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[Management Brief]

Effect of Relative Volume on Radio Transmitter Expulsion in Subadult Common Carp

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Abstract.—Expulsion of surgically implanted radio transmitters is a problem in some fish telemetry studies. We conducted a 109-d experiment to test the hypothesis that variation in relative volume of transmitters surgically implanted in subadult common carp *Cyprinus carpio* would affect transmitter expulsion. We also necropsied fish at the end of the experiment to evaluate histological evidence for the mechanism of expulsion. Survival rate was high during our experiment; all control fish and 88% of the fish subjected to the implantation surgery survived. Expulsion rate was low; of the 23 fish that received transmitters and survived the experiment, only two (9%) expelled the transmitters. One of these expulsions occurred through a rupture of the incision and the other occurred via the intestine. Retained transmitters were all encapsulated by tissue, and most exhibited multiple adhesions to the intestine, gonads, and body wall. Adhesions were more numerous in fish that received larger transmitters.

Expulsion of surgically implanted radio transmitters is a problem in some fish telemetry studies (Summerfelt and Mosier 1984; Knights and Lasee 1996). Transmitter expulsion may occur by rupture of the incision, necrosis of the body wall, or expulsion through the intestine, and has been reported in several species of fish, including African catfish *Heterobranchus longifilis* (Baras and Westerloppe 1999), bluegill *Lepomis macrochirus* (Paukert et al. 2001), channel catfish *Ictalurus punctatus* (Summerfelt and Mosier 1984; Siegwarth and Pitlo 1999), rainbow trout *Oncorhynchus mykiss* (Chisholm and Hubert 1985; Bunnell and Isely 1999), shortnose sturgeon *Acipenser brevirostrum* (Collins et al. 2002), and common carp *Cyprinus carpio* (Stuart and Jones 2002; Okland et al. 2003). All of the aforementioned species have been observed to expel transmitters through the site of incision and body wall, but only African catfish, channel catfish, and rainbow trout have been documented passing transmitters through the intestine.

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In a concurrent radiotelemetry study with subadult common carp in a northern Iowa lake, we observed apparent transmitter expulsion from 36 fish in which transmitter weight ranged from 1.3% to 4.9% of body weight (C.R.P., unpublished data). Because of the wide range in relative weight of expelled transmitters, we hypothesized that the transmitter volume relative to fish size might be a more important determinant of expulsion than relative transmitter weight. Therefore, the primary purpose of this study was to experimentally assess the effect of relative transmitter volume on expulsion. Our secondary purpose was to document the mechanism of expulsion.

Methods

We conducted a 109-d experiment to test the hypothesis that variation in relative volume of radio transmitters surgically implanted in subadult common carp would affect the occurrence, timing, and mechanism of expulsion. Fish were observed frequently during the experimental period, and all were euthanized at the end of the experiment and necropsied to evaluate histological evidence for expulsion and mechanisms involved.

Fish collection, handling, and holding.—Thirty subadult common carp used as experimental fish were collected in September 2005 from Ventura Marsh, which is connected to Clear Lake, Iowa, by a water control gate. Fish were collected using electrofishing and graded to obtain fish of similar size (total length [TL] mean ± SE = 307 ± 8 mm; mean weight ± SE = 364 ± 27 g).

During the experiment, fish were held in three 1,900-L indoor aquaria. Fish with implanted transmitters were held in separate aquaria from control fish to facilitate the visual inspection of treatment fish for transmitter loss. Fish were observed through the aquarium glass at least four times per week for signs of transmitter loss, which was first recognized when a whip antenna was not visibly protruding from a fish or when a transmitter was seen on the bottom of the tank. Upon detecting

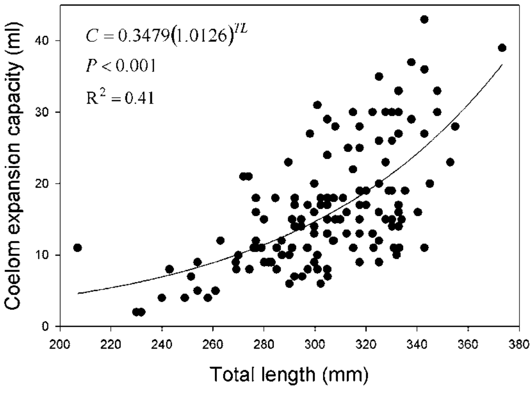

FIGURE 1.—Regression of coelom expansion capacity (*C*; mL) versus TL (mm) of common carp collected from Ventura Marsh, Iowa.

transmitter loss or fish mortality, the date and identification number of the fish was noted. Dead fish were removed and frozen until necropsies were performed. Fish were maintained in water ranging from 13°C to 16°C. To maintain water quality in the holding aquaria, which lacked a solids removal system, we fed the fish sparingly approximately twice per week.

Estimating coelom expansion capacity.—To establish a relevant measure of available internal volume for transmitter implantation, we defined coelom expansion capacity as the volume of the coelomic cavity at maximum expansion. We reasoned that coelom expansion capacity represented the absolute upper limit for volume of a foreign body (such as a transmitter) to be implanted. Our experimental transmitter volumes were expressed as percentages of this upper limit of internal volume.

To estimate coelom expansion capacity, we collected 137 subadult common carp (TL range = 207–305 mm) from Ventura Marsh in August 2005. After euthanization with Finquel (tricaine methanesulfonate), the TL, mass, and coelom expansion capacity were recorded for individual fish. Coelom expansion capacity was determined by placing each fish ventral side up on a flat surface and puncturing the body cavity at the deepest point along the ventral side with a hypodermic needle. Water was then injected into the coelom until excess water could be seen exiting the puncture site. The volume of water (mL) injected into the coelom was our estimate of the coelom expansion capacity.

We performed an exponential growth regression of coelom expansion capacity versus fish TL with data from the 137 fish collected in August 2005 (Figure 1). This relationship was used to estimate the coelom expansion capacity of experimental fish based on their TLs (Table 1).

Experimental transmitters.—Five radio transmitter models (Advanced Telemetry Systems, Isanti, Minnesota; F1800 Series) with external antennae but lacking internal electronics or batteries were modified for use in the experiment. Our goal was to achieve similar weight for all transmitters, but vary the volume of the five groups (Table 1). To achieve similar weight in the different models, we either removed portions of the internal epoxy material to reduce weight or added small lead shot to increase weight. After modification, all experimental transmitters were sealed similarly with epoxy supplied by the manufacturer.

Transmitter implantation surgery.—Experimental fish were held in the laboratory in a V-shaped foam cradle resting partially in the water, which allowed us to surgically implant the experimental transmitters. Before surgeries, fish were anesthetized with Finquel and a numbered anchor tag (10 mm) was inserted below the dorsal spine to identify the individual. Next, fish TL, fish weight, and transmitter size were recorded.

Once the fish was in the surgery cradle, a short line of scales was removed from just off center and to the

TABLE 1.—Description of weight and volume of radio transmitters implanted in common carp held in the laboratory for 109 d to assess transmitter expulsion rates. Fish weight, coelom expansion capacity, and the relative weight and volume of the transmitters are shown. Weights are means (±SE).

Transmitter volume group	Transmitter		Fish		Relative weight (%)[a]	Relative volume (%)[b]
	Weight (g)	Volume (mL)	Weight (g)	Coelom expansion capacity (mL)		
1	5.2 ± 0.1	1.3	364 ± 6	16.1	1.4	8.1
2	5.3 ± 0.1	4.1	373 ± 12	16.7	1.4	24.6
3	5.5 ± 0.1	4.9	368 ± 13	16.6	1.5	29.5
4	5.3 ± 0.0	6.0	349 ± 15	15.4	1.5	39.0
5	5.5 ± 0.2	6.5	366 ± 15	16.1	1.5	40.4

[a] Relative weight = (transmitter weight/body weight) × 100.
[b] Relative volume = (transmitter volume/coelom expansion capacity) × 100.

TABLE 2.—Comparison of initial and final mean (±SE) weights, lengths, and condition (relative weight [W_r]) values of subadult common carp that received radio transmitters of differing relative volumes (see Table 1). Paired *t*-tests examined differences within groups, and ANOVA was used to examine differences among groups ($\alpha = 0.05$; 5 replicates/treatment).

