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Effects of suture material on incision healing, growth and survival of juvenile largemouth bass implanted with miniature radio transmitters: case study of a novice and experienced fish surgeon

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Juvenile largemouth bass *Micropterus salmoides*, intraperitoneally implanted with microradio transmitters exhibited short-term (5 days) inflammation around the incision and suture insertion points for both non-absorbable braided silk and non-absorbable polypropylene monofilament, but in the longer term (20 days) almost all sutures were shed and the incisions were completely healed. Cumulative mortality was higher for fish with braided silk sutures, however, post-mortem analysis revealed that violations to the gastro-intestinal tract from the surgical procedure were the usual cause of the mortality. Mortality was generally low in control fish. The two surgeons who performed the implantations differed substantially in experience. Despite receiving basic training, the novice surgeon took longer to complete the surgeries, had reduced suture precision and experienced more fish mortality relative to the experienced surgeon. For both surgeons, it took longer to complete suturing with polypropylene than with braided silk. During the surgery day, the experienced surgeon exhibited consistently rapid surgery times, whereas the novice surgeon exhibited significantly improved speed as the number of surgeries completed increased. This study suggests that microtransmitters can be successfully implanted in juvenile largemouth bass but some mortality can be expected. This mortality seems to be independent of suture material, but dependent upon the experience of the surgeon.

Key words: surgeon experience; surgery; suture material; telemetry; transmitter implantation.

INTRODUCTION

The intraperitoneal surgical implantation of ultrasonic transmitters, radio transmitters, and passive integrated transponders has become a common technique

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for monitoring the movement and habitat use of an individual fish (Winter, 1996; Lucas & Baras, 2000). Technological advances in miniaturizing electronic components have facilitated the use of transmitters and tags for monitoring increasingly smaller fishes. When implanting devices in fishes of any size it is important to determine whether there are any negative consequences arising from the surgery or the presence of the device. To that end, a variety of studies have been conducted to evaluate the effects of different transmitter implantation techniques and devices on the swimming performance (Peake *et al.*, 1997; Cooke & Bunt, 2001), behaviour (Martinelli *et al.*, 1998; Wagner & Stevens, 2000), growth (Lucas, 1989; Adams *et al.*, 1998*a*), physiology (Martinelli *et al.*, 1998) and mortality (Lucas, 1989; Thoreau & Baras, 1997; Paukert *et al.*, 2001). Although common for large fishes, these studies are still relatively scarce in smaller bodied fishes. As demand for examining the movement and habitat use of smaller fish species or smaller life stages increases, coupled with the continued reduction in transmitter size, so does the need to examine the consequences of implanting transmitters in smaller fishes (Brown *et al.*, 1999).

In addition to evaluating the effects of the surgical procedure and presence of the transmitter on fish performance, researchers have also investigated tissue histology, healing of the incision and transmitter expulsion rates following surgery (Lucas, 1989; Adams *et al.*, 1998*a*; Wagner *et al.*, 2000; Paukert *et al.*, 2001). Factors such as suture material (Thoreau & Baras, 1997; Lowartz *et al.*, 1999; Swanberg *et al.*, 1999; Wagner & Stevens, 2000; Wagner *et al.*, 2000) and water temperature (Knights & Lasee, 1996; Bunnell & Isely, 1999) have been deemed as important determinants of the wound healing process, however, few of these studies have focused on warm water fishes (Thoreau & Baras, 1997; Baras *et al.*, 1999). At warm water temperatures healing can be accelerated, however, opportunities for infection are increased and absorbable sutures break down rapidly. The most commonly used suture materials in fisheries science are non-absorbable braided silk and non-absorbable polypropylene (Stoskopf, 1993). No studies, however, have evaluated the role of these two different suture materials on the wound healing of warm water fishes. Furthermore, most studies are conducted in laboratory or aquaculture facilities that do not incorporate realistic predator exposure, foraging demands and complex habitats that could enhance the realism and applicability of findings.

Another factor that has not been considered in fisheries science, but has been deemed as important in the outcome of surgical procedures in medical and veterinary science, is the experience of the surgeon and the volume of procedures conducted (Califf *et al.*, 1996). In recent years, the study of outcomes resulting from performing different volumes of procedures and with differing levels of experience has become commonplace in medicine (Freund *et al.*, 1999). This trend seems to reflect a combination of the litigious nature of society, genuine care and concern for public well being and an increase in professional responsibility (Califf *et al.*, 1996). Research has shown that novice medical surgeons have reduced dexterity compared with more experienced surgeons. Not only does this dexterity affect the accuracy of the suture placement and suture holding, it also affects the time required to complete the surgery (Annett, 1971; Engelhorn, 1997). Longer surgeries translate into extended anaesthetization and thus potential delays in recovery. Although this evidence is based on medical and veterinary medicine, there is no reason to believe that this is not also of importance in fisheries surgery. Indeed, medical and veterinary surgeons receive formal surgical instruction and clinical experience and still exhibit significant differences in surgical aptitude. Because most fisheries biologists who perform surgeries learn their techniques through mentoring, reading or trial and error, there is greater opportunity for increased variation in ability and thus outcome.

The primary purpose of this study was to investigate the effects of two commonly used suture materials on the wound healing, growth and mortality rates of largemouth bass *Micropterus salmoides* (Lacépède), implanted with microradio transmitters in an outdoor raceway and pond. The dummy transmitters used in this study replicated some of the smallest commercially available radio transmitters adding further realism to this study (Brown *et al.*, 1999). In addition to evaluating the effects of transmitter implantation and the different suture materials, there was also interest in the role that surgical experience played in affecting characteristics of the surgery and the surgical outcome. This assessment must be viewed as preliminary in that only two surgeons were compared.

MATERIALS AND METHODS

CHOICE OF STUDY SPECIES

In this study, juvenile largemouth bass were chosen as study organisms for several reasons. First, most studies on fish surgery focus on salmonids, however, largemouth bass occupy substantially warmer and more eutrophic systems. Second, the early life history of largemouth bass is poorly understood. The development of techniques for monitoring the movement and habitat use of juvenile largemouth bass would be extremely useful (Copeland & Noble, 1994).

EXPERIMENTAL FISH

A single 1349 m^2 pond containing juvenile largemouth bass at the Sam Parr Biology Station in central Illinois was drained on 10 April 2002 to collect fish for experimentation. While held in the pond, fish consumed natural food of invertebrates and fathead minnows *Pimephales promelas* (Rafinesque). Temperature at the time of draining was 15·5° C. Fish were transported 150 m in 120 l cool boxes from the pond to the Homer Buck Laboratory at the Sam Parr Fisheries Research Station and held in a single circular tank (1·3 m deep and 1·1 m diameter) supplied with a continuous flow of aerated fresh water. Water temperatures in the Buck Laboratory varied on a diel basis similar to the natural fluctuations observed in the ponds. During retention water temperature generally remained between 14 and 18° C. Fish were not fed during the 48 h holding period preceding surgery so that they would be in a post-absorptive state for surgery. All experiments described in this study were conducted under the authority of The Committee for Laboratory Animal Resources at the University of Illinois.

SURGICAL EXPERIENCE

For this study, there were two different surgeons, each with different levels of experience, referred to here as ‘expert’ and ‘novice’. The ‘expert’ surgeon had been conducting fish surgeries for 6 years, and had completed >1150 surgeries on several different fish species including fishes of similar size to those used in this study. These surgeries included transmitter implantation and the surgical attachment of cardiac output monitoring devices and it was estimated that in this time, the expert surgeon had administered >5000 individual sutures. This surgeon was trained by individuals noted as experts in the field of fish telemetry, however, none of these individuals or the 'expert' were qualified veterinarians or physicians. The 'novice' surgeon was taught how to conduct surgeries by the 'expert' in a similar manner to that by which the 'expert' learned to perform surgeries. Prior to instruction, the 'novice' read a common reference for conducting surgery on fishes (Summerfelt & Smith, 1990). Formal instruction included the novice observing the expert perform surgeries, the novice practicing sutures and incisions on foam and moribund fishes and then practicing on live specimens under the guidance of the 'expert'. This level of training is very representative of the skills required to intraperitoneally implant fishes with transmitters. The 'novice' surgeon successfully completed fish surgeries on five largemouth bass ranging in size from 135 to 300 mm total length (L_T) prior to this study and felt satisfied with the level of knowledge attained. Total training for the novice was 5 h.

DUMMY TRANSMITTERS AND SURGICAL PROCEDURES

The dummy transmitters were intended to replicate the characteristics of some of the smallest radio transmitters that are currently commercially available (Brown *et al.*, 1999). Dummy tags were fashioned out of Teflon rod (diameter 4 mm) cut into 7 mm lengths. Ends of the cut rods were ground down to create rounded edges. A small hole was drilled within the axis of the rod through which lengths of antenna wire (sava fine antenna wire) were passed and secured with a single knot. The entire 'transmitter' was then sealed with a synthetic plastic coating that is used by transmitter manufacturers, and is certified by the manufacturer to be physiologically inert when cured (Plastidip International, Blaine, MN, U.S.A.). When completed, the mass of the transmitters was 0·65 g in air and measured 6 mm in diameter and 9 mm in length. The antenna wire was trimmed to a length of 10 cm (Brown *et al.*, 1999). Both surgeons were provided with the same set of surgical tools and used the same anaesthetic induction bath, maintenance bath and surgical platform.

On 12 April 2002, fish were anaesthetized in 60 ppm clove oil bath for 6 min (Anderson *et al.*, 1997) prior to being measured (L_T and mass), fin clipped (small notches in the caudal fin) and introduced supine into a shallow maintenance bath (30 ppm clove oil) on the surgical platform (means $\pm$ S.E.: novice, 140·3 $\pm$ 0·8 mm, 29·2 $\pm$ 0·6 g; expert, 140·3 $\pm$ 0·8 mm, 27·7 $\pm$ 0·7 g). The platform consisted of a 2 l nalgene instrument tray with soft foam cut and shaped to hold the fish stationary in dorsal recumbency by applying gentle pressure to the caudal region. The fish's head and opercular cavity were immersed unobstructed in water. A small incision, *c.* 9 mm long was made in the ventral body surface, posterior to the pelvic girdle, just off the midline, using a scalpel (number 3 blade, rounded cutting point). A 20 gauge needle was then inserted externally in an anterior direction, to the left of the cloaca exiting into the body cavity. A blunt, closed haemostat was used to protect viscera and to guide the needle (Ross & Kleiner, 1982). The antenna wire was passed out through the inside of the needle prior to its withdrawal. The transmitter was then placed gently into the body cavity and positioned at the incision site. Two simple interrupted sutures through both the integument and musculature using either braided non-absorbable silk suture (perma-hand, sterile, Ethicon Inc., 'silk') or polypropylene non-absorbable suture (prolene, sterile, Ethicon Inc., 'poly') were used to close the incision site. Scales were too small to require removal prior to suturing. For both suture materials, size 3/0 with FSL cutting needles integrated with the suture material *via* the swage, were utilized. Each surgeon alternated suture materials until they each had completed 30 surgeries (15 of each suture material).

When the surgeon was comfortable and the fish was held properly in the surgery platform, a timer was started. The length of time (s) required to complete each of the following phases of the surgery was recorded: (1) incision time (start of the timer until the incision site was large enough to allow the transmitter to be implanted); (2) transmitter insertion time (from completion of incision to the insertion of the transmitter in the body cavity including drawing the antenna wire to the outside of the fish); (3) suture time (from the insertion of the transmitter to the completion of the surgery). Upon completion of surgery, a caliper was used to measure the length of the incision. A modification of the techniques outlined in Platt *et al.* (1997) was used to assess the accuracy of suture point entry. The deviation of the suture insertion points from the ideal location was measured and termed suture point deviation.

Following recovery from surgery, fish were introduced into a round, aerated outdoor raceway (0·6 m deep and 2·5 m diameter). The raceway contained ample cover and natural foods. In addition to experimental fish, 30 control fish (*i.e.* fish that received no surgical treatments but were fin clipped) were also added that were measured on day 0 (means $\pm$ S.E., 140·2 $\pm$ 0·7 mm, 26·2 $\pm$ 0·7 g). All fish ($n = 90$) were held in the raceway for 5 days during which time temperatures ranged from 17·5 to 22° C.

POST SURGERY EXAMINATIONS

Daily, dead fish were removed from the raceway and post-mortem investigations were conducted. The fin clip (and thus surgeon) and the suture material were identified, the fish were measured (L_T and mass), the condition of the fish (*i.e.* presence of fungus) and incision site were noted and an internal examination was conducted. Viscera were examined for lacerations and punctures using fibre optic light and head mounted magnifying glasses ($\times$6 magnification).

Five days following surgery, the raceway was drained to a depth of 0·10 m and a low dose of clove oil (10 ppm) was used to calm the fish. Fish were then individually netted and examined for several variables. First, fin clip and suture material were identified and the number of intact sutures (0, 1 or 2) was noted. An incision score was then assigned to each fish based on the scale developed by Wagner (1999): 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, >50% of wound open, moderate to high inflammation along wound edges; 6, completely open wound, moderate to high inflammation along edges. Based on a study by Wagner (1999), the incision site was scored quantifying the percentage of intact suture sites that were inflamed. This was termed as the suture score. The general health of the fish was also assessed on a relative scale of 1 to 3 (1, moribund; 2, some fungal lesions, moderate condition; 3, excellent condition, apparently healthy). For control fish, only overall health was assessed. All fish were then introduced into a 1349 m^2 pond.

While in the pond, fish fed on natural foods. The pond did not contain fish predators of largemouth bass, however, avian predators, turtles and snakes all visited the ponds with considerable but unquantified frequency. Pond water temperatures ranged from 18 to 24° C throughout the duration of the monitoring period. On day 20 (1 May 2002) the pond was drained and fish were collected and held in a small raceway. All fish were anaesthetized with a lethal dose of MS 222 (120 ppm) and then examined as they were on day 5. Transmitters were removed prior to assessing mass of the fish. Most fish had lost sutures and the wounds were nearly completely healed so suture score was not assessed. The main objective at day 20 was to monitor growth and survival of experimental fish relative to control fish.

ANALYSIS

The effect of suture material on suture time, incision score, suture score, number of sutures intact and total surgery time was tested using a *t*-test when data were normally distributed. All non-normal data were analysed using Kruskal–Wallis ANOVA. Life tables and survival rates were calculated for both suture treatments and the control treatment. Wilcoxon χ^2 tests were used to analyse survival rates, and the covariance matrix from the Wilcoxon statistics was used to calculate *z*-scores for each pair-wise comparison (Fox, 1993).

The effect of surgeon experience on incision score, suture score, number of sutures intact, incision length, suture time, total surgery time, suture deviation, incision time and transmitter time was tested using a *t*-test when normal. Again, all non-normal data were analysed using Kruskal–Wallis ANOVA. If the effect of suture material significantly affected any of the above variables, then a two-factor (suture material and surgeon experience) ANOVA was used to investigate the effects of surgeon experience level. Life tables and survival rates were calculated for both suture treatments and the control treatment. Wilcoxon χ^2 tests were used to analyse survival rates, and the covariance matrix from the Wilcoxon statistics was used to calculate *z*-scores for each pair-wise comparison (Fox, 1993).

RESULTS

The mass of the tags in air (minimum 1·62, maximum 2·74; mean $2 \cdot 15 \pm 0 \cdot 04\%$) and in water (minimum 1·14, maximum 1·92; mean $1 \cdot 50 \pm 0 \cdot 03\%$) relative to the mass of the fish at the initiation of the study were generally close to the widely accepted '2% rule'.

Surgical procedures were somewhat affected by suture material. The average time to administer sutures was lower for silk ($166 \cdot 0 \pm 5 \cdot 4$ s) as compared with polypropylene ($184 \cdot 7 \pm 7 \cdot 0$ s; *t*-test, $t = 2 \cdot 12$, d.f. = 58, $P = 0 \cdot 04$). Overall surgery time was not affected by suture material (silk, $276 \cdot 9 \pm 7 \cdot 8$ s, polypropylene $285 \cdot 9 \pm 10 \cdot 4$ s; $P = 0 \cdot 49$).

Mortality rates were affected by suture material and the experience level of the surgeon (Wilcoxon $\chi^2 = 13 \cdot 21$, d.f. = 2, $P < 0 \cdot 01$; Fig. 1). Control fish experienced no mortality by day 5. Combined data for fish implanted by both surgeons resulted in both silk and polypropylene exhibiting mortality that was significantly higher than that observed in control fish ($\chi^2 = 8 \cdot 00$, d.f. = 1, $P < 0 \cdot 01$). Incision score was similar between the suture materials ($P = 0 \cdot 07$). Furthermore, the number of sutures intact and suture scores at day 5 were similar for both suture materials ($P = 0 \cdot 38$ and $P = 0 \cdot 83$, respectively). Differences in surgeon experience had a stronger impact on surgical outcome than suture material. Mortality of fish in the control and expert treatment were

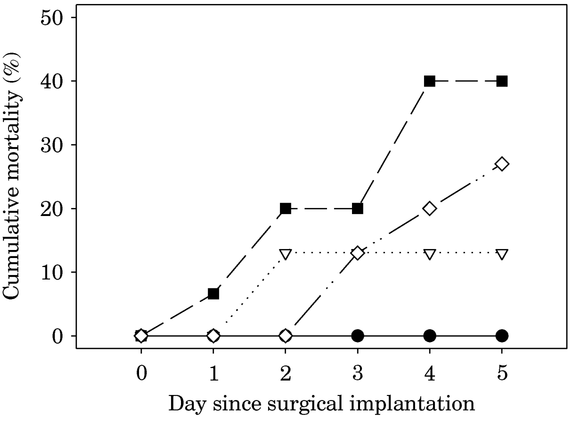

FIG. 1. Cumulative mortality during the 5 days post surgery for juvenile largemouth bass implanted with transmitters by an experienced surgeon using braided silk (●) and polypropylene (▽) and a novice surgeon using braided silk (■) and polypropylene (◇).

similar (almost 100% survival), whereas fish in the novice treatment had lower survival than fish in the expert and control treatments (Wilcoxon $\chi^2 = 13{\cdot}21$, d.f. = 2, $P < 0{\cdot}01$; Fig. 1).

The differences observed in mortality could be partly explained by the characteristics of the incision. Although incision scores were similar between surgeons ($P = 0{\cdot}17$), the number of sutures intact and suture scores differed between experience levels. The number of sutures intact at day 5 was significantly lower for the novice as compared with the expert [Kruskall–Wallis, $H_{20,28} = 9{\cdot}29$, $P < 0{\cdot}01$; Fig. 2(a)] and overall suture score was significantly higher for the novice [$H_{18,28} = 6{\cdot}27$, $P = 0{\cdot}01$; Fig. 2(b)]. Overall, a lack of surgical experience resulted in higher mortality and less desirable surgery characteristics (*e.g.* suture scores) than if the surgeon was experienced.

The novice surgeon was consistently slower than the experienced surgeon at all stages of the surgical procedure (Fig. 3) including the time required to complete the incision (*t*-test, $t = 5{\cdot}06$, d.f. = 58, $P < 0{\cdot}01$) and the time to insert the transmitter ($t = 3{\cdot}58$, d.f. = 58, $P < 0{\cdot}01$). Suture time was influenced by the suture material used ($t = 2{\cdot}12$, d.f. = 58, $P = 0{\cdot}04$), so both surgeon and suture material were factors in the analyses. The time to complete the sutures was highest for the novice using the polypropylene and significantly lower for the silk (ANOVA, $F_{1,28} = 7{\cdot}91$, $P < 0{\cdot}01$; Fig. 3). Total surgery time was influenced by the expertise of the surgeon but not suture material ($t = 6{\cdot}13$, d.f. = 58, $P < 0{\cdot}01$; Fig. 3). In addition to being more expedient than the novice, the expert surgeon

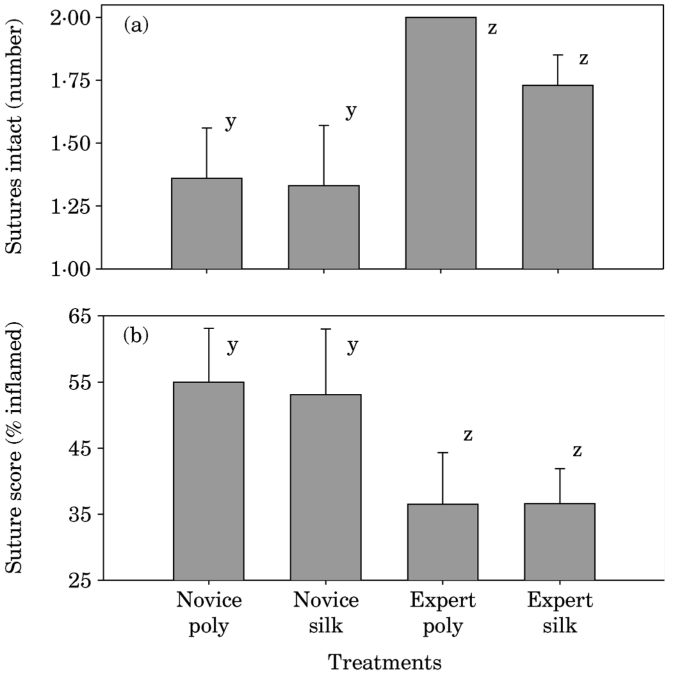

FIG. 2. Sutures intact (a) and suture scores (b) (means ± S.E.) for surgeries conducted using braided silk and polypropylene suture material by a novice and experienced surgeon 5 days after implantation. Means with a different letter are significantly different ($P < 0{\cdot}01$).

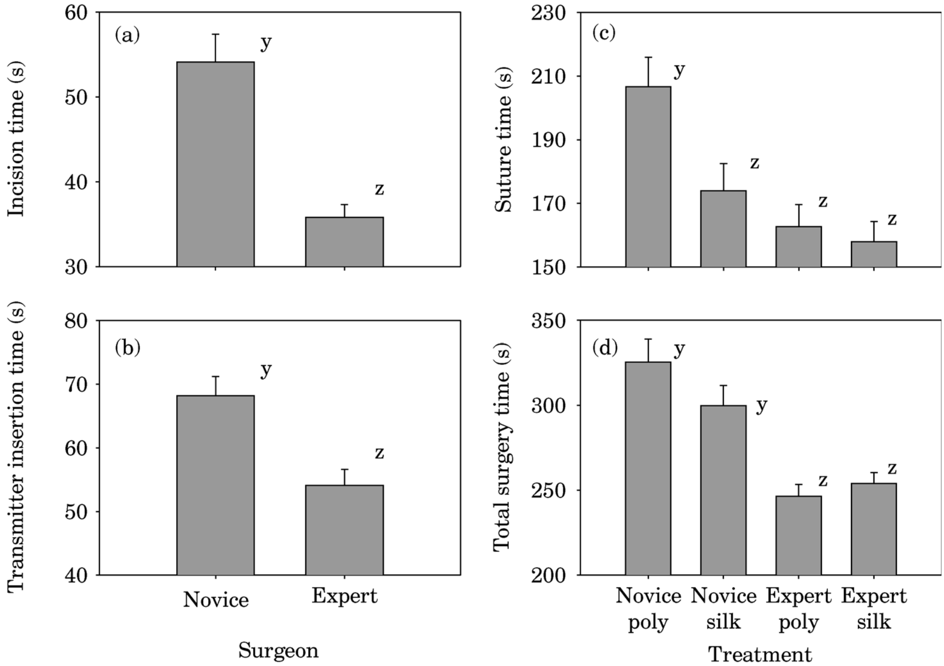

FIG. 3. Time periods (means ± S.E.) required for a novice and experienced surgeon to accomplish different phases of the intraperitoneal implantation of transmitters in largemouth bass. (a) The incision time (time required to complete the incision) and (b) transmitter insertion time (time from completion of incision to insertion of transmitter) were pooled for both suture materials. (c) The suture time (time from transmitter insertion to completion of surgery) and (d) total surgery time are plotted for both surgeons and both suture materials. Means with a different letter are significantly different ($P < 0{\cdot}01$).

also created a smaller incision [$t = 6{\cdot}62$, d.f. $= 58$, $P < 0{\cdot}01$; Fig. 4(a)] and placed sutures more accurately [Kruskall–Wallis, $H_{30,30} = 15{\cdot}75$, $P < 0{\cdot}01$; Fig. 4(b)]. For the novice surgeon, there was a trend towards decreasing surgery time as the number of surgeries completed increased (ANOVA, $F_{1,28} = 16{\cdot}38$, $P < 0{\cdot}01$; Fig. 5), however, no such relationship existed for the expert surgeon ($P = 0{\cdot}28$; Fig. 5).

The number of intact sutures after 5 days varied by surgeon and suture material (ANOVA, $F_{3,44} = 4{\cdot}47$, $P < 0{\cdot}01$). Both of the novice suture materials were less intact than those of the expert surgeon (both $P < 0{\cdot}05$), however, similar variation among treatments was not seen with regards to the incision score ($P = 0{\cdot}14$) and suture score ($P = 0{\cdot}17$). There was no evidence of size-specific mortality during the 5 days post surgery. There were also no differences in the L_T of fish that survived the 5 days and those that did not survive for both silk (survivors, $140{\cdot}1 \pm 0{\cdot}66$ mm and dead fish, $140{\cdot}33 \pm 1{\cdot}65$ mm; $P = 0{\cdot}89$) and polypropylene (survivors, $140{\cdot}46 \pm 0{\cdot}68$ mm and dead fish, $139{\cdot}00 \pm 1{\cdot}98$ mm; $P = 0{\cdot}41$) sutures. By day 20, mortality had increased to be highest in the novice-implanted fish, intermediate in the expert-implanted fish and lowest in the control fish (Fig. 6).

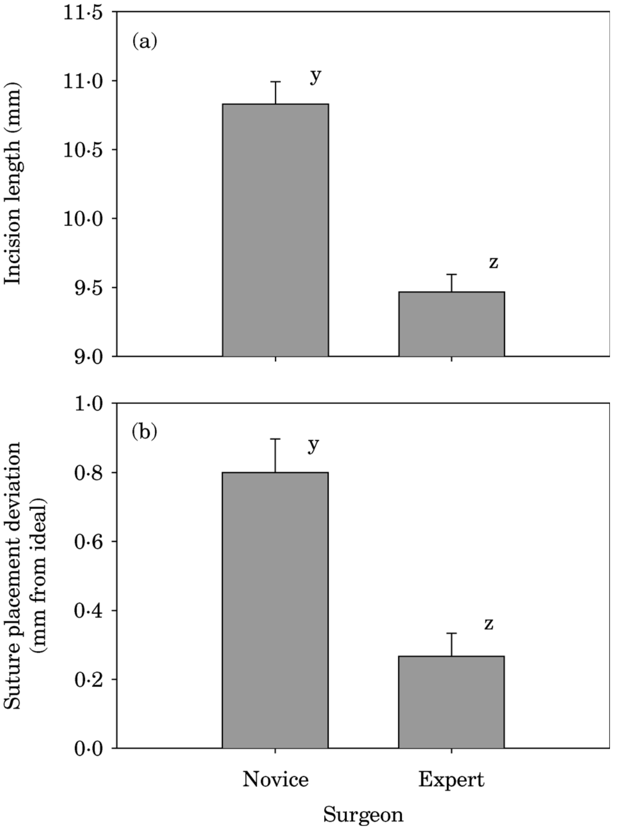

FIG. 4. Surgical variables (means ± S.E.) indicative of precision in making the incision (a) and for ideal placement of sutures (b) for a novice and expert surgeon. Means with a different letter are significantly different ($P < 0{\cdot}01$).

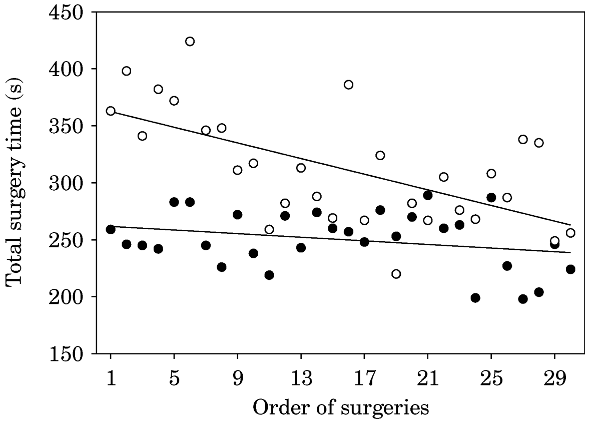

FIG. 5. Relationship between total surgery time and the order of surgeries completed by a novice (○) and experienced (●) surgeon on juvenile largemouth bass. The lines were fitted by: $y = -0{\cdot}34x + 365{\cdot}90$ for novice and $y = -0{\cdot}79x + 262{\cdot}50$ for expert.

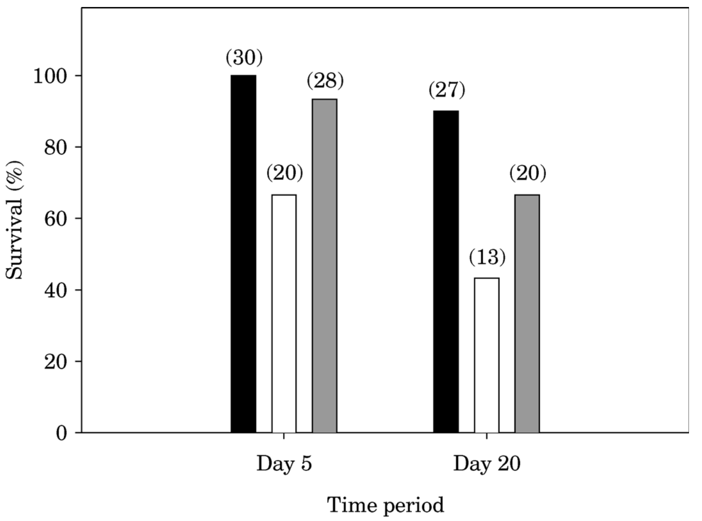

FIG. 6. Survival rates of juvenile largemouth bass either 5 or 20 days after intraperitoneal implantation by either a novice (□) or expert (▩) surgeon. Data for control fish (■) are also given.

The L_T of fish used in the study did not vary among suture materials, surgeons or with control fish at day 0 ($P = 0{\cdot}99$). At the conclusion of the study (day 20), fish were all similar in L_T ($P = 0{\cdot}30$). Interestingly however, only fish on which surgeries were performed by the novice surgeon exhibited statistically significant length increments ($t = 2{\cdot}23$, d.f. $= 41$, $P = 0{\cdot}03$). Increases in mass were similar among control fish (mean mass gain of 6·0 g) and those fish implanted with transmitters by the novice (mean mass gain of 5·6 g) and experienced (mean mass gain of 5·1 g) surgeon. At the beginning of the experiment, the fish implanted by the novice had slightly higher mass than the control fish and the fish in the expert surgeon treatment (ANOVA, $F_{2,87} = 5{\cdot}02$, $P < 0{\cdot}01$). At the conclusion of the experiment, fish in the control group ($t = 5{\cdot}35$, $P < 0{\cdot}01$), novice group ($t = 17{\cdot}81$, $P < 0{\cdot}01$) and expert group ($t = 4{\cdot}11$, $P < 0{\cdot}01$) had all increased in mass and no differences were noted among the size of the fish at the final time period ($P = 0{\cdot}50$). All fish examined at the conclusion of the study appeared healthy.

DISCUSSION

These results suggest that juvenile largemouth bass can be successfully implanted with microradio transmitters for at least 20 days. Although some mortality was experienced, at the termination of the study almost all of the incisions were completely closed, lacked inflammation and redness and sutures were no longer present. Fish looked healthy and had gained substantial mass during the study period. Wagner *et al.* (2000) compared healing in rainbow trout *Oncorhynchus mykiss* (Walbaum) using silk and polypropylene sutures at 9·4° C. The incision scores at 5 days in this study were similar to that of Wagner *et al.* (2000) at day 14. At 28 days, the incision scores of Wagner *et al.* (2000) were *c.* 0·75 for polypropylene and *c.* 3·75 for silk and incision scores were all close to zero by 20 days. The rapid healing of the largemouth bass incisions in the pond at Sam Parr Biology Station may have been influenced by water temperature. Other researchers have noted both positive and negative consequences of higher water temperatures on healing rates of fishes following surgery. Cool temperatures are usually consistent with low mortality but slow healing, whereas warm temperatures not only facilitate healing but also seem to increase mortality (Knights & Lasee, 1996). The pattern of expedited healing yet increased mortality was observed in this study.

There were no significant differences in healing or inflammation among silk and polypropylene which is in contrast to the conclusions of Thoreau & Baras (1997) and Wagner *et al.* (2000). They suggest that monofilament sutures result in less inflammation and improved wound healing. In fact, although not significant, there was a consistent pattern in the data collected in this study: the incision scores were better with silk as opposed to monofilament sutures. Interestingly, however, monofilament sutures had a tendency to stay intact longer, although they also took longer for the surgeons to stitch than did the silk. Anecdotally, both surgeons reported that they felt braided silk was easier to use than the monofilament.

The early mortality observed in the first 5 days post surgery was attributed to 'nicks' in the gastro-intestinal tract from the use of a needle to create an exit site for the antenna despite using a shield. Although less likely, the initial incision using the scalpel also may have 'nicked' the viscera. The novice surgeon's fish mortalities during the first 5 days were the result of perforated intestines from the use of the needle to create an exit site for the antenna, from the physical obstruction of the digestive tract by the antenna wire or from the initial incision that 'nicked' viscera. The experienced surgeon's fish mortalities were both because of 'nicks' to the stