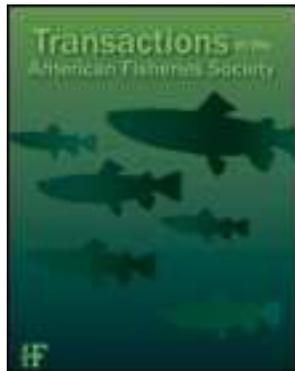


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Effects of Suture Type and Patterns on Surgical Wound Healing in Rainbow Trout

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Abstract.—In two separate experiments we investigated the effects of different types of suture material and patterns on wound healing in rainbow trout *Oncorhynchus mykiss* with and without transmitter implants. We used absorbable and nonabsorbable monofilament and braided silk sutures in simple interrupted and vertical mattress patterns to close 3-cm incisions on rainbow trout. Braided silk sutures and vertical mattress suture patterns caused significantly more tissue inflammation ($P < 0.05$) as shown by macroscopic analysis. However, there were no significant differences in the histology or strength of the wounds related to the type of suture material or the type of suture pattern used. Dummy radio transmitters compounded the inflammatory effect silk had on healing incisions compared with inflammation without transmitters.

Many studies have tracked fish using ultrasonic or radio telemetry in the past 50 years. These studies date back to Trefethen (1956), who tracked the movements of a chinook *Oncorhynchus tshawytscha* and coho *O. kisutch* salmon with external sonic transducers. Research on the methods used to implant transmitters into fish has occurred mainly during the last 25 years (Hart and Summerfelt 1975; Bidgood 1980; Summerfelt and Mosier 1984; Petering and Johnson 1991; Knights and Lasee 1996). Only a few studies have empirically tested the effect different surgical materials or techniques have on the healing of surgical incisions (Schramm and Black 1984; Kaseloo et al. 1992; Thoreau and Baras 1997). Empirical testing of surgical methods is important to determine if

they affect the quality of results obtained from performance and behavioral studies.

The majority of incisions made for the purpose of implanting transmitters have been closed using a simple interrupted suture pattern with either braided silk sutures (Hart and Summerfelt 1975; Chisolm and Hubert 1985; Brown and Mackay 1997) or synthetic mono- or polyfilament (Hart and Summerfelt 1975; Mellas and Haynes 1985; Adams et al. 1998). A few researchers also have tested surgical staples (Mulford 1984) and cyanoacrylate adhesives (Petering and Johnson 1991; Kaseloo et al. 1992) as alternatives to suture material. The results of these nonsuture alternatives have been mixed with both success and failure, garnering positive and negative recommendations for the materials. Some fish surgeons continue to use silk suture material for experiments such as transmitter implantations despite evidence it causes wound inflammation in mammals due to bacteria wicking (Smeak 1998) and slows healing in blue tilapia *Oreochromis aureus* (Thoreau and Baras 1997). Only one similar report has been made on synthetic monofilament suture by Knights and Lasee (1996), who found tissue necrosis occurring at suture sites of nonabsorbable monofilament in bluegills in 20°C water. Smeak (1998) reported monofilament suture material caused little to no tissue inflammation in mammals because it is noncapillary in nature.

The objective of this study was to ascertain which of the different wound closure techniques is best for a particular species of fish by quantifying the effect the technique has on the healing of the wound. In two separate experiments we examined the effect of absorbable, nonabsorbable, and silk suture types on wound healing by macroscopic evaluation of tissue inflammation and mechanical testing of wound strength. We hypothe-

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sized silk sutures would slow healing and decrease wound strength at low temperature (8–10°C) by increasing inflammation of the suture and incision sites compared to monofilament suture materials. For our second experiment we also examined the effect of two suture patterns on wound healing of fish implanted with a dummy radio transmitter by macroscopic evaluation of tissue inflammation and mechanical testing of wound strength. Simple interrupted and vertical mattress suture patterns were selected to compare the effect of tissue alignment on healing. The vertical mattress pattern was chosen because it brings the separated integument, muscle and fascia, and peritoneum tissues into closer approximation than does the simple interrupted pattern. Dummy transmitters were implanted because their presence has been reported to increase pressure on the incision site and cause more inflammation (Schramm and Black 1984; Kaseloo et al. 1992). We hypothesized that the vertical mattress suture pattern would expedite healing and improve wound strength by aligning the tissue layers more closely. Conversely, we hypothesized that the presence of a transmitter would increase the amount of inflammation caused by the sutures, thus slowing healing and decreasing wound strength.