Transmitter volume group	Weight (g)			TL (mm)			W_r		
	Initial	Final	*P*	Initial	Final	*P*	Initial	Final	*P*
Control	380.0 ± 17.5	286.3 ± 15.0	<0.01	311.0 ± 5.4	301.4 ± 4.2	0.09	87.3 ± 0.8	73.7 ± 1.5	0.03
1	364.0 ± 6.2	304.8 ± 7.9	<0.01	306.2 ± 1.3	299.2 ± 2.3	<0.01	87.3 ± 0.8	78.2 ± 1.4	<0.01
2	373.0 ± 11.6	301.2 ± 7.9	<0.01	309.6 ± 2.3	291.6 ± 11.6	0.17	88.7 ± 2.3	77.6 ± 1.4	0.02
3	368.0 ± 13.2	295.8 ± 8.6	<0.01	309.0 ± 4.3	292.6 ± 9.9	0.12	85.8 ± 1.1	76.7 ± 2.0	<0.01
4	349.0 ± 14.6	289.4 ± 15.1	<0.01	302.8 ± 4.4	292.8 ± 4.7	<0.01	86.3 ± 1.5	79.0 ± 2.9	0.03
5	366.0 ± 15.4	294.0 ± 26.5	<0.01	306.4 ± 5.5	301.8 ± 8.2	0.42	87.6 ± 2.4	72.9 ± 2.8	0.02
ANOVA *P*	0.71	0.97		0.77	0.85		0.41	0.77	

left of the ventral midline, beginning at the posterior margin of the left pelvic fin and ending just short of the anus. An incision of approximately 15 mm was made in the center of the descaled area. The transmitter was inserted into the body cavity and pushed slightly anterior to the incision. A needle threaded with the transmitter's external whip antenna was used to create a small puncture in the body wall posterior and lateral to the incision, allowing the external antenna to be pulled to the fish's exterior. The incision was closed, the two incision planes were aligned, and two interrupted surgeon's knots were tied using external suture material (3–0, monofilament, nonabsorbable). Surgery time ranged from 4 to 6 min. After surgery, the incision site was cleaned with saline solution to remove any clotted blood. The fish were held in a recovery tank for up to 10 min to recover from anesthesia.

Postexperiment necropsies.—At the end of the experiment, all surviving fish were euthanized with an overdose of Finquel and necropsied for evidence of transmitter expulsion. Fish TL and weight were measured to provide data for comparison with the presurgical condition. A postmortem examination sheet was used to record observations (Lasee 1995).

Experimental design and statistical procedures.—The experimental treatments consisted of five groups, each with a different relative transmitter volume, and a control group in which no surgeries were performed. Five fish were assigned to each group randomly from a pool of 30 fish that were collected and handled identically. The resulting six groups consisted of fish of similar size (Table 1).

We used *t*-tests ($\alpha = 0.05$) to test for differences in initial and final values of fish TL, weight, and condition within each experimental treatment group, and one-way analyses of variance (ANOVA; $\alpha = 0.05$) to test for among-treatment differences in those same variables. All statistical procedures were performed using the StatView software package (SAS Institute 1999).

Results

Survival

Survival rate was high during the experiment. All control fish and 88% of fish that received transmitters survived. Of the three mortalities that occurred, two were from transmitter volume group 1 and one was from transmitter volume group 3. Mortalities from transmitter volume group 1 occurred on days 18 and 28, while the fish from transmitter volume group 3 died on day 31.

Changes in Weight, Length, and Condition

Fish experienced losses in length, weight, and condition during the experiment (Table 2). Significant losses of weight and condition occurred in all treatment and control groups, while a significant reduction in length occurred in transmitter volume groups 1 and 4. The ANOVAs used to assess changes in TL, weight, and condition across treatments yielded *P*-values that were not significant, indicating that the losses were similar among the six groups.

Transmitter Expulsion

Expulsion rate was low during the experiment. Of the 23 fish that received transmitters and survived the experiment, only two (9%) expelled transmitters. The first (on day 53) was expelled through the intestine in a fish from transmitter volume group 1. The second (on day 109) was expelled through a rupture in the incision in a fish from transmitter volume group 5 (Figure 2). Necropsy revealed that during the expulsion process, the latter fish had formed a layer of tissue that effectively sealed the abdominal cavity from the water column.

Mechanisms of Transmitter Expulsion

In addition to the observed expulsions, one transmitter from volume group 1 was staged for transintestinal expulsion, as it was completely encapsulated in tissue and fused to the intestine at two points (Figure

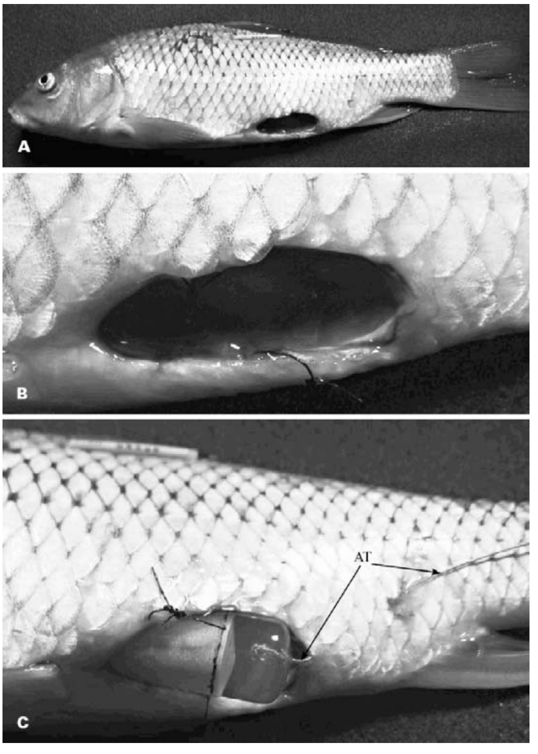

FIGURE 2.—External mechanisms for radio transmitter expulsion in subadult common carp: **(A)** fish whose transmitter was expelled through the incision site at 109 d postimplantation; **(B)** close-up of the aforementioned incision rupture, showing how the sutures were pulled in opposite directions to allow transmitter passage and the formation of tissue sealing the abdominal cavity; and **(C)** transmitter before expulsion occurred, showing antenna (AT) orientation.

3). Encapsulation of transmitters and adhesions to the intestine, body wall, or gonads were observed in all treatment fish except the two earliest mortalities. As transmitter volume increased, the degree and frequency of adhesion also increased (Table 3). Adhesion with a single structure (body wall, gonads, or intestine) occurred primarily in individuals from transmitter volume groups 1 and 2. Fish from groups 3–5 exhibited not only an increased frequency of adhesions but also adhesions with multiple structures.

Discussion

Relative volume of radio transmitters surgically implanted into subadult common carp did not have a significant effect on transmitter expulsion in our experiment. Complete transmitter expulsion occurred in only 9% of the fish we observed in the laboratory for over 3 months. The first expulsion was through the intestine and the second occurred after rupture of the incision. Transmitter expulsion in common carp has been previously reported as occurring through the body wall (Stuart and Jones 2002; Okland et al. 2003), but our study is the first to describe transintestinal expulsion in this species.

In contrast to the low rate of expulsion observed in the laboratory, transmitter loss was 80% in the concurrent radiotelemetry field study. Many differences exist between laboratory and field environments that could potentially explain this discrepancy. Fish in the laboratory were maintained in temperatures of 13–16°C, similar to those experienced by fish released into the lake immediately after transmitter implantation. However, water temperatures in the lake increased to 26°C during the time that field expulsions occurred. Previous studies have associated high water temperatures with rapid healing and closure of surgical incisions but also with increased rates of infection, transmitter expulsion, and fish mortality (Bunnell and Isely 1999; Jepsen et al. 2002; Okland et al. 2003). In rainbow trout that were implanted with simulated transmitters and held at 10°C and 20°C, expulsion was significantly higher at 20°C (Bunnell and Isely 1999).

All our experimental fish experienced length, weight, and condition reductions that we attribute to relatively low water temperature and feeding rate. These conditions may have also been partly responsible for the low expulsion rate we observed. Stuart and Jones (2002) also reported transmitter expulsion in common carp held in tanks under conditions resulting in loss of length and weight. Those authors observed a 7.2% loss of initial weight; although they provided no details about temperature or feeding, they stated that, "Carp ... appeared to behave and feed normally throughout," which is similar to our general observations.

Our experimental aquaria were barren compared with the lake; in the laboratory environment, the transcutaneous external antenna may have served to anchor the transmitter in place within the body cavity, thus impeding expulsion (Jepsen and Aarestrup 1999). Fish in the lake, however, were often located within dense stands of emergent vegetation (authors' unpublished data), which could potentially result in entanglement of the antenna, stress on the implantation site, and ultimate loss of the transmitter.

