, Ren W. Does suture type influence bacterial retention and biofilm formation after irrigation in a mouse model? *Clin Orthop Relat Res*. 2019;477(1):116-126.
13. Masini BD, Stinner DJ, Waterman SM, Wenke JC. Bacterial adherence to high-tensile strength sutures. *Arthroscopy*. 2011;27(6):834-838.
14. Morris MR, Bergum C, Jackson N, Markel DC. Decreased bacterial adherence, biofilm formation, and tissue reactivity of barbed monofilament suture in an in vivo contaminated wound model. *J Arthroplasty*. 2017;32(4):1272-1279.
15. Najibi S, Banglmeier R, Matta J, Tannast M. Suture materials in orthopaedic surgery. *Iowa Orthop J*. 2010;30:84-88.