Methods

Experiment 1: Wound Healing Without Implants

Experimental animals.—Twenty-four prespawning rainbow trout *Oncorhynchus mykiss* (length = 30.6 ± 0.3 cm SE; weight = 337.5 ± 10.0 g) were obtained from a 50:50 sex ratio population at the Alma Aquaculture Facility, Alma, Ontario. The fish were placed in filtered, recirculated well water ($9.4 \pm 0.1^\circ\text{C}$) held in a round 1,000-L tank at the Hagen Aqualab, University of Guelph. Standard five-point trout food (Martin Mills Inc., Elmira, Ontario) was used to feed the fish. The effects of temperature and diet were controlled by maintaining an even temperature and feeding the same daily amount of food (2% body weight). We held the fish for 2 weeks prior to surgery to allow them to adjust to their new environment. The fish were starved for 48 h prior to surgery, as recommended by Summerfelt and Smith (1990), to minimize regurgitation of food and defecation in the water circulating through the surgery table.

All fish were sampled 14 d (wound scores) and 28 d (wound scores and tissue samples) after surgery. Macroscopic inflammation analysis and mechanical wound testing were performed on all fish.

Surgical procedures.—All surgeries were performed between 26 and 27 June 1998. Prior to surgery, we anesthetized all fish individually in a solution of 70 mg/L tricaine methanesulfonate (MS-222) until stage 5 of anesthesia was reached. As defined by Summerfelt and Smith (1990) stage 5 of anesthesia occurs when reactivity and reflexes are absent and opercular movements are slow and irregular. We placed the fish on a Plexiglas V-board in the surgery table and continuously perfused their gills with recirculating $10 \pm 0.1^\circ\text{C}$ water, also containing MS-222 (70 mg/L), through two soft rubber tubes. Water was changed in the table reservoir every five to eight surgeries.

The surgeon's hands were covered with clean, nonsterile medical examination gloves. All surgery tools were autoclaved at 121°C for 25 min prior to use. Between surgeries, the single needle driver was cold-sterilized for 30 s using the disinfectant Conflikt (Fisher Scientific; active ingredient ammonium chloride) then rinsed with sterile saline to maintain low bacterial loads within the time constraints of each surgery.

We made a single 30-mm incision parallel to and 15 mm to the right side of the linea alba. Each incision was made between the pectoral and pelvic girdles using a number 11 scalpel blade. Blunt forceps were used to retract the body wall and depress the viscera to prevent internal damage while deepening the incision through to the peritoneal cavity. The incision was then closed with four simple interrupted stitches approximately 6 mm apart that were tied with surgeons knots. The three suture materials used were 4-0 Biosyn (U.S. Surgical Corporation, Norwalk, Connecticut), an absorbable monofilament; 4-0 Surgipro (U.S. Surgical Corporation), a nonabsorbable polypropylene monofilament; or 4-0 Sofsilks (U.S. Surgical Corporation), a braided silk; all in individual sterile packs. Each type was used to close the incisions of fish ($n = 8$) using a swaged-on 3/8 reverse cutting needle. Suture materials were used in rotating order during surgery.

Macroscopic assessment.—A wound scoring system was developed to quantify the macroscopic inflammation at the incision and suture sites (Figure 1) separately because results from a preliminary study suggested they were independent variables. Inflammation of the incision site was estimated using a rating scale (Table 1). The maximum value, six, indicated an open, inflamed wound, and the minimum value, zero, indicated a totally closed incision with no inflammation. Macroscopic inflammation at each of eight suture en-