Predation could also account for some apparent transmitter loss in the lake. Muskellunge *Esox masquinongy*, flathead catfish *Pylodictis olivaris*, and walleye *Sander vitreus* are present in the lake, and some individuals of these species are large enough to consume subadult common carp (J. Wahl, Iowa Department of Natural Resources, unpublished data). Although we cannot rule out this potential explanation,

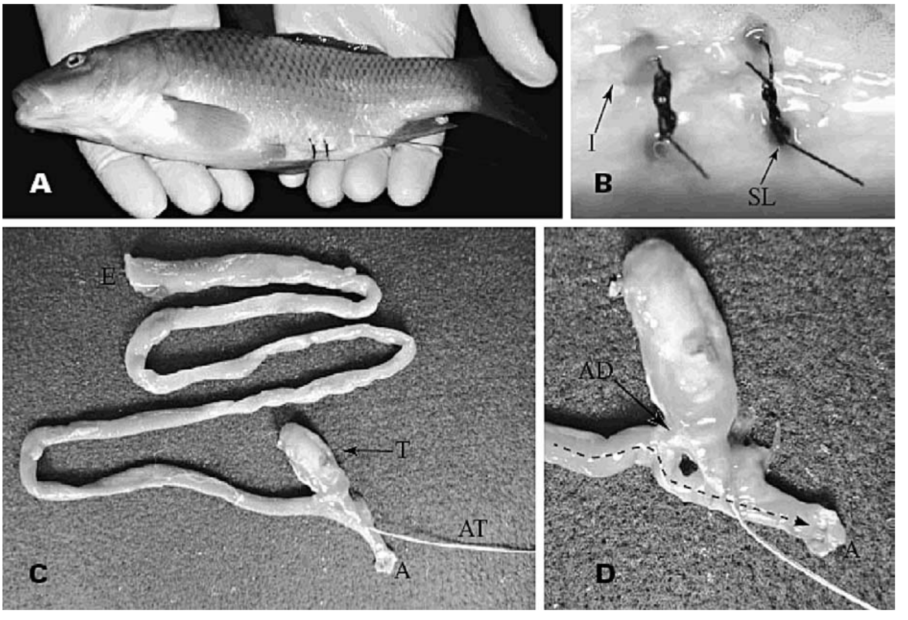

FIGURE 3.—Internal mechanisms for radio transmitter expulsion in subadult common carp: **(A)** incision, sutures, and whip antenna immediately after surgery; **(B)** healed incision (I) and sutures (SL) at 109 d postimplantation; **(C)** complete gastrointestinal tract (esophagus [E] to anus [A]) at 109 d postimplantation, showing the encapsulated transmitter (T) fused with the intestine and the whip antenna (AT) protruding from the rectum; **(D)** two adhesion (AD) points between the encapsulated transmitter and intestine in the same fish depicted in (C). The dashed line is the path of intestinal lumen from esophagus to anus.

it seems unlikely that predation would account for a large percentage of the observed transmitter loss in the lake given the dominance of common carp in the fish assemblage.

All retained transmitters in our experimental fish were encapsulated and had multiple adhesions to the intestine, body wall, or gonads. Thoreau and Baras (1997) suggested that encapsulation of implanted transmitters in tilapia *Oreochromis aureus* limited transmitter mobility within the coelom and decreased the risk of internal damage. Most of our experimental fish, especially those with larger transmitters, exhibited multiple adhesions of the intestine, gonads, and body wall to the encapsulated transmitter. Although adhesion is apparently necessary for transintestinal expulsion to occur (Marty and Summerfelt 1986), the increased adhesion we observed in association with larger transmitters may have resulted from increased contact with internal organs and did not necessarily indicate progress toward eventual transintestinal expulsion. Clear evidence of transintestinal expulsion was found only in transmitter volume group 1, and it is possible that only these relatively small transmitters were capable of passage through the intestine due to size alone or indirectly due to lack of stabilizing adhesions. Adhesions to the larger transmitters in groups 2–5 may have served to further fix the transmitters within the coelom.

Although further research will be necessary to better define the effect of relative transmitter volume on expulsion, it is worth noting that the two transmitters expelled during our experiment were from the lowest- and highest-volume groups and exited via different routes. Thus, although our direct evidence is scant, it seems plausible that transmitters encompassing a wide range of relative volumes are potentially susceptible to expulsion. We further speculate that different mechanisms of expulsion might predominate at opposite ends of the relative volume spectrum. We recommend that future experiments be conducted under conditions

TABLE 3.—Percent occurrence of radio transmitter adhesion to the intestine, body wall, and gonads of subadult common carp necropsied after a 109-d experiment used to assess transmitter expulsion rates.

Transmitter volume group	Transmitter adhesions (% of fish)		
	Intestine	Body wall	Gonads
1	50	50	0
2	60	20	20
3	100	75	75
4	80	100	80
5	100	75	100

(e.g., temperature, food, habitat, and water quality) that more closely mimic natural lake environments. Furthermore, we recommend use of a larger number of fish and extending the experimental duration to allow expulsion to occur in a much greater percentage of individuals.

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