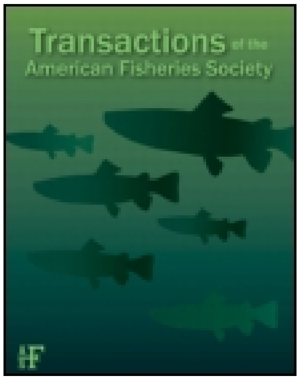

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Effects of Suture Material and Ultrasonic Transmitter Size on Survival, Growth, Wound Healing, and Tag Expulsion in Rainbow Trout

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ARTICLE

Effects of Suture Material and Ultrasonic Transmitter Size on Survival, Growth, Wound Healing, and Tag Expulsion in Rainbow Trout

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Abstract
We examined the effects of suture material (braided silk versus Monocryl) and relative ultrasonic transmitter size on healing, growth, mortality, and tag retention in rainbow trout *Oncorhynchus mykiss*. In experiment 1, 40 fish (205–281 mm total length [TL], 106–264 g) were implanted with Sonotronics IBT-96–2 (23 × 7 mm; weight in air, 4.4 g; weight in water, 2.4 g) or IBT 96–2E (30 × 7 mm; weight in air, 4.9 g; weight in water, 2.4 g) ultrasonic telemetry tags. In experiment 2, 20 larger fish (342–405 mm TL; 520–844 g) were implanted with Sonotronics IBT-96–5 ultrasonic tags (36 × 11 mm; weight in air, 9.1 g; weight in water, 4.1 g). The tag burdens for all implanted fish ranged from 1.1% to 3.4%, and fish in both studies were held at 10–15°C. At the conclusion of both experiments (65 d after surgery), no mortalities were observed in any of the 60 tagged fish, most incisions were completely healed, and all fish in both experiments grew in length, although tagged fish grew more slowly than control fish in experiment 1. In both experiments, fish sutured with silk expelled tags more frequently than those sutured with Monocryl. Expulsion was observed in 45–50% of the fish sutured with silk and 0–25% of the fish sutured with Monocryl. Tag expulsion was not observed until 25–35 d after surgery. Fish sutured with silk exhibited a more severe inflammatory response 3 weeks after surgery than those sutured with Monocryl. In experiment 1, the rate of expulsion was linked to the severity of inflammation. Although braided silk sutures were applied faster than Moncryl sutures in both experiments, knots tied with either material were equally reliable and fish sutured with Monocryl experienced less inflammation and lower rates of tag expulsion.

The validity of any biotelemetry study depends on the assumptions that the attachment of a transmitter tag does not affect behavior, growth, or survival, and that tag loss is minimal. Summerfelt and Smith (1990) provided early technical guidelines for surgically implanting telemetry tags; however, there are many variations on the basic technique and there is little consensus regarding the efficacy of common modifications. Because there is substantial interspecific variation in the anatomy, morphology, and physiology of fishes, the efficacy of modifications to surgery techniques probably differs on a species-specific basis. The findings and recommendations of methodological studies are outlined in several more recent reviews of surgical implantation techniques (Jepsen et al. 2002; Bridger and Booth 2003; Mulcahy 2003; Brown et al. 2010).

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Sutures are used in tag implantation surgeries to close the wound that the transmitter was inserted through, thereby inhibiting passive ejection of the implanted tag and maintaining tissue contact, which aids in healing. Suture materials are classified as either monofilament or braided multifilament. Multifilament sutures are generally regarded as easier to work with (Wagner and Cooke 2005), which can decrease the time needed to apply sutures (Cooke et al. 2003), but multifilament sutures produce tissue drag and facilitate bacterial wicking (Smeak 1998). Wagner et al. (2000) reported greater inflammation of the suture site in rainbow trout *Oncorhynchus mykiss* implanted with radio transmitter tags equipped with antennae when braided silk suture was used compared with when monofilament sutures were used. Similar findings have been reported from studies using Chinook salmon *O. tshawytscha* (Deters et al. 2010), koi carp *Cyprinus carpio* (Hurty et al. 2002), and largemouth bass *Micropterus salmoides* (Cooke et al. 2003). Most (74%) fish surgeons typically use a monofilament suture to close incisions (Wagner and Cooke 2005). Wagner et al. (2000) had better results using a simple interrupted suture pattern than a vertical mattress pattern to close the wound on rainbow trout.