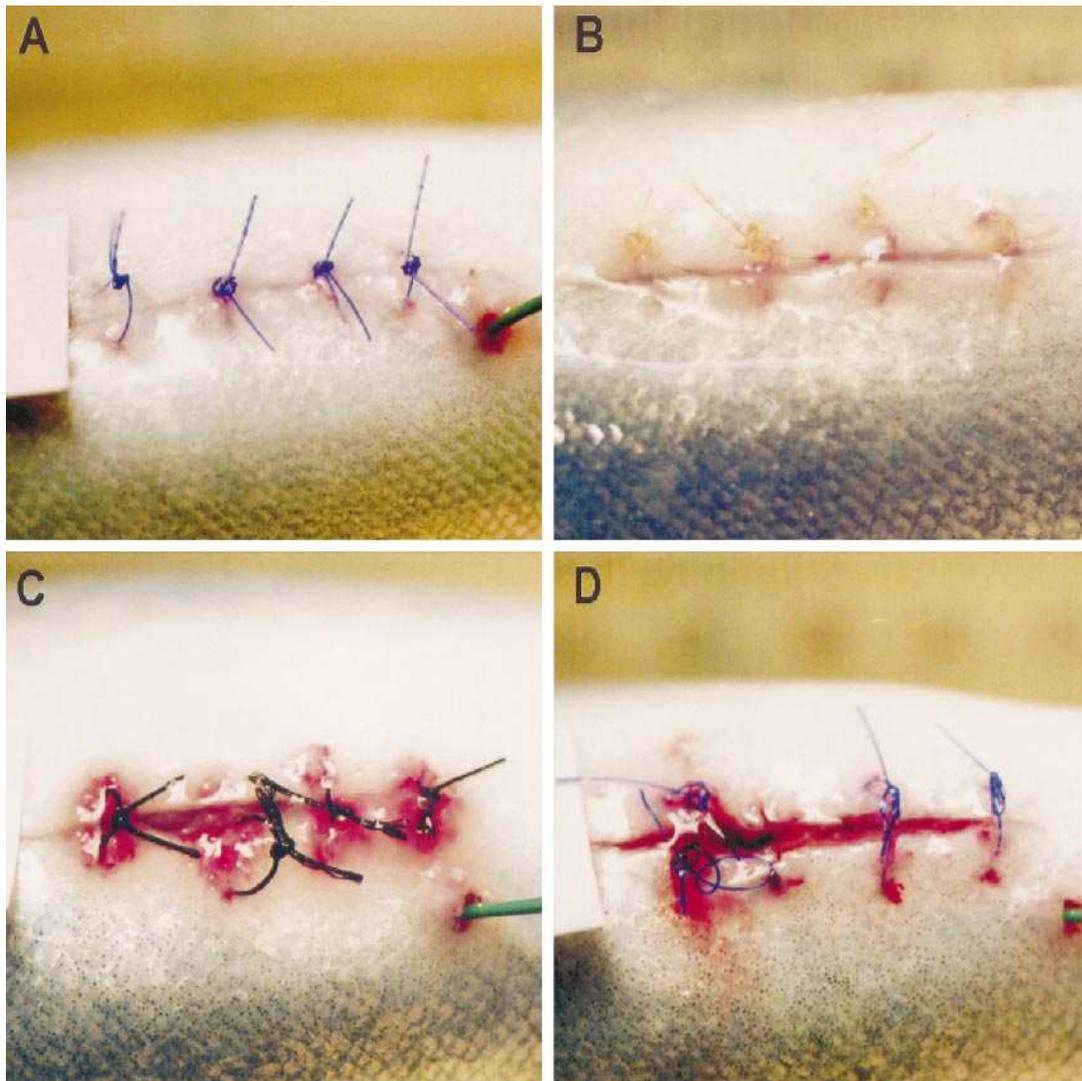


FIGURE 1.—Macroscopic appearance of the incision and suture sites. Photographs are organized by incision ratings (according to Table 1) on a scale of 0–6, where (A) is the minimum rating 0, (B) is 2, (C) is 4, and (D) is the maximum rating 6. Suture site inflammation ratings are also included using a scale of 0–8, where (A) is 0, (B) is 1, (C) is almost the maximum, 7, and (D) is 4. Macroscopic inflammation at each of eight suture sites was determined using a scoring system of presence (1) or absence (0). The sum of all suture site scores became a total out of eight. The incisions are closed with nonabsorbable suture in (A, D) a simple interrupted pattern, (B) absorbable monofilament in a vertical mattress pattern, and (C) silk suture in a simple interrupted pattern.

try–exit sites was ranked using a scoring system of presence (1) or absence (0). The sum of all suture site scores became a total out of eight. The sum of all suture site scores became the score; 0 = no sites inflamed, 1 = one site inflamed, . . . , 8 = eight sites inflamed. Inflammation was deemed to be present if the skin surface around the suture material was red and raised. All wound scoring was performed by three people individually, and

the scores were averaged. There were no significant differences between the people's scores.

Mechanical wound testing.—Mechanical testing and analysis of wound strength was performed as per Albina et al. (1993), with some modifications. We cut full-thickness strips of tissue for wound testing between the second and third stitches. The strips were butterfly-shaped with extended wings of tissue on either end of a 5–6-mm middle section.

TABLE 1.—Rating scale used to describe macroscopic inflammation of the incision site. Inflammation was deemed to be present if the skin surface around the suture material was red and raised.

Rating	Rating criteria
0	Incision completely closed. No inflammation.
1	Incision closed. Little inflammation along incision site (less than 10% of incision inflamed).
2	Incision closed. Little to moderate inflammation (10–50% of incision inflamed).
3	Incision held in proximity but not completely closed, as edges still slide. Moderate inflammation (up to 50% of incision inflamed).
4	Incision partially open at one end or middle. Moderate to high inflammation (up to 100% of incision inflamed).
5	More than 50% of wound open. Moderate to high inflammation along wound edges (up to 100% of incision inflamed).
6	Completely open wound. Severe inflammation along wound edges (up to 100% of incision inflamed).

All sutures were removed from the sample. The wings were gripped using 2-cm binder clips, with an emery board glued to each clipping surface to improve grip, without crushing the tissue. Each clip was then bound in the hydraulic clamps of an Instron testing system (Instron 5500, Instron Corporation, Canton, Massachusetts), and the tissue was stretched at 10 cm/min until failure. Breaking strength (maximum force required to break apart the incision) and breaking energy (total amount of energy required to break apart the incision) for each incision were determined from the resultant force–deformation curves. Full-thickness sections of tissue 5 mm anterior and posterior to the incision were removed from four fish in each treatment and tested as nonincision controls.

