

Performance Assessment of Suture Type, Water Temperature, and Surgeon Skill in Juvenile Chinook Salmon Surgically Implanted with Acoustic Transmitters

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Abstract.—This study assessed performance of seven suture types in subyearling Chinook salmon *Oncorhynchus tshawytscha* implanted with acoustic microtransmitters and held at two water temperatures (12°C and 17°C). Nonabsorbable (Ethilon) and absorbable (Monocryl) monofilament sutures and nonabsorbable (Nurolon and silk) and absorbable (Vicryl, Vicryl Plus, and Vicryl Rapide) braided sutures were used to close incisions in Chinook salmon. When differences existed among suture types, tag and suture retention were generally highest for monofilament sutures. Wound inflammation and ulceration were generally lower for Ethilon and Monocryl than for most of the braided sutures. In this study, Nurolon (braided) often resulted in low wound inflammation and ulceration, although suture retention was poor. Generally, fish held in 12°C water had more desirable postsurgery healing characteristics (i.e., higher tag and suture retention; lower incision openness, wound inflammation, and ulceration) at 7 and 14 d postsurgery than fish held in 17°C water. On days 34 and 63, tag retention remained high among fish in 12°C water, while suture retention decreased dramatically in both water temperatures. We found a significant effect of surgeon on tag and suture retention, wound inflammation and ulceration, and incision openness. Surgeons in this study were initially thought to have similar surgical proficiency based on their extensive previous experience. However, surgeons who had received feedback on their previous surgical technique performed better in this study. Results indicate that surgical training (i.e., feedback) and perhaps aptitude, rather than surgeon experience alone, may be as important as suture type in influencing the retention of sutures and tags. The overall results support the conclusion that Monocryl is the best suture material for closing incisions created during surgical implantation of acoustic microtransmitters in subyearling Chinook salmon. Future research should include testing different suturing patterns and knotting techniques as well as the number of knots required for different incision lengths.

Biotelemetry research involves attaching a device that emits an acoustic or radio signal from a tagged individual to a receiving system (Winter 1996). Ideally, the attachment or presence of a transmitter should not affect the behavior or survival of tagged fish, allowing inferences from a sample of tagged fish to a population of interest. However, there is evidence that biotelemetry devices can indeed affect fish behavior, growth, and survival (Lucas 1989; Moore et al. 1990; Robertson et al. 2003; Brown et al. 2006). Therefore, studies using this technology must aim to minimize this effect.

Acoustic transmitters are often implanted into the peritoneal cavity of study fish, and incisions are closed with suture material. Ideal suture material should maintain adequate tensile strength and knot security until the surrounding tissue integrity has returned. The suture material should (1) have minimal interference with the healing process, (2) resist bacterial contamination, and (3) elicit minimal foreign body reactions (Lin et al. 1996; Roush 2003). Although suture materials have been studied extensively for use in human and veterinary medicine (Lin et al. 1996; Roush 2003), comparatively little effort has been focused on suture performance in fish (Thoreau and Baras 1997; Wagner et al. 2000; Hurty et al. 2002; Jepsen et al. 2008).

One survey-based article suggested that the most common suture material used in fish surgery is

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synthetic monofilament (Wagner and Cooke 2005). Several studies have shown that synthetic monofilaments may elicit less tissue inflammation and promote more rapid incision healing compared with silk sutures. For example, rainbow trout *Oncorhynchus mykiss* experienced less tissue inflammation from monofilament than from braided silk sutures (Kaselloo et al. 1992; Wagner et al. 2000). Surgical wound healing was significantly faster when monofilament sutures were used rather than silk in blue tilapia *Oreochromis aureus* (Thoreau and Baras 1997) and koi (ornamental variant of common carp *Cyprinus carpio*; Hurty et al. 2002). However, wound healing and incision inflammation in largemouth bass *Micropterus salmoides* did not differ between incisions closed with monofilament and those closed with braided silk sutures (Cooke et al. 2003). Conflicting results among extant studies and an overall lack of research on the effects of different suture materials used in fish surgeries suggest that more research is needed.

Surgeon experience is an important factor in telemetry studies. In their study comparing suture types, Cooke et al. (2003) examined the role that surgical experience may play in telemetry studies. It was evident that the largemouth bass receiving transmitters implanted by a novice surgeon exhibited lower suture retention, higher suture inflammation, and higher mortality than largemouth bass for which implantation was conducted by an expert surgeon. Many telemetry studies, especially those in large river systems such as the Columbia River basin, rely on multiple surgeons with various experience levels to perform transmitter implantations (e.g., McMichael et al. 2008). Therefore, it is important to include surgeon as a factor in studies involving more than one surgeon.

Water temperature is another factor that can influence postsurgery healing characteristics in fish. Walsh et al. (2000) found that hybrid striped bass *Morone saxatilis* (striped bass \times white bass *M. chrysops*) held at a higher water temperature (22–29°C) experienced greater irritation at the suture site early on in the study than fish held at a lower water temperature (12–18°C). Conversely, fish in the lower temperature had greater suture site irritation at 60 d postsurgery. It was suggested that this may be attributed to the higher suture retention in the low-temperature group. Similarly, bluegills *Lepomis macrochirus* held in 20°C water experienced greater inflammation and increased transmitter loss than those held in 6°C water (Knights and Lasee 1996).

The objective of this study was to determine the best overall suture material to close incisions from the surgical implantation of acoustic microtransmitters in juvenile Chinook salmon *Oncorhynchus tshawytscha*.

Additionally, it was important to determine whether a single suture material excelled at mean water temperatures typical of spring and fall Chinook salmon smolt migration or whether the preferred material would be dependent on water temperature. Because a large number of fish was needed to compare among many suture types at two temperatures, multiple surgeons were used in this study. Therefore, surgeon also was included as a factor. This study quantified the effects of seven suture materials, four surgeons, and two water temperatures on tag retention, suture retention, incision openness, wound inflammation, and wound ulceration.