Once the incision wound is healed, transmitters are often encapsulated by the body and can be expelled through the site of the incision (Bunnell and Isely 1999), another part of the body wall (Lucas 1989; Helm and Tyus 1992), the site of the antenna exit wound (i.e., for radio transmitters, Bunnell and Isely 1999), or the intestine (Chisholm and Hubert 1985; Helm and Tyus 1992). Lucas (1989) and Jepsen et al. (2008) described and photographed the biological processes involved with encapsulation and expulsion of a telemetry tag. This process of encapsulation and expulsion does not seem to affect fish health (Lucas 1989). The use of heavier or larger tags can increase the likelihood of transmitter expulsion in trout (Chisholm and Hubert 1985).

Discrepancies in methods used for disinfection and sterilization of surgical tools, the suture type, and relative transmitter size can inadvertently bias telemetry field studies. A number of tag implantation studies involving rainbow trout (e.g., Martin et al. 1995; Bunnell and Isely 1999; Wagner et al. 2000) used radio tags equipped with antennae. Several studies (e.g., Chisholm and Hubert 1985; Lucas 1989; Helm and Tyus 1992) used nonsurgical implants (e.g., wooden dowels coated with paraffin) without antennae and each only investigated one suture type. Before beginning a telemetry study of movements and survival of rainbow trout stocked into Tennessee reservoirs, we undertook the present study to evaluate the effects of two common suture materials (braided silk and Monocryl) and relative ultrasonic transmitter size on healing, growth, mortality, and transmitter retention in rainbow trout.

METHODS

Experiment 1.—Forty rainbow trout were implanted with transmitters; 2/0 monofilament Monocryl suture (Ethicon) and 2/0 multifilament braided silk (Ethicon) with FS-1 reverse cutting needles were used on equal numbers of fish. Ten fish received a sham treatment (i.e., fish were operated on but no transmitter was implanted); five were sutured with each material. Ten fish served as controls (i.e., fish were handled like those receiving other treatments but did not undergo invasive surgery). Mean ± SE total length (TL) of all fish was 247 ± 2.02 mm and mean weight was 187 ± 3.99 g. Fish ranged in size from 205 mm TL and 106 g to 281 mm TL and 264 g. Fish were chosen at random from a selection provided from several raceways at Dale Hollow National Fish Hatchery, Celina, Tennessee. All surgeries were performed on 16 July 2008. Manufactured replicas (dummy tags) of nonfunctioning original equipment of Sonotronics IBT-96–2 ultrasonic transmitter tags (23 × 7 mm; weight in air, 4.4 g; weight in water, 2.4 g) and IBT 96–2E tags (30 × 7 mm; weight in air, 4.9 g; weight in water, 2.4 g), were used in this experiment. The percent ratio of transmitter weight to body weight (hereafter referred to as "burdens") ranged from 1.7% to 3.4%. A passive integrated transponder (PIT) tag was injected into the dorsal musculature of each fish and dummy transmitters were individually numbered for identification purposes.

Treatments were applied in a rotational order to avoid bias due to possible serial correlation (Cooke et al. 2003). The two surgeons who performed the surgeries classified themselves as competent in skill (Wagner and Cooke 2005) but novice in experience (Cooke et al. 2003). Both surgeons had prior experience implanting transmitters and received informal training on proper surgical practices. Surgeon 1 had 15 years of experience conducting implantation surgeries and had operated on more than 120 fish, whereas, surgeon 2 had less than 1 year of experience and had operated on 20 fish.