Statistics.—We analyzed all incision and suture inflammations by analysis of variance (ANOVA) and Tukey's multiple comparison method and mechanical wound testing results by analysis of covariance (ANCOVA) and least square means according to Steel et al. (1997). Inflammation and strength of wound differences among the suture types were compared in the three simple interrupted pattern treatments. For strength testing of the wounds, cross-sectional area (width \times thickness) of the tissue excision, incision inflammation, and suture inflammation were the covariates; the breaking strength and energy were the variables; and suture types were the treatments. All scaled data were tested for nonnormality graphically by performing a normal probability plot of the residuals. Cases of nonnormality were tested using a Kruskal–Wallis one-way ANOVA (Steel et al.

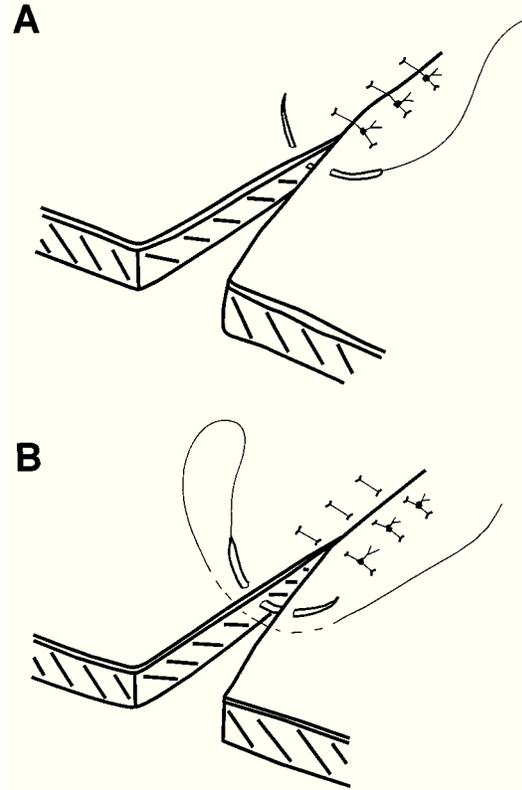


FIGURE 2.—Simple (A) interrupted and (B) vertical mattress suture patterns used to close surgical incisions on rainbow trout. Redrawn from Fossum (1997).

1997). A protected pairwise comparison was performed if a significant result was obtained.

Experiment 2: Wound Healing With Transmitter Implants and Two Suture Patterns

All the materials and methods for the second experiment were identical to the first experiment except for the following.

Experimental animals.—Thirty-five prespawning rainbow trout (length = 30.9 cm \pm 0.2 SE; weight = 346.8 g \pm 6.3) were kept in filtered, recirculated well water at 10 \pm 0.1°C. Fish were sampled 21 d (wound scores) and 42 d (wound scores and tissue samples) after surgery. Macroscopic and microscopic inflammation analysis and mechanical wound testing were performed on all fish.

Surgical procedures.—All surgeries were performed on 16 August 1998. We inserted a dummy radio transmitter (15 \times 40 mm, 4.5 g \pm 0.01 in air, 1.3% of fish body weight) anteriorly through the incision into the peritoneal cavity. The antenna

TABLE 2.—Histological criteria and rating scale values used to quantify healing of incisions. Based on absolute numbers relative to all tissue samples. Asterisks indicate the rating value representing the best wound healing for each category.

Histological criteria	Rating value	Actual rating parameters
A. Wound apposition	0*	Perfect alignment and layers continuous
	1	Aligned tissue layers, but partially offset
	2	Misaligned tissue layers
	3	Open or gaping wound
B. Tissue in wound space (epithelium, scales, bone)	0*	Not present
	1	Present
C. Epidermal covering	0*	Complete, full thickness with basement membrane
	1	Complete, less than full thickness
	2	Incomplete, basement membrane missing
D. Tissue repair and reorganization	0	Not seen or low frequency
	1	Little granulation tissue formation (beginning of collagen organization and vascularization) or granulomatosis (macrophage dominated, little organization)
	2–3	Moderate granulation tissue formation or granulomatosis
	4–5*	Large relative amount of granulation tissue formation or granulomatosis
	0*	Not present
E. Peritonitis beyond immediate wound area	1	Mild peritoneal inflammation relative to all tissue samples
	2–3	Moderate peritoneal inflammation relative to all tissue samples
	4–5	Severe peritoneal inflammation relative to all tissue samples
	0*	Not present
F. Suppuration	1	Little neutrophil accumulation relative to all tissue samples
	2–3	Moderate neutrophil accumulation relative to all tissue samples
	4–5	Abundant neutrophil accumulation relative to all tissue samples
	0	Not present
G. Skeletal muscle regeneration	1	Little muscle tissue formation relative to all tissue samples
	2–3	Moderate muscle tissue formation relative to all tissue samples
	4–5*	Abundant muscle tissue formation relative to all tissue samples
	0	Not present
H. Pigment layer under stratum compactum	1	Minimal layer relative to all tissue samples
	2–3	Some structure to layer relative to all tissue samples
	4–5*	Highly structured layer relative to all tissue samples
	0	Not present

was passed from the peritoneal cavity through the body wall using a 16-gauge, 3.8-cm needle. The back end of forceps were used to shield the viscera from damage. We angled the antenna to trail posteriorly and ventrally to the right side of the fish. The dummy transmitter was constructed of a 2-mL cryogenic polyethylene vial (Fisher Scientific) and a 27-mm-long 18-gauge coated wire and was filled and coated with paraffin wax. Prior to implantation, each tag was sterilized by submergence in disinfectant then rinsed with distilled water.

Incisions were closed with either four simple interrupted or vertical mattress sutures (Figure 2) placed approximately 6 mm apart, and tied with surgeon's knots. All three suture types were used with the simple interrupted pattern ($n = 7$). Only the two monofilament sutures were used with the vertical mattress pattern ($n = 7$) to prevent inflammation caused by silk from interfering with the comparison of the patterns.

Histological assessment.—Fish were killed by submergence in a receptacle containing a lethal dose of MS-222. Incision areas on each fish (ap-

proximately 4×2 cm) were then excised separately and placed in a tissue cassette into 10% buffered formalin. The tissue blocks were dehydrated in a graded ethanol series and embedded in paraffin. Sections ($6\text{--}7 \mu\text{m}$) of the incision site stained with Hematoxylin–eosin were mounted on slides and examined under light microscopy (oil immersion at $\times 1,000$) by a fish pathologist to quantify wound healing criteria (Table 2). The rating values for the different cell types are based on the number of cells along the entire incision site cross-section relative to the size of the tissue sample. All the single-blind histological analyses were performed separately on two histological sections then averaged.

Statistics.—Inflammation and strength of wound differences among the suture patterns were compared in the two monofilament suture treatments.

Because of nonnormality, we used a Kruskal–Wallis one-way ANOVA to analyze the histological data, with each criterion as a variable and suture type and suture pattern as treatments. A

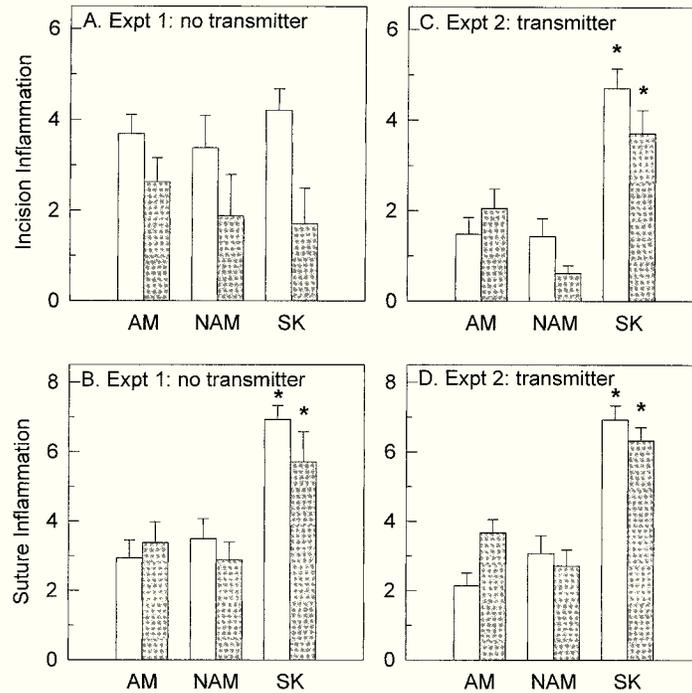


FIGURE 3.—Macroscopic wound inflammation at 2 (open bars) and 4 weeks (filled bars) postsurgery for experiment 1 and at 3 (open bars) and 6 weeks (filled bars) postsurgery for experiment 2. Inflammation of both (A, C) incision and (B, D) suture sites were evaluated using rating scales of 0–6 and 0–8, respectively (mean \pm SE). Treatment suture types include absorbable monofilament (AM), nonabsorbable monofilament (NAM), and braided silk (SK). All incisions were closed using a simple interrupted pattern. Each treatment consisted of eight fish. An asterisk (*) indicates the treatment was significantly different from treatments without an asterisk for the same time period.

protected pairwise comparison was performed only if significant results were obtained.

The type of suture was added to the analysis of wound strength as a treatment.

Results

Experiment 1

There were no significant differences between treatments with respect to inflammation at the incision site (Figure 3A). Braided silk sutures caused significantly more macroscopic inflammation at the suture site ($P < 0.05$) than either type of monofilament suture at both 2 and 4 weeks after surgery (Figure 3B). In all cases, wound strength testing at 4 weeks revealed no significant differences between any of the treatments for either breaking strength ($P = 0.66$) or breaking energy ($P = 0.82$) (Figure 4). The control tissues all had significantly higher breaking strength and energy ($P < 0.05$) than any surgery treatments.

Experiment 2

Incision sites closed with the braided silk were significantly more inflamed ($P < 0.05$) than those

closed with either monofilament at both time periods using the simple interrupted suture pattern (Figure 3C). At the suture entry and exit sites, braided silk caused significantly more macroscopic inflammation ($P < 0.05$) than either monofilament at both 3 and 6 weeks using the simple interrupted suture pattern (Figure 3D). There were no significant differences between the two types of monofilament suture materials. The vertical mattress suture pattern caused significantly more inflammation at the incision site ($P < 0.05$) than the simple interrupted pattern at both 3 and 6 weeks for each suture type (Figure 5). Surgery times using the vertical mattress suture pattern (10.86 ± 0.23 min) were significantly longer ($P < 0.05$) than with the simple interrupted pattern (8.86 ± 0.30 min).

Histological analysis revealed no significant differences among suture types or suture patterns for any of the eleven criteria at 6 weeks (Table 3). Wound apposition was improved in the simple interrupted, nonabsorbable suture treatment, and epidermal covering was worse in the vertical mat-

stress, absorbable suture treatment, but neither were significant when tested statistically ($P = 0.23$, $P = 0.08$, respectively).

At 6 weeks there were no significant differences in breaking strength ($P = 0.41$) or breaking energy ($P = 0.55$) attributable to either suture material or pattern (Figure 6). The surgical treatments also were analyzed separately without controls to determine if the significantly higher control tissue breaking strength and energy values ($P < 0.05$) confounded the analysis. The results obtained when control tissues were removed from the analysis also showed no significant differences.

Discussion

Braided silk sutures elicited a greater inflammatory response in the skin of fish than either type of monofilament. This response confirms braided silk suture causes moderate to severe tissue inflammation in fish, similar to the response of tissues in mammals reported by Smeak (1998). The use of dummy transmitters compounded the effect silk had on healing incisions compared with inflammation without transmitters. Incisions closed with silk were significantly inflamed with transmitters implanted in the fish, whereas the opposite was true when implants were absent. Increased tissue inflammation may be due to pressure and wear on incision sites by the dummy transmitters similar to results found by Schramm and Black (1984) for grass carp *Ctenopharyngodon idella* and Lucas (1989) and Kaseloo et al. (1992) for rainbow trout. The results of these studies combined with our own suggest the use of monofilament suture is preferable to silk because it causes less tissue inflammation when combined with an implanted transmitter.

Contrary to our hypothesis, the use of the vertical mattress pattern was detrimental to the health of fish because it increased surgery times, did not provide better apposition of wound margins (see Table 3), and in fact resulted in more incision inflammation than did the simple interrupted pattern. Hart and Summerfelt (1975) found similar results when suturing the peritoneum and integument separately in flathead catfish. Healing and survival of the catfish were impaired compared with the use of a simple interrupted pattern. The vertical mattress pattern we used may have increased inflammation by doubling tissue trauma because the suture material is passed through the incision twice (see Figure 2). The additional passage of the suture material through the tissues did not increase inflammation by increasing the presence of bacteria.

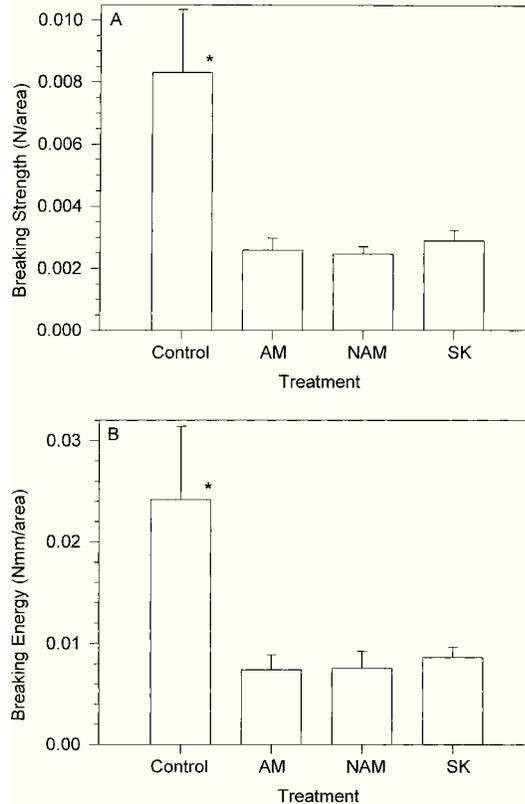


FIGURE 4.— (A) Mechanical breaking strength and (B) breaking energy of the incision site. Treatment suture types include absorbable monofilament (AM), nonabsorbable monofilament (NAM), and braided silk (SK). Each treatment consisted of seven fish. All forces (mean \pm SE) were calculated relative to the cross-sectional area (width \times thickness) of the excised incision site that was tested. Each control consisted of a nonincision cross-section of tissue abutting the incision. An asterisk (*) indicates the treatment was significantly different from treatments without an asterisk.

If this was the case, the inflammation would have increased posteriorly as each incision was sutured, beginning at the anterior end. However, the middle suture sites were inflamed 35% more than the anterior or posterior sites. This increased inflammation in the middle of the incision may be due to increased tension on those sutures from the outward force of the tag and the lack of support from surrounding intact tissue that is present at either end of the incision.

The significant macroscopic inflammation found at the silk suture sites and the vertical mattress incision sites was not found when the tissues were analyzed microscopically. Histological examination of the incision sites showed the inflammation

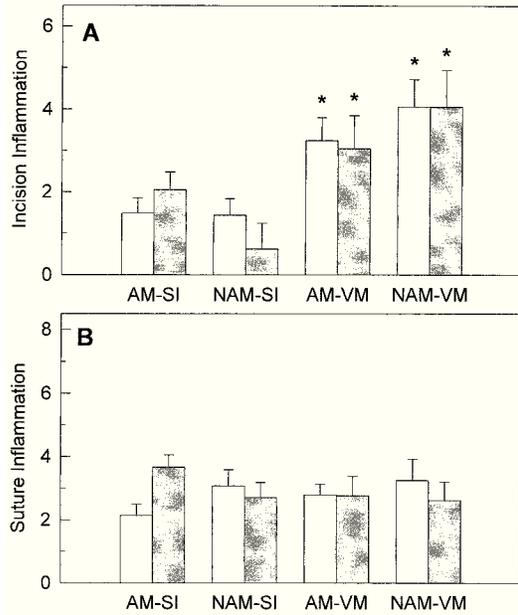


FIGURE 5.—Macroscopic wound inflammation at 3 (open bars) and 6 weeks (filled bars) postsurgery. Inflammation of both (A) incision and (B) suture sites were evaluated using rating scales of 0–6 and 0–8, respectively (mean ± SE). Suture patterns include simple interrupted (SI) and vertical mattress (VM). Suture types include absorbable monofilament (AM) and nonabsorbable monofilament (NAM). Each treatment consisted of seven fish. An asterisk (*) indicates the treatment was significantly different from treatments without an asterisk for the same time period.

at the skin did not seem to continue into the healing subcutaneous tissues. The silk sutures and vertical mattress patterns may have caused more inflammation only to the surface tissues because of increased local bacteria and tissue trauma, respectively. This lack of tissue damage may help explain our mechanical wound testing results.

Although braided silk sutures and vertical mattress patterns caused significantly more macroscopic tissue inflammation, wound strength was not affected in the surgical treatments. Breaking strength and breaking energy, our direct measures of wound healing, did not differ significantly among surgical treatments, but the intact control tissues were significantly stronger. This result is contrary to observations made by Pedersen and Andersen (1985), who implanted transmitters into the body cavities of Atlantic cod *Gadus morhua*. They reported healed incisions appeared to have the same strength and integrity as surrounding tissues, but no mechanical wound strength testing was performed. Although we were unable to find other published studies that tested tissues without an incision, their breaking strength should be markedly greater than healed tissues (D. Holmberg, University of Guelph, personal communication). Our hypothesis that wounds closed with monofilament (little inflammation) would be stronger than those closed with silk (moderate to severe inflammation) was proven incorrect because wound strength did not differ significantly among surgical treatments. The lack of significant differences among treatments was not due to poor equipment sensitivity because all force measurements for the mechanical wound tests (average 0.005 ±

TABLE 3.—Results of histological assessment of 6-week postsurgical incisions closed with three types of suture material and two types of suture pattern. A nonabsorbable monofilament (NAM), an absorbable monofilament (AM), a braided silk (SK), and the simple interrupted (SI) and vertical mattress (VM) patterns were tested; the level of significance was $\alpha = 0.05$. The means are presented for each treatment consisting of seven fish. There were no significant differences between treatments.

Histological criteria	Rating scale	Best score	P	Surgery treatments				
				NAM SI	AM SI	SK SI	NAM VM	AM VM
A. Wound apposition	0–3	0	0.23	0.4	1.4	1.3	1.3	1.9
B. Tissue in wounds	0–1	0	0.40	0.1	0.4	0.3	0.4	0.7
C. Epidermal covering	0–2	0	0.08	0.6	0.6	1.0	0.9	1.8
D ₁ . Macrophage activity	0–5	5	0.92	3.1	3.1	3.3	3.3	3.2
D ₂ . Fibroblast activity	0–5	5	0.63	2.8	2.4	2.3	2.4	2.3
D ₃ . Angiogenesis	0–5	5	0.98	2.4	2.4	2.5	2.6	2.3
D ₄ . Collagen organization	0–5	5	0.45	2.7	2.5	2.4	2.4	2.0
E. Peritonitis	0–5	0	0.07	2.5	2.6	3.2	3.3	2.2
F. Suppuration	0–5	0	0.19	0.1	1.6	0.8	1.3	0.9
G. Muscle regeneration	0–5	5	0.94	1.4	1.4	1.0	1.1	0.8
H. Pigment layer	0–5	5	0.12	3.8	3.1	3.4	2.4	2.8

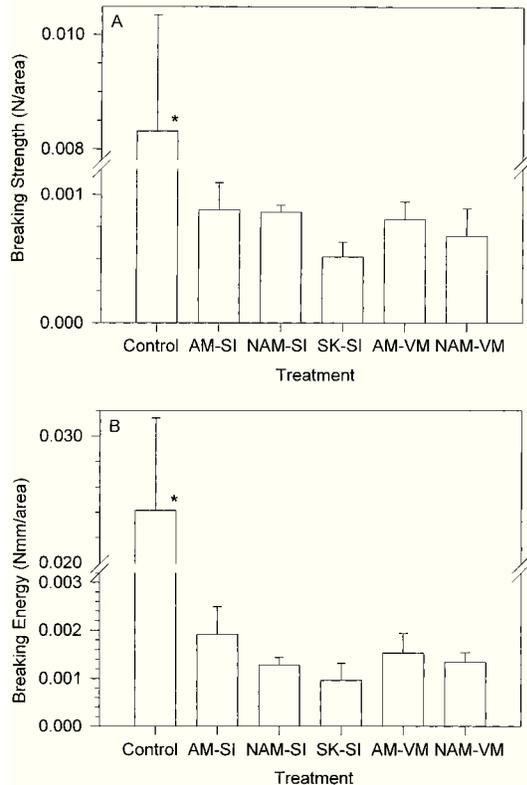


FIGURE 6.—(A) Mechanical breaking strength and (B) breaking energy of incision site tissues 6 weeks after surgery. Suture patterns include simple interrupted (SI) and vertical mattress (VM). Suture types include absorbable monofilament (AM), nonabsorbable monofilament (NAM), and braided silk (SK). Each treatment consisted of seven fish. All forces (mean \pm SE) were calculated relative to the cross-sectional area (width \times thickness) of the excised incision that was tested. Each control consisted of a nonincision cross-section of tissue abutting the incision. An asterisk (*) indicates the treatment was significantly different from treatments without an asterisk.

0.001 N) were above the lower sensitivity range (0.00001 N) of the Instron.

Most studies that have examined fish wound healing have done so histologically (Vogelbein and Overstreet 1987; Knights and Lasee 1996) or macroscopically (Petering and Johnson 1991; Kaseeloo et al. 1992), and none to our knowledge have used mechanical testing of wounds. However, several mammalian studies (Kenyon et al. 1986; Rosin and Richardson 1987; Albina et al. 1993) have shown wound strength testing to be an effective measure of wound healing. Albina et al. (1993) suggest differences in collagen fiber orientation, and the degree of cross-linking of the fibers can affect

wound strength. These properties likely were not affected by the increased macroscopic incision inflammation caused by the silk suture, because the inflammation did not seem to continue into the underlying tissues. Rosin and Richardson (1987) found that wound strengths of canine abdominal incisions with both the internal and external rectus sheaths closed did not differ significantly from incisions with only the external sheath closed. The similar results of our study suggest the apposition of both the internal and external tissue layers in fish incisions using the vertical mattress pattern will not help wound healing. Although the macroscopic incision inflammation was greater with the vertical mattress pattern, similar to the inflammation caused by silk sutures, it did not affect the wound strength. Collagen organization may not be affected by increases in surface inflammation caused by suture type or suture pattern.

Macroscopic suture inflammation was reduced by approximately 50% when monofilament suture was used instead of silk, but this difference was not reflected in greater wound strength. Our first study did not simulate the use of suture materials in the field because no transmitters were implanted. The addition of transmitter implantations in our second study increased pressure and wear on incision sites closed with silk suture. This increased stress still did not show monofilament to be superior to silk because the inflammatory effect silk suture had on the healing wounds did not affect their histology or strength. We still recommend the use of absorbable or nonabsorbable monofilament over braided silk suture, however, because they do reduce the macroscopic inflammatory response of tissues at cold water temperatures.

Although macroscopic inflammation caused by silk suture did not correlate significantly with decreased incision strength, high tissue inflammation may still affect overall fish health. We recommend use of the simple interrupted suture pattern over the vertical mattress pattern because it is faster to perform, causes less inflammation at the incision site, and provides equal apposition of wound margins.

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