Methods

Experimental animals.—Subyearling spring Chinook salmon were obtained from the Entiat National Fish Hatchery in Chelan County, Washington, and were transported to the Pacific Northwest National Laboratory (PNNL) Aquatic Research Laboratory in Richland, Washington, in August 2006. Mean (\pm SE) fork length and weight of fish were 101 ± 1 mm (range = 95–121 mm) and 13.4 ± 0.1 g (range = 9.8–23.7 g), respectively. All fish were held in chilled 12°C well water in four 890-L, circular fiberglass tanks and were fed daily to satiation (ad libitum) with BioDiet pellets (Bio-Oregon, Inc., Longview, Washington). Prior to surgery, half of the fish were gradually acclimated to 17°C well water over a period of 3 d (rate < 2°C per day). Water temperatures of 12°C and 17°C were used to simulate the mean water temperatures during out-migration of yearling and subyearling Chinook salmon, respectively, in the Columbia River basin. Once acclimated, fish were held at 17°C for 1 week before experimentation. All fish were exposed to a photoperiod of 12 h light : 12 h dark for the duration of the study. Feed was withheld for 24 h before and 24 h after surgery.

Surgical equipment and procedures.—Surgeries were performed on 1,008 subyearling Chinook salmon on November 30 and December 1, 2006. Four surgeons performed all surgeries to minimize bias resulting from differences in surgeon performance. Suture type was assigned randomly without replacement. Each surgeon performed surgery on three fish with the same suture type before switching to the next suture in the designated order. Each surgeon performed an equal number of surgeries with each suture type. Fish from a different water temperature (12°C and 17°C) were assigned to the surgeons after one full rotation of the suture order.

Prior to surgery, all fish were brought to stage 4 anesthesia (as described by Summerfelt and Smith 1990) using tricaine methanesulfonate (MS-222) at a concentration of 80 mg/L of water. After fork length

TABLE 1.—Properties of suture types and needles used for surgical implantation of transmitters into juvenile Chinook salmon.

Suture type	Material	Absorbable	Properties	
			Filament	Needle
Ethilon	Nylon	No	Mono	Reverse cutting (FS-2)
Monocryl	Polyglactone 25	Yes	Mono	Precision point-reverse cutting (PS-2)
Nurolon	Nylon	No	Braided	Precision cosmetic-conventional cutting (PC-1)
Vicryl Rapide	Polyglactin 910 (coated)	Yes	Braided	Precision point-reverse cutting (P-3)
Silk (Perma-hand)	Organic protein	No	Braided	Reverse cutting (FS-2)
Vicryl	Polyglactin 910	Yes	Braided	Reverse cutting (FS-2)
Vicryl Plus	Polyglactin 910	Yes	Braided	Taper point (RB-1)

(mm) and weight (g) were obtained, fish were placed ventral side up on a foam rubber pad and supplied with a maintenance anesthesia dose of MS-222 (40 mg/L). Surgical incisions were made using a BD Beaver Micro-Unitome knife with a 3-mm blade (Becton, Dickinson, and Company, Franklin Lakes, New Jersey). An incision approximately 8 mm long was placed 3 mm lateral to and parallel with the linea alba. All fish were implanted with an acoustic transmitter and a passive integrated transponder (PIT) tag (Destron Technologies, St. Paul, Minnesota). Acoustic transmitters were either 2006 Model JSATS (Juvenile Salmon Acoustic Telemetry System) acoustic transmitters or “dummy” transmitters, both manufactured by Sonic Concepts, Inc. (Bothell, Washington). The 2006 Model JSATS transmitters were (mean \pm SD) 5.9 ± 0.1 mm wide, 17.0 ± 0.2 mm long, and 4.8 ± 0.2 mm high. Transmitters had a weight in air of 0.64 ± 0.01 g (0.36 ± 0.01 g in water) and a mean volume of 0.28 mL. The dummy transmitters (0.63 ± 0.03 g in air, 0.38 ± 0.02 g in water, 0.25-mL volume) were 5.8 ± 0.2 mm wide, 16.3 ± 0.4 mm long, and 4.1 ± 0.3 mm high. The PIT tags were 12.5 mm long and 2.1 mm wide and weighed 0.10 g in air (0.06 g in water; 0.04-mL volume). Tag burden for all fish was (mean \pm SE) $5.5 \pm 0.1\%$ (range = 3.5–6.7%). After the incision was made, the PIT tag and the acoustic transmitter were inserted into the peritoneal cavity of the fish. The incision was closed using two simple interrupted stitches secured with reinforced surgeon’s knots. A reinforced surgeon’s knot consisting of three double throws in alternating directions was used for all braided sutures. Ethicon (Somerville, New Jersey; the suture manufacturer) suggests the use of additional throws when knotting monofilaments (Dunn 2007). Therefore, a fourth double throw was used for Ethilon and Monocryl. After surgery, fish were released to their respective holding tanks. Feeding to satiation (ad libitum) resumed 1 d after surgery.

Seven suture types were selected for comparison in this study. All suture types were Ethicon brand with 5-0 thickness and were manufactured with varying

needle types (Table 1). Suture types were chosen for this study based on high prevalence of use in telemetry studies and potential benefits to fish. Ideally, the best suture material would provide the wound apposition necessary for healing and would then be quickly absorbed, causing minimal irritation to the fish. Vicryl and silk have been commonly used in telemetry studies in the Columbia River basin and elsewhere (e.g., Brown and Mackay 1995; Hockersmith et al. 2008). Vicryl Rapide was selected for its rapid absorption rate, while other sutures (Nurolon, Monocryl, and Ethilon) potentially offered minimal reaction with tissue (Dunn 2007). Vicryl Plus has an antibacterial agent and was chosen because it may minimize infection and inflammation of the wound (Dunn 2007).

Response examinations.—All fish were examined at 7, 14, 34, and 63 d postsurgery. Fish were fasted for 24 h prior to examinations. With the use of a microscope, a single evaluator graded all fish on all examination days. Examinations consisted of anesthetizing fish with MS-222 at 80 mg/L and obtaining fork length (mm) and weight (g). Fish were then placed ventral side up on a foam rubber pad and supplied with a maintenance anesthesia dose of MS-222 at 40 mg/L. Evaluations were made on both the anterior and posterior sutures separately as well as on the incision. Functional suture retention was assessed for all fish (response values of 0, 1, or 2 functional sutures remaining). A functional suture was defined as any suture that was present in the fish, remained knotted, and did not tear through the body wall of the fish. Tag retention, wound inflammation, and wound ulceration were each recorded as present (1) or absent (0). Incision openness was scored on a 0–1 ordinal scale for all fish, with lower values representing less incision openness (Table 2).

Analysis.—Categorical covariates included surgeon at four levels and suture type at seven levels. Response variables for days 7 and 14 were analyzed separately for fish held at 12°C and 17°C. Temperature and day were not included as covariates.

Binary response variables, tag retention, wound inflammation, and wound ulceration were modeled

TABLE 2.—Rating criteria used to characterize incision openness in Chinook salmon.

Rating	Rating criterion
0.00	Incision completely closed
0.25	Incision < 50% open
0.75	Incision > 50% open but not completely open
1.00	Incision completely open

using generalized linear models based on a logistic link function and Bernoulli error structure. The suture effect was added to the model after adjusting for surgeon. Analysis of deviance was used to model the data and to perform either pairwise comparisons or likelihood ratio tests. Wound inflammation and wound ulceration analyses were limited to fish that retained two functional sutures because the extent of inflammation and ulceration attributed to sutures is dependent on the presence of the suture and the length of time since the suture was lost (Table 3). The exact date of suture loss and the lasting effect of a lost suture on inflammation and ulceration were unknown.

Suture retention and incision openness were modeled as continuous response variables using a multivariate normal model with surgeon and suture as regression variables. Analysis of variance (ANOVA) and pairwise comparisons were performed. All analysis was performed using R statistical software (version 2.9.1).

For each variable, the seven suture types from each of the four day-temperature combinations were ranked from best to worst. Analysis of deviance (for binary variables), ANOVA (for continuous variables; $\alpha = 0.05$ for both), and pairwise comparisons were performed among suture types. In cases where binary response variables had only one outcome, likelihood ratio tests were used in place of pairwise comparisons. For example, there was 100% tag retention for Monocryl. In this case, likelihood ratio tests were used in comparisons between Monocryl and other suture types.

TABLE 4.—Adjusted α values for pairwise comparisons of suture types used for surgical implantation of transmitters in juvenile Chinook salmon, presented by response variable, day (7 or 14 d postsurgery), and temperature.

Response variable	Day 7		Day 14	
	12°C	17°C	12°C	17°C
Tag retention	0.050	0.009	0.009	0.007
Suture retention	0.007	0.004	0.004	0.003
Incision openness	0.003	0.050	0.050	0.009
Inflammation	0.005	0.017	0.003	0.005
Ulceration	0.050	0.003	0.003	0.005

A pairwise comparison or likelihood ratio test between the suture ranked first (best) and the suture ranked seventh (worst) was performed. If there was a significant difference between the first- and seventh-ranked sutures, then a pairwise comparison or likelihood ratio test between the first- and sixth-ranked sutures was performed. This was repeated until a nonsignificant pairwise comparison or likelihood ratio test was found. The second-ranked suture was then compared with the seventh-ranked suture, the sixth-ranked suture, and so on until a nonsignificant pairwise comparison was found. Ranking the sutures and performing pairwise comparisons in this fashion limited the number of pairwise comparisons required.

The probability α_C is the risk of making a type I error for a single comparison. The probability α_T is the risk of making at least one type I error among n independent comparisons. The following relationship expresses the experimentwise type I error rate as a function of the comparisonwise type I error rate:

$$\alpha_T = 1 - \sqrt[n]{1 - \alpha_C}$$

If each of the tests is conducted with an α_C value of 0.05, the risk of at least one type I error escalates as the number of tests increases. The probability α_T was calculated for each combination of response variable, day postsurgery, and temperature, depending on the number of comparisons (Table 4).

TABLE 3.—Sample sizes of juvenile Chinook salmon used in analyses by day (7 or 14 d postsurgery), suture type, and temperature. Retention refers to both tag retention and suture retention; openness refers to incision openness.

Suture type	Day 7				Day 14			
	Retention and openness		Inflammation and ulceration		Retention and openness		Inflammation and ulceration	
	12°C	17°C	12°C	17°C	12°C	17°C	12°C	17°C
Ethilon	72	72	64	57	72	71	62	52
Monocryl	71	72	68	69	70	71	66	51
Nurolon	72	72	51	38	71	70	28	17
Vicryl Rapide	72	71	67	46	72	67	54	34
Silk	71	71	68	45	68	68	51	38
Vicryl	72	69	66	46	71	62	52	31
Vicryl Plus	70	72	68	53	68	68	48	37

Results

Most sutures (73%) were retained through day 14; however, few (28%) sutures were retained and functional by day 34. In addition, most fish had closed incisions by day 14. Percentages of fish with completely closed incisions were 76, 72, and 86% at 14, 34, and 63 d, respectively. Thus, with the decreased sample size of fish with two sutures and the major differences occurring through day 14, some results are provided for day 34 and day 63. However, statistical analysis was conducted only on data from 7 and 14 d postsurgery.

Tag Retention

Among fish held at 12°C, tag retention was generally high (mean = 100% on day 7 and 99% on day 14; Figure 1). On day 7, fish with all suture types except Nurolon and Vicryl Plus exhibited 100% retention of tags. By day 14, Monocryl, Vicryl Rapide, and Vicryl were the only suture groups for which tag retention was 100%. Among fish held at 12°C, there were no significant differences in tag retention among suture types at either 7 or 14 d postsurgery.

Tag retention was typically lower among fish held at 17°C (mean = 97% on day 7 and 86% on day 14) than among those held at 12°C. Among fish held at 17°C, Monocryl and Vicryl Plus had significantly higher tag retention on day 7 than Nurolon and Vicryl Rapide. No other pairwise comparisons were significantly different. After being held for 14 d, fish sutured with either Monocryl or Ethilon had significantly higher tag retention than those sutured with Vicryl Rapide. The other pairwise comparisons indicated no significant differences.

Throughout the rest of the study (days 34 and 63), tag retention remained higher in the colder water. On day 34, mean tag retention was 92% and 77% for 12°C and 17°C, respectively. On day 63, mean tag retention was 81% and 74% for 12°C and 17°C, respectively.

Suture Retention

Among fish held at 12°C, suture retention was generally high (mean = 94% on day 7 and 82% on day 14; Figure 1). However, at 7 d postsurgery, Nurolon had significantly lower suture retention than all other types. There were no other significant differences in retention among the remaining suture types on day 7. At 14 d postsurgery, retention of Nurolon sutures was still significantly lower than that of all other types. In addition, retention of Monocryl was significantly higher than that of Vicryl Plus and silk. No other pairwise comparisons for day 14 were significant.

Suture retention was typically lower among fish held at 17°C (mean = 78% on day 7 and 64% on day 14)

than among fish held at 12°C. For fish held at 17°C, Monocryl had significantly higher retention on day 7 than all other sutures except Ethilon. In addition, retention of Ethilon was significantly higher than that of Nurolon, silk, and Vicryl Rapide. All other pairwise comparisons were not significantly different for day 7. At 14 d postsurgery, both Monocryl and Ethilon had significantly higher retention than all other suture types, but there was no significant difference between the two monofilaments. Additionally, Vicryl Rapide and Vicryl Plus had significantly higher retention than Nurolon. The other pairwise comparisons for day 14 were not significantly different.

Throughout the rest of the study (days 34 and 63), there was less variation in suture retention between the two water temperatures. On day 34, mean suture retention was 27% and 28% for 12°C and 17°C, respectively. By day 63, mean suture retention dropped to 6% and 7% for 12°C and 17°C, respectively.

Incision Openness

Among fish held at 12°C, mean incision scores for the suture types ranged from 0.07 to 0.23 on day 7 and from 0.07 to 0.13 on day 14 (Figure 1). At 7 d postsurgery, openness was significantly lower for Vicryl Plus than for Monocryl and Ethilon. Additionally, incisions closed with silk and Vicryl had significantly less openness than those closed with Monocryl. All other pairwise comparisons were not significantly different for day 7. There were no significant differences among suture types at 14 d postsurgery for fish held in 12°C water.

Incision openness was generally higher for fish held at 17°C than for those held at 12°C; means for the suture types ranged from 0.25 to 0.36 on day 7 and from 0.11 to 0.28 on day 14. At 7 d, incision openness did not differ significantly among suture types. However, on day 14, incisions closed with Ethilon and Monocryl had significantly less openness than those closed with Nurolon. No other significant pairwise comparisons were obtained for day 14.

For the rest of the study (days 34 and 63), water temperature had a greater effect on incision openness at day 63 than at day 34. Thirty-four days after surgery, the mean incision openness score was 0.15 for fish held at 12°C and for fish held at 17°C. The mean openness score on day 63 in 12°C water was similar at 0.16. However, among fish held in 17°C water for 63 d, the mean incision openness score was 0.0, indicating complete closure.

Wound Inflammation

At 12°C, the percentage of fish with wound inflammation generally increased from day 7 (mean =

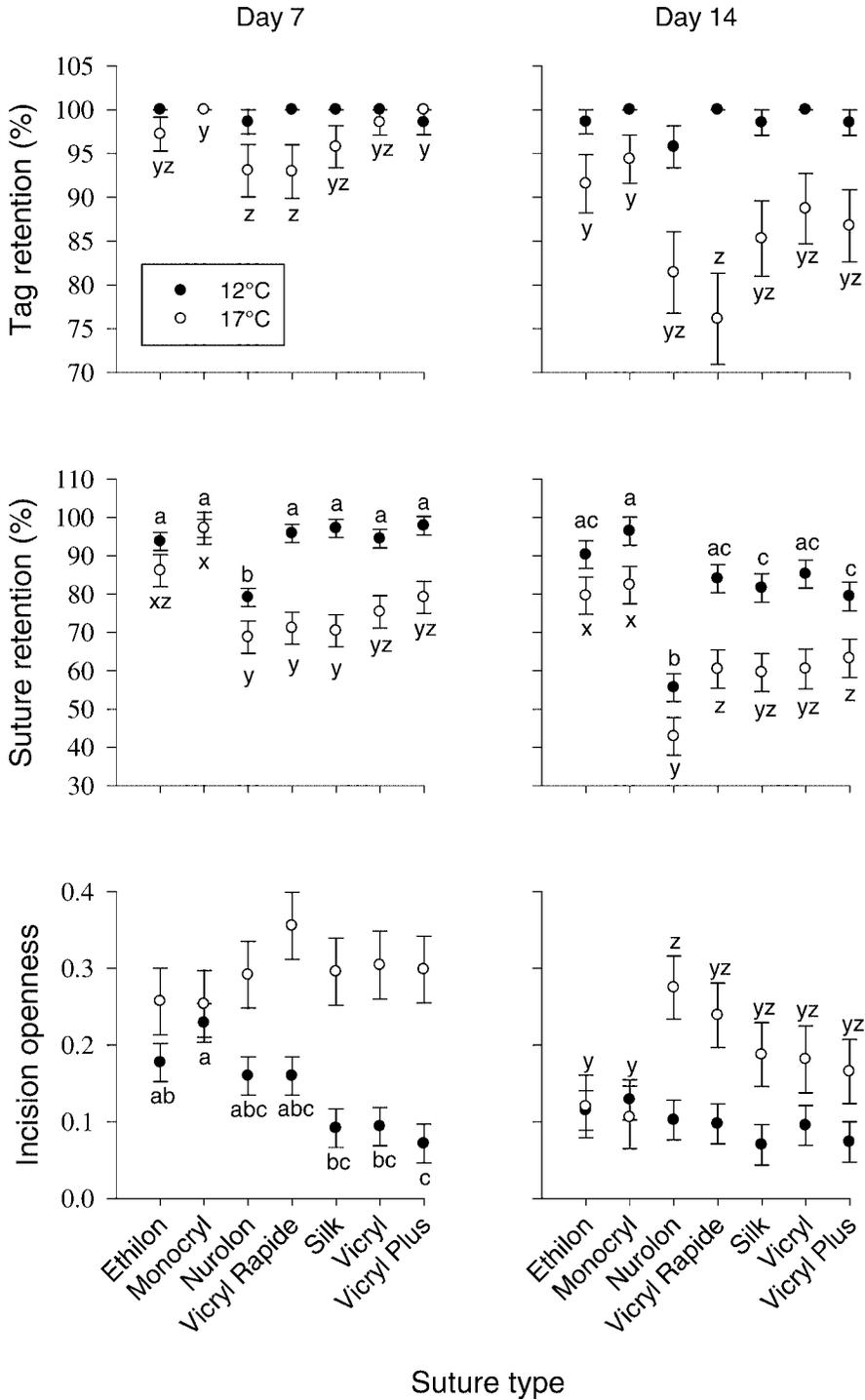


FIGURE 1.—Mean (\pm SE) tag retention (%), suture retention (%), and incision openness at 7 and 14 d postsurgery for Chinook salmon that were subjected to surgical implantation of transmitters using seven suture types and held at 12°C or 17°C. For a given temperature and day, data points with the same letter are not significantly different (different lettering sequences were used for each temperature). Absence of lettering indicates that no significant differences were found among suture types at the given temperature.

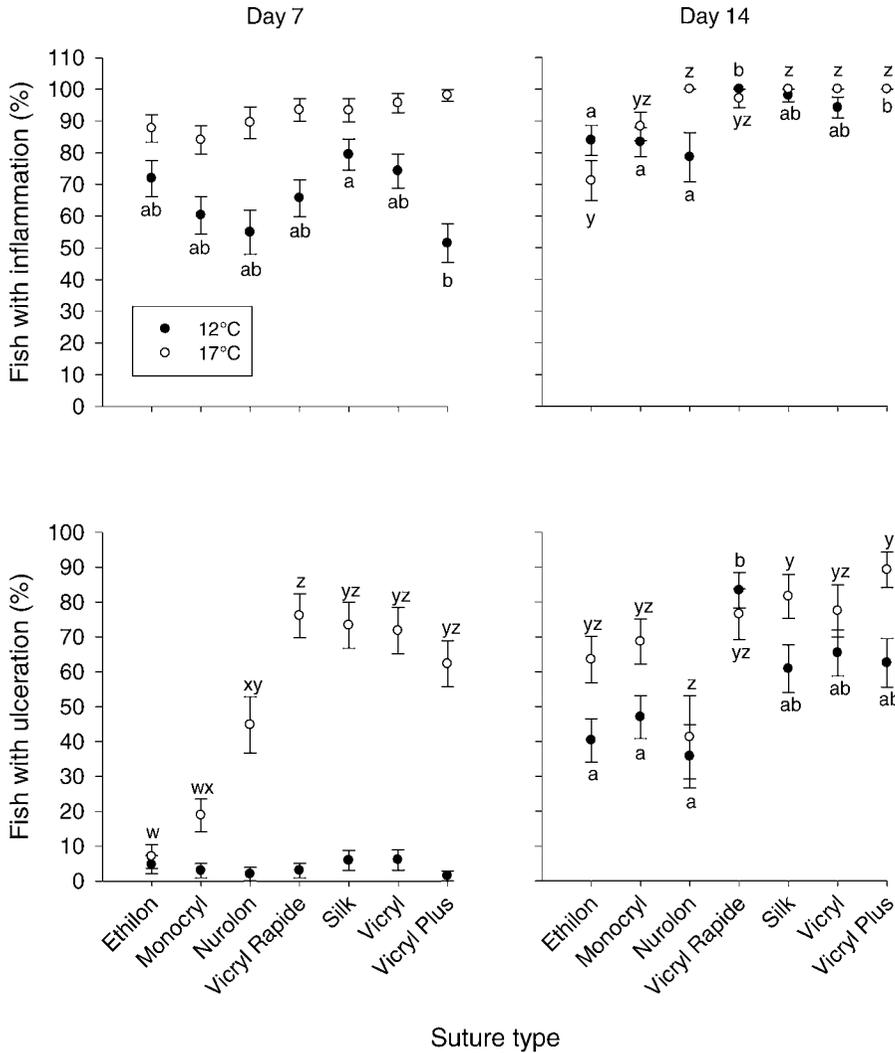


FIGURE 2.—Mean (±SE) percentage of Chinook salmon exhibiting inflammation or ulceration at 7 and 14 d after surgical implantation of transmitters using seven suture types for fish held at 12°C or 17°C. For a given temperature and day, data points with the same letter are not significantly different (different lettering sequences were used for each temperature). Absence of lettering indicates that no significant differences were found among suture types at the given temperature.

66%) to day 14 (mean = 91%; Figure 2). Seven days after surgery, fish sutured with Vicryl Plus had significantly less inflammation than those sutured with silk. Other pairwise comparisons for day 7 were not significantly different. By day 14, fish sutured with Nurolon, Monocryl, and Ethilon had significantly lower inflammation than those sutured with Vicryl Rapide and Vicryl Plus. No other pairwise comparisons were significant.

Inflammation was generally common among fish held at 17°C (mean = 91% on day 7 and 92% on day 14). There were no significant differences among

suture types at 7 d postsurgery. By day 14, there was significantly less inflammation with Ethilon than with Vicryl Plus, silk, Vicryl, and Nurolon. Significant differences were not found for the other pairwise comparisons.

By day 34, 25% of fish retained both sutures; however, by day 63, only 2% of fish retained both sutures. Among the fish that retained both sutures through day 34, the prevalence of inflammation was high (mean = 93% and 85% for 12°C and 17°C, respectively). Inflammation prevalence was still high at 63 d postsurgery for the few fish retaining two sutures

(mean = 100% and 33% for 12°C and 17°C, respectively).

Wound Ulceration

Among fish held at 12°C, wound ulceration increased with holding time (mean = 4% on day 7 and 57% on day 14; Figure 2). Seven days after surgery, less than 7% of fish in any suture group had ulceration, and there was no significant difference among suture types. By day 14, ulceration had increased to as high as 83% in fish with Vicryl Rapide sutures. Ulceration was significantly lower for Nurolon, Ethilon, and Monocryl than for Vicryl Rapide. No other significant pairwise comparisons were observed.

Ulceration was typically higher among fish held at 17°C (mean = 47% on day 7 and 73% on day 14) than for those held at 12°C. For fish held at 17°C, Ethilon and Monocryl sutures led to significantly less ulceration on day 7 than silk or any of the three Vicryl suture types. In addition, fish with Ethilon sutures had significantly less ulceration than fish sutured with Nurolon. Nurolon had significantly lower ulceration than Vicryl Rapide. The other pairwise comparisons for day 7 were not significantly different. By day 14, there was significantly less ulceration with Nurolon than with Vicryl Plus and silk; no other significant pairwise comparisons were observed.

The number of fish with two sutures dropped from 25% on day 34 to 2% on day 63. Among the fish that retained both sutures through day 34, the prevalence of ulceration was high (mean = 67% and 79% for 12°C and 17°C, respectively). At 63 d postsurgery, ulceration prevalence was still high for the few fish retaining two sutures (mean = 100% and 33% for 12°C and 17°C, respectively).

The effect of suture type on healing was consistent among surgeons because the surgeon \times suture interaction was not significant for any of the metrics examined during this study (i.e., tag retention, ulceration, etc.). The surgeon effect can be described with the overall range of means for each surgeon (separated by temperature). Means are illustrated for day 14 because the greatest surgeon differences appeared on this day (Figure 3).

Retention characteristics varied considerably and differed significantly among surgeons. Tag retention differed significantly among surgeons on days 7 and 14 at 17°C but only on day 14 at 12°C. Overall means ranged from 88% for surgeon 1 to 100% for surgeons 3 and 4 on day 7. On day 14, means ranged from 65% for surgeon 1 to 100% for surgeons 3 and 4. Suture retention on day 14 at 17°C also differed significantly among surgeons. On day 7, mean suture retention by

temperature ranged from 55% for surgeon 1 to 98% for surgeon 2. Suture retention ranged from 33% for surgeon 1 to 96% for surgeon 4 on day 14.

Wound healing characteristics also varied considerably and differed significantly among surgeons. Incision openness for fish held at 17°C was significantly different among surgeons on days 7 and 14. On day 7, mean openness scores ranged from 0.05 for surgeon 4 to 0.51 for surgeon 1. Openness ranged from 0.01 for surgeons 3 and 4 to 0.36 for surgeon 1 on day 14. Inflammation differed significantly among surgeons on days 7 and 14 at 17°C and on day 7 at 12°C. On day 7, mean inflammation scores ranged from 0.55 for surgeon 2 to 0.95 for surgeon 4. Inflammation ranged from 0.71 for surgeon 2 to 0.97 for surgeon 3 on day 14. Ulceration differed significantly among surgeons on day 7 at 17°C and on day 14 at 12°C. Overall mean ulceration ranged from 0.01 to 0.58 on day 7 and from 0.44 to 0.80 on day 14 for surgeons 2 and 3, respectively.

Survival was relatively high on days 7, 14, and 34 (mean = 99, 97, and 82%, respectively). However, an unidentified disease outbreak occurred, and survival was reduced to 55% by day 63.

Discussion

When differences existed among suture types, tag retention and suture retention were generally highest for monofilament sutures. Monofilament sutures may reduce wicking of bacteria into the peritoneal cavity and elicit a lesser foreign body response (Hurty et al. 2002), thus minimizing inflammation in the body wall and enabling sutures to remain intact longer. At 7 d postsurgery, retention of monofilament sutures was higher than that of silk sutures when fish were held in 17°C water. Contrary to this result, suture retention at 5 d postsurgery did not differ between nonabsorbable monofilament and silk sutures in juvenile largemouth bass implanted with radio microtransmitters and held at 17.5–22°C (Cooke et al. 2003). However, when fish were held at 12°C for 7 d during this study, suture retention did not differ between monofilament and silk sutures.

Wound inflammation and ulceration were generally lower for Ethilon and Monocryl than for most of the braided sutures. In this study, Nurolon (braided) often exhibited low wound inflammation and ulceration, although suture retention was poor. Similar studies with rainbow trout have reported lower levels of inflammation associated with monofilament sutures than with other suture types (Kaselloo et al. 1992; Wagner et al. 2000). Histological studies also reported lower inflammation with absorbable monofilament in koi (Hurty et al. 2002). Interestingly, they found that

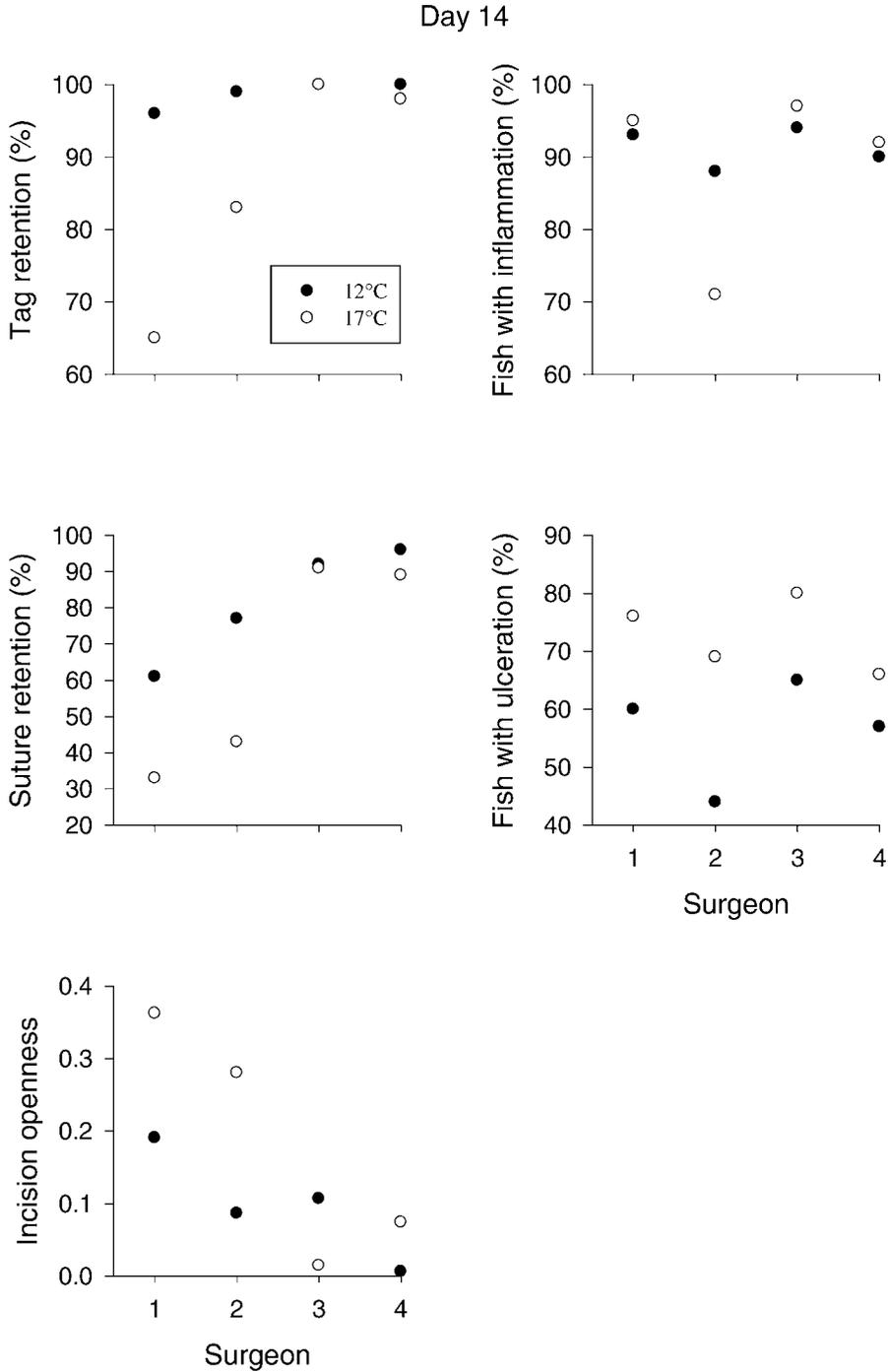


FIGURE 3.—Surgeon-specific mean tag retention, suture retention, incision openness, inflammation, and ulceration in Chinook salmon at 14 d after transmitter implantation by one of four surgeons (all seven suture types pooled); fish were held at 12°C or 17°C.

koi skin had a severe reaction to nonabsorbable monofilament (similar to Ethilon) when observed grossly at 14 d postsurgery. In this study, Ethilon did not produce a severe reaction in the skin of Chinook salmon, even when observed with a microscope. This result indicates possible differences between species may affect suture performance.

Cooler water temperature (12°C) during holding resulted in better overall postsurgery characteristics (i.e., higher tag and suture retention; lower incision openness, wound inflammation, and ulceration) in juvenile Chinook salmon than warmer water temperature (17°C). Similarly, bluegills had higher tag retention and lower tissue inflammation at incision and suture sites when held at 6°C than at 18°C (Knights and Lasee 1996). Inflammatory responses have been shown to be slower at 5°C than 15°C in rainbow trout (Finn and Nielsen 1971). In addition, Bunnell and Isely (1999) observed that the rates of tag loss in rainbow trout were lower at 10°C than at 20°C. With tissue reactivity of sutures being dependent on water temperature, researchers should consider the water temperature range that the study fish are likely to experience.

A significant effect of surgeon on tag and suture retention, wound inflammation and ulceration, and incision openness was observed in this study, suggesting differential performance among surgeons. For example, suture retention was lower for surgeons 1 and 2 than for surgeons 3 and 4 (Figure 4; day-14 suture retention is shown because differences were greatest on this day and because suture retention affects all other variables). Surgeons in this study were initially thought to have similar surgical proficiency based on extensive previous experience. For surgeons 3 and 4, experience included laboratory-based studies in which healing and transmitter loss were monitored for several weeks. These surgeons obtained feedback on their surgical techniques, which allowed them to remediate areas of lower surgical proficiency (e.g., suture placement and tightness, knotting ability). Previously, surgeons 1 and 2 had performed a very large number of surgeries in field studies but without the benefit of observing the effects of their surgical techniques on factors associated with incision healing.

Results from this study indicate that surgical training (i.e., feedback) and perhaps aptitude—rather than experience alone—influence the retention of sutures and tags as much as suture type. However, some sutures used in this study (monofilaments) had higher retention even when used by surgeons with less feedback training. Alternatively, Nurolon had lower retention than all other sutures independent of which

surgeon performed the surgery. This may suggest that the technique used for Nurolon was inadequate for this method of incision closure. Although three of the surgeons had never used Monocryl sutures, retention was still higher with Monocryl than with the Vicryl suture that they were accustomed to using; this indicates that Monocryl has higher retention rates even when used by novice surgeons.

One factor that may influence suture retention is needle type. Unfortunately, it was not possible to get all suture types with the same needle. Thus, needle type could have influenced our results. For example, the Ethicon wound closure manual (Dunn 2007) suggests that due to their design, conventional cutting needles (the type present on Nurolon sutures) may be likely to cause the suture to tear through the tissue. Further research is needed to determine whether needle type influences suture retention and incision healing; however, needle type is probably a minor factor in suture retention and incision healing in comparison with suture material and surgeon training.

The majority (62%) of surveyed fisheries researchers performing surgical implantation in telemetry projects considered the effects of surgeon performance to be large enough to necessitate the inclusion of surgeon as a variable in analyses (Wagner and Cooke 2005). Although experience can be a predictor of surgical competence (Cooke et al. 2003), this study suggests that surgical volume (number of surgeries performed) should not be the only measure of aptitude. Training for potential surgeons should include visual feedback. Feedback could include a series of photographs taken on surgery and postsurgery days (prior to considerable healing) to document the condition of sutures and surrounding tissue. Areas of surgical technique needing improvement could be identified and remediated. Differences among surgeons could be minimized and proficiency could be increased if surgeons were able to acquire feedback after performing surgeries.

Despite differences among surgeons, monofilament sutures had the highest suture retention. Higher suture retention typically resulted in lower incision openness and higher tag retention (Figure 3). In addition to having higher tag and suture retention, Monocryl and Ethilon were equal to or better than all other suture types with respect to levels of wound inflammation and ulceration up to 14 d after surgery. Because some researchers have seen undesirable effects from long-term retention of nonabsorbable sutures (Jepsen et al. 2008), we conclude that absorbable Monocryl is the best suture material for closing an incision created by surgical implantation of acoustic transmitters in subyearling Chinook salmon.

The results from this study prompt several sugges-

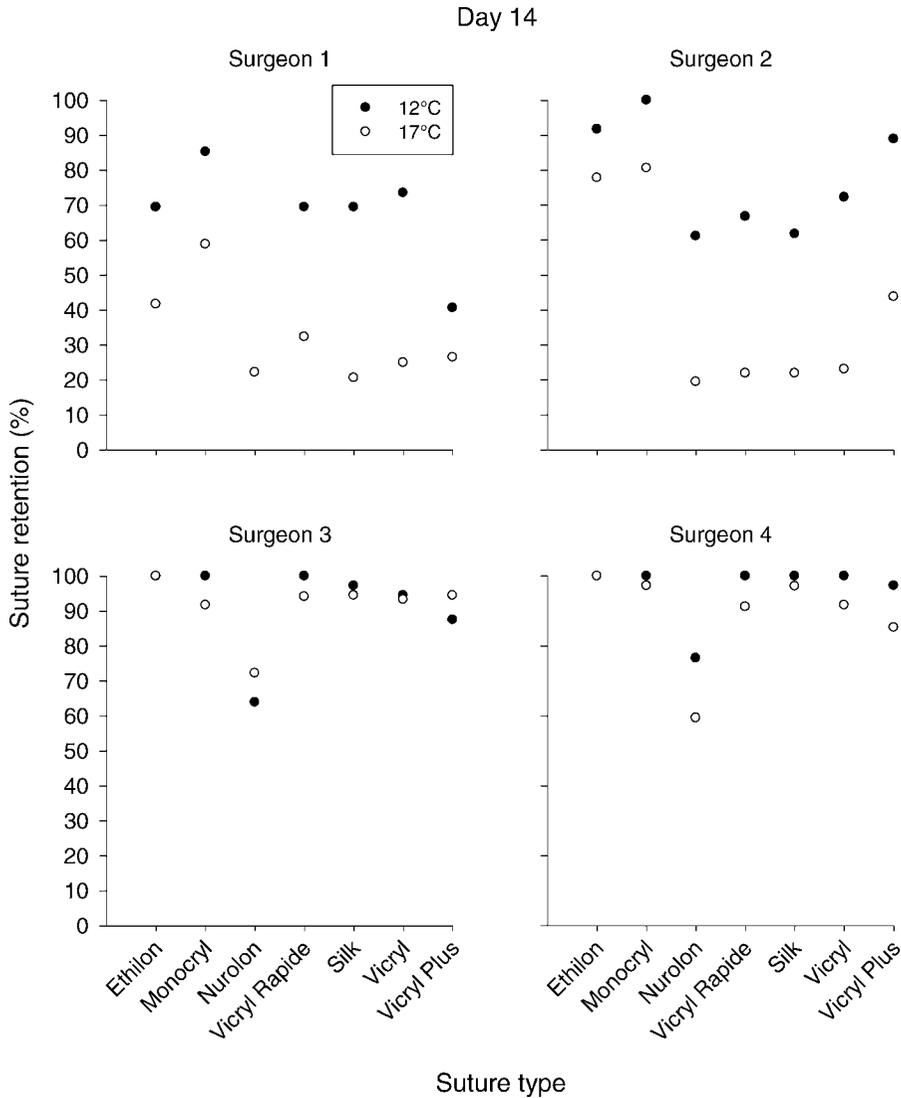


FIGURE 4.—Percentage suture retention in Chinook salmon at 14 d after transmitter implantation by one of four surgeons using seven suture types; fish were held at 12°C and 17°C.

tions for additional research. Because Nurolon produced low inflammation and ulceration prevalence, further testing with this suture type could be valuable to determine whether retention would increase with a different suturing technique or needle type. Other areas for future research include testing different suturing patterns, different knotting techniques, and the number of knots required for different incision lengths. Our results show that due to the possibility of a surgeon effect in field or laboratory tagging studies, the effect of surgeon differences should always be included as a variable in research studies.

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