Generally accepted surgical practices were followed (Wagner and Cooke 2005). Surgeons wore clean, nonsterile gloves that were changed between every surgery, and the work area and fish were covered in a sanitary drape that was replaced every few surgeries. Tags were disinfected by soaking for at least 30 min in a bath of chlorhexadine gluconate solution and then rinsed with sterile saline (Burger et al. 1994). Tools were sterilized in a damp-heat autoclave before each experiment and were disinfected between surgeries by soaking for at least 30 min in the chlorhexadine gluconate solution and rinsed with sterile saline. Needles and excess suture material were discarded after use on a single fish.

Trout receiving an implanted transmitter were anesthetized in a 75-mg/L solution of tricaine methanesulfonate (MS-222) at a temperature of 10°C for approximately 3 min until ventilation rate became slow and the fish began to exhibit a total loss of equilibrium (Summerfelt and Smith 1990). They were then measured (mm TL), weighed (g), and injected with the PIT tag. During surgery, trout were restrained ventral side up in a U-shaped trough lined with a water-repellant nonabrasive sterile drape and were continuously provided with anesthetic by pumping a 35-mg/L MS-222 solution over the gills. The incision site was prepared by gently swabbing the epithelial mucous with an untreated sterile cotton swab (Wildgoose 2000). The tag was inserted through a small ventral incision along the linea alba. The incision was closed with two interrupted sutures, each secured with a surgeon's knot and the minimum number of throws needed to cinch the knot with minimal slippage (2 × 1 × 1 throws for braided silk and 2 × 1 × 1 × 1 throws for Monocryl). Each step of the surgical procedure was timed.

Fish receiving a sham surgery treatment were handled and treated in the same manner as those that received an internal tag: they were anesthetized, measured, weighed, injected with a PIT tag, and underwent surgery, but no transmitter was implanted. Control fish were anesthetized, weighed, measured, and injected with a PIT tag.

Trout were held in an indoor, concrete raceway with flow-through water at Dale Hollow National Fish Hatchery. The water feeding the raceway was drawn from the Obey River below Dale Hollow Lake and was consistently 10–15°C. Fish were fed to satiation once daily. The raceway was examined daily for dead fish and shed tags. At 21 d after surgery, all fish were netted and sedated in a 75-mg/L solution of MS-222. They were scanned for the PIT tag, weighed, and measured, and the incision site was assigned a score that reflected the severity of inflammation based on macroscopic indicators (Wagner 1999; our Table 1).

All trout were removed 65 d after surgery and euthanized in a lethal dose of MS-222. Fish were individually weighed and measured and the overall condition of each fish was noted (Cooke et al. 2003). Necropsy was conducted and the degree of tag encapsulation, internal attachment points of the fibrous capsule, presence of hemorrhaging, and any other macroscopic physiological responses to the treatment were noted. For fish that expelled tags, the expulsion location was determined from external scars or tunneling within the fibrous capsule.

TABLE 1. Scores used to describe the extent of macroinflammation occurring at the wound and sutures, as presented by Wagner (1999). Lower scores represent a less extreme inflammatory response.

Score	Description
0	Incision completely closed; no inflammation.
1	Incision closed; some inflammation along incision site.
2	Incision held in proximity, but part not completely closed as edges still slide; little to moderate inflammation.
3	Incision held in proximity, but edges slide if fish moves; moderate inflammation.
4	Incision partially opened at one end or middle; moderate to high inflammation.
5	More than 50% of wound open; moderate to high inflammation along wound edges.
6	Completely open wound; moderate to high inflammation along edges.

Experiment 2.—Larger IBT-96–5 ultrasonic transmitters (36 × 11 mm; weight in air, 9.1 g; weight in water, 4.1 g) were used in this experiment and the fish were larger than those used in experiment 1. Mean length of fish in experiment 2 was 372 ± 3.25 mm TL and mean weight was 660 ± 16.07 g. Fish ranged in size from 342 mm and 520 g to 405 mm and 844 g and were obtained from the Flintville State Fish Hatchery, Flintville, Tennessee. All surgeries were performed on 2 September 2008. Transmitters represented burdens of 1.1% to 1.7% of the weight of each fish. Twenty fish were implanted with transmitters; 10 received Monocryl and 10 received silk sutures. Five fish were sham tagged; two received Monocryl and three received silk sutures. Five fish served as controls; however, one control fish jumped out of the tank and died during the first 21 d. Surgical procedures in this experiment were nearly identical to those described in experiment 1. The only exception was that a larger incision was necessary for transmitter insertion and three interrupted sutures were used to close the incision.

Fish in this experiment were held at a facility at Tennessee Technological University, Cookeville, in a round 1,000-L tank that was part of a 2,250-L recirculating aquaculture system maintained at 10°C. Water quality was checked daily and partial water changes were conducted at least three times per week, which momentarily raised water temperatures up to 15°C. Fish were fed a minimal ration once daily. As with experiment 1, the tank was checked daily for expelled transmitters and fish were sedated and removed for observation after 21 d, and were necropsied after 65 d.

Statistical analysis.—The results of each experiment were analyzed separately to avoid the possibly confounding effects of holding different sizes of fish in different holding facilities. All statistical analyses were performed with SAS programs with $\alpha = 0.05$. The times required to apply sutures were compared between surgeons and suture materials by means of *t*-tests. Because fish were identified with PIT tags, it was possible to estimate individual growth rates (G; %/d) between days 0 and 21 and over the duration of the study with the equations:

$$G_{\text{Length}} = 100\left(\frac{\log_e(\text{TL}_{final}) - \log_e(\text{TL}_{initial})}{\Delta t}\right).$$

and

$$G_{\text{Weight}} = 100\left(\frac{\log_e(\text{Weight}_{final}) - \log_e(\text{Weight}_{initial})}{\Delta t}\right).$$

The weights of implanted tags were taken into account in growth equations. Mean growth rates were compared among implanted, sham, and control fish by means of analysis of variance (ANOVA) and Tukey's honestly significant difference (HSD) test with $\alpha = 0.05$. Growth was compared between implanted fish sutured with Monocryl and braided silk by means of a *t*-test. Incision scores for Monocryl and silk were compared with the Kruskal–Wallis test. Simple linear regression was used to test the null hypothesis that growth was not affected by transmitter burden. Logistic regression was used to test whether transmitter expulsion after 65 d was related to burden. Logistic regression was also used to determine whether expulsion was related to the 21-d incision score.

RESULTS

Experiment 1

Silk sutures were applied faster than Monocryl sutures (t-test: $P = 0.0002$). Mean suturing time was 1 min, 42 s (SE = 4 s) for silk and 2 min, 38 s (11 s) for Monocryl. Suturing time with both materials did not vary with surgeon (t-test: $P = 0.0783$). The time to complete surgery (i.e., incision, transmitter insertion, and suturing) averaged 2 min, 56 s (4 s) when silk was used and 3 min, 54 s (11 s) when Monocryl was used. No mortality or morbidity was observed during this experiment.

After 21 d, implanted fish, sham fish, and control fish exhibited significant differences in growth in weight (ANOVA: $F = 3.43$; df = 2, 57; $P = 0.0391$) but not in length (ANOVA: $F = 0.38$; df = 2, 56; $P = 0.6826$). Implanted fish grew slower than control fish, and growth of sham fish was not significantly different from either treatment group (Tukey's HSD test: $P = 0.05$). Among implanted fish, there was no difference in growth in weight (t-test: $P = 0.1119$) or in length (t-test: $P = 0.1553$) due to suture material (Table 2). After 65 d, growth differences manifested themselves among treatment groups in terms of both length (ANOVA: $F = 5.47$; df = 2, 56; $P = 0.0067$) and weight (ANOVA: $F = 3.58$; df = 2, 56; $P = 0.0346$). Implanted fish grew slower than control and sham fish and there was no difference in growth between sham and control fish (Tukey's HSD test: $P = 0.05$). The mean growth rate (G) for implanted fish was 74% (by weight) and 70% (by length) of that of nonimplanted fish (Table 2). Among implanted fish, suture material had no effect on growth in weight (t-test: $P = 0.1438$) or length (t-test: $P = 0.6435$), and growth in weight and length was independent of transmitter burden (linear regression: $P \geq 0.6290$).

The 21-d incision score was lower for fish sutured with Monocryl than with silk (Kruskal—Wallis test: $\chi^2 = 10.94$, df = 1, $P = 0.0009$). After 21 d, granulation tissue had closed the edges of all wounds. No sutures were lost during the 21 d after surgery.

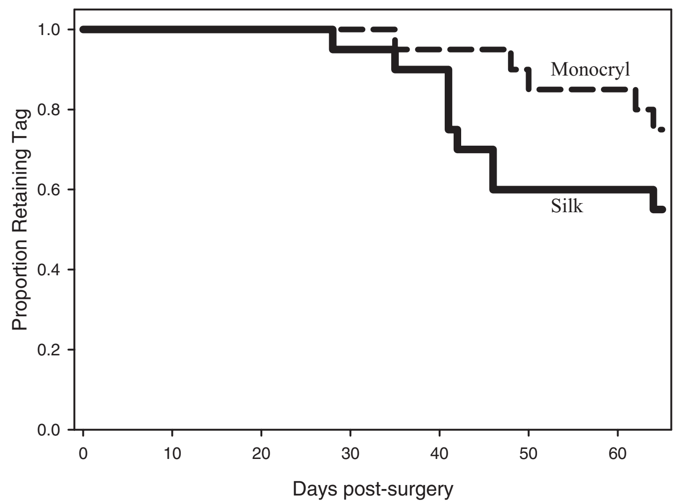

FIGURE 1. Retention of Sonotronics IBT 96–2 ultrasonic transmitter tags for rainbow trout 205–281 mm TL in length and sutured with braided silk or Monocryl suture materials.

During the 65-d course of the study, transmitter expulsion occurred in 45% of fish sutured with silk and 25% of fish sutured with Monocryl. Expulsion was first observed after 28 d and 35 d for fish sutured with silk and Monocryl, respectively (Figure 1). The likelihood of transmitter expulsion was linked to the 21-d incision score (logistic regression: $\chi^2 = 4.7845$, df = 1, $P = 0.0287$; Table 3), and fish with better scores (i.e., less inflammation) were less likely to expel transmitters. The likelihood of transmitter expulsion was directly related to transmitter burden for fish sutured with silk (logistic regression: $\chi^2 = 3.9017$, df = 1, $P = 0.0482$) but not for fish sutured with Monocryl (logistic regression: $\chi^2 = 0.3872$, df = 1, $P = 0.5338$). Transmitters were expelled most frequently through the lateral body wall (39%) or through the granulation tissue at the incision site (31%). Transintestinal passage was the most probable cause of expulsion in 15% of the cases. The expulsion location was indeterminable for the other 15% of expulsions. Expulsion sites were evidenced by scar tissue and tunneling within the persisting fibrous capsule that formed around the implanted tag. The two fish suspected of having transintestinal passage of the transmitter exhibited intestinal swelling and scar tissue on the intestine.

TABLE 2. Growth rates (G;%/d) and associated variances for rainbow trout implanted with IBT 96-2 transmitters calculated over the first 21 and 65 d after surgery.

		21 d after surgery				65 d after surgery			
Treatment	n	$\overline{G}_{weight}$	Variance	$\overline{G}_{length}$	Variance	$\overline{G}_{weight}$	Variance	$\overline{G}_{length}$	Variance
Implanted, Monocryl	20	0.310	0.431	0.218	0.064	0.580	0.136	0.176	0.017
Implanted, silk	20	0.607	0.232	0.131	0.008	0.728	0.061	0.161	0.004
Sham	10	0.712	0.573	0.212	0.022	0.857	0.133	0.243	0.004
Control	10	0.994	0.206	0.212	0.004	0.913	0.065	0.259	0.002

TABLE 3. Observed frequencies of 21-d incision scores for fish retaining and expelling IBT 96-2 (experiment 1) and IBT 96-5 (experiment 2) transmitters over a 65-d period.

Experiment 1			Experiment 2		
21-d incision score	Number expelled	Number retained	21-d incision score	Number expelled	Number retained
0	1	7	0	0	2
1	6	15	1	0	5
2	5	3	2	2	2
3	1	1	3	1	0
4	1	0	4	1	4
5	0	0	5	1	0
6	0	0	6	0	1

At 65 d, all transmitters that were not expelled were encapsulated. Fibrous capsules were held in place via connective tissue to one (74% of fish) or more points of attachment. Attachment points included the parietal peritoneum (65%), granulation tissue at the incision site (15%), viscera (15%), intestine (15%), stomach (5%), and the testes (5%), or a combination of sites. Tunneling at one or both ends of the fibrous capsules was apparent in most fish. Severe transmigration through the lateral abdominal wall was observed in 12% of fish, which suggested transmitter expulsion was imminent. Macroscopic petechial or diffuse hemorrhaging on the capsule, connective tissue, or adjacent musculature occurred in 39% of fish. Hyperemia was also common near the capsule. Fungus was visible on the braided silk sutures applied to one fish.

Experiment 2

As in experiment 1, silk sutures were applied faster than Monocryl (*t*-test: $P = 0.0013$); mean suturing time was 1 min, 52 s (SE, 6 s) for silk and 2 min, 35 s (SE, 11 s) for Monocryl and did not differ by surgeon (*t*-test: $P = 0.0539$). Surgery times averaged 2 min, 42 s (SE, 14 s) for silk and 3 min, 48 s (SE, 10 s) for Monocryl. No mortality or morbidity resulted from the surgical procedure.

After 21 d, implanted fish, sham fish, and control fish exhibited no difference in growth in weight (ANOVA: $F = 2.51$; df = 2, 24; $P = 0.1027$) or in length (ANOVA: $F = 1.92$; df = 2, 24; $P = 0.1685$) due to transmitter implantation or the surgical process. Among implanted fish, there was no difference in growth in weight (*t*-test: $P = 0.8546$) or in length (*t*-test: $P = 0.8576$) due to suture material (Table 4). After 65 d, fish in all treatment groups grew in length, but all fish lost weight. There was no difference in growth in length (ANOVA: $F = 0.65$; df = 2, 25; $P = 0.5330$) among implanted, control, and sham fish. In terms of weight, sham fish lost less weight than implanted fish, but control fish did not differ from either group (Tukey's HSD test: $P = 0.05$). Among implanted fish, suture material had no effect on growth in weight (*t*-test: $P = 0.4774$; Table 4) or length (*t*-test: $P = 0.8004$). We detected no influence of transmitter burden on growth in length (linear regression: $P = 0.5958$) or weight (linear regression: $P = 0.1193$).

Incision scores after 21 d were generally lower for fish sutured with Monocryl than for those sutured with silk (Kruskal—Wallis test: $\chi^2 = 2.8397$, df = 1, $P = 0.0920$) and all wounds were healed to some extent, as evidenced by the proliferation of granulation tissue. At 21 d after surgery, there was no difference in the number of sutures that came undone, were ripped out, or were expelled (*t*-test: $P = 0.4073$); two fish sutured with Monocryl and four sutured with silk exhibited at least one missing suture.

During the 65-d course of experiment 2, transmitter expulsion occurred in 50% of the fish sutured with silk but was not observed for any fish sutured with Monocryl. Expulsion was first observed after 25 d (Figure 2). The probability of a fish expelling a transmitter was not influenced by the 21-d incision score (logistic regression: $\chi^2 = 1.16$, df = 1, $P = 0.2807$; Table 3) or transmitter burden (logistic regression: $\chi^2 = 0.2782$, df = 1, $P = 0.5979$). All expulsions in this experiment occurred through the granulation tissue at the incision location. Dehiscence (i.e., a rupture of the incision site) was evident in one fish that expelled its transmitter.

At 65 d, all transmitters except one were encapsulated. The nonencapsulated transmitter was lodged between the intestine and lateral wall, posterior to the anus. All encapsulated transmitters were held in place by connective tissue from the fibrous capsule to one (72% of observations) or more points of attachment. Attachment points included the parietal peritoneum (47%), granulation tissue at the incision site (14%), viscera

TABLE 4. Growth rates (G;%/d) and associated variances for rainbow trout implanted with IBT 96-5 transmitters calculated over the first 21 and 65 d after surgery.

Treatment	n	21 d after surgery				65 d after surgery			
		$\overline{G}_{weight}$	Variance	$\overline{G}_{length}$	Variance	$\overline{G}_{weight}$	Variance	$\overline{G}_{length}$	Variance
Implanted, Monocryl	10	−0.053	0.009	0.037	0.002	−0.146	0.054	0.027	0.0004
Implanted, silk	10	−0.045	0.011	0.034	0.001	−0.162	0.048	0.025	0.0003
Sham	5	−0.011	0.006	0.054	0.00001	−0.108	0.0001	0.037	0.00003
Control	4	0.051	0.003	0.013	0.003	−0.088	0.002	0.027	0.0002

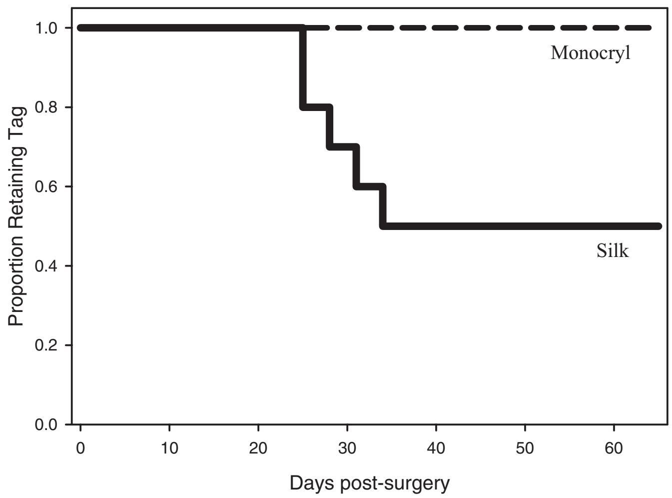

FIGURE 2. Retention of Sonotronics IBT 96–5 ultrasonic transmitter tags for rainbow trout 342–405 mm TL in length and sutured with braided silk or Monocryl suture materials.

(34%), intestine (7%), and the spleen (7%), or a combination of sites. Tunneling at one or both ends of the capsule was apparent. Macroscopic petechial or diffuse hemorrhaging on the capsule, connective tissue, or adjacent musculature occurred in 47% of fish. Hyperemia was also common. One fish exhibited an enterocutaneous fistula, probably resulting from the accidental trapping of omentum in the wound during the surgical process. Fungus was visible on the braided silk sutures applied to two fish.

DISCUSSION

Although transmitters were shed, the results reported herein indicate that rainbow trout can be successfully implanted with ultrasonic transmitters, especially when the tag burden is low and Monocryl sutures are used. At the conclusion of both experiments, no mortality was observed, most incisions were completely healed, and all implanted fish grew in length, although tagged fish grew slower than control fish in experiment 1.

These experiments underscored the importance of good surgical technique. The presence of competent assistants facilitated rapid implantation of transmitters. No mortality or morbidity resulted from the surgical procedure or postoperative infections. Mortality in other studies is usually attributed to internal injury caused during the surgical process (Cooke et al. 2003) or to postoperative fungal (Adams et al. 1998; Brown et al. 2006) or bacterial infection (Chisholm and Hubert 1985). The preoperative condition of the fish should also be considered before performing surgeries because stress is known to compromise a fish's ability to heal and fight infection (Walters and Plumb 1980; Wendelaar Bonga 1997). All of the hatchery fish used in these experiments were in good health and were handled with care to avoid injury and minimize stress.

Experiment 1 provided evidence that tagging slowed the growth of rainbow trout over a 65-d period in a hatchery setting. Because growth rates never differed significantly between control and sham-surgery fish, it is unlikely that the surgical procedure alone affected growth, and this finding is comparable with other studies that used different species of salmonids implanted with different types of tags (Adams et al. 1998; Brown et al. 2006). One possible explanation for slower growth is the reduced expandability of the stomach when a tag is present in the caecal cavity, which may limit the amount of food a trout is able to consume in one feeding bout. Differential growth of implanted fish versus nonimplanted fish was not observed in experiment 2, where transmitter burdens were lower and rations were limited. It is possible that no differential growth occurs in the wild, as trout in natural settings can theoretically feed on smaller rations ad libitum.

Fish did not begin to shed transmitters until 25–35 d after surgery. Because granulation tissue closed and filled in all incision wounds by that time, it was presumed that all shed transmitters had been encapsulated and actively expelled. These findings suggest that in field studies, tagged hatchery rainbow trout should be released into the wild after a short recovery period of no more than a few hours or days. Doing so would increase the number of observations for the telemetered cohort and reduce the confounding effects of transmitter expulsion. Studies involving rainbow trout implanted with radio tags (e.g., Martin et al. 1995; Bunnell and Isely 1999; Wagner et al. 2000) generally experienced lower expulsion rates than those observed in the current study, possibly because the antenna served to "anchor" the tag in the body cavity. In longer-term field studies involving rainbow trout implanted with ultrasonic transmitters, expulsion must be recognized and corrected for.

Both experiments demonstrated that Monocryl performed better than braided silk in terms of surgical outcomes. In both experiments, fewer expulsions were observed for fish sutured with Monocryl. The encapsulation–expulsion process was accelerated in fish exhibiting a more severe inflammatory response, and this and other studies (Wagner et al. 2000; Hurty et al. 2002; Deters et al. 2010) have shown that braided silk sutures elicit a more severe inflammatory response than do monofilament suture materials. Additionally, braided silk sutures provide a superior medium for fungal growth. Although knots tied with silk suture material seemed more durable with fewer throws, no transmitter losses for either experimental group were attributed to passive ejection through an open incision.

The commonly cited "2% rule" cautions against implanting transmitters that represent burdens greater than 2% (Winter 1983). Results from this and other studies indicate that strict adherence to the 2% rule may be unnecessary. Critical swimming speeds (Brown et al. 1999) and swimming endurances (Thorstad et al. 2001) of salmonids implanted with transmitter burdens greater than 2% did not differ from those of control fish. In the present study, the negative consequences of imposing tag burdens near or exceeding 2% were limited to a higher probability of tag expulsion with increasing burden in experiment 1, but only when silk sutures were used (which we do not advocate).

Despite maintaining a sanitary surgical field, postoperative fish in this and other experiments are released into unsterile environments. The open wound provides a pathway for water to enter, bringing with it contamination and possible infection. However, the implementation of a nonwicking, nonabrasive, fungus-resistant suture material is the best option for deterring postoperative infection and reducing inflammation, thereby decreasing the occurrence of transmitter expulsion. Regardless of the material used to close the incision, researchers who use ultrasonic transmitter tags for field studies involving rainbow trout must be aware that expulsion is a common phenomenon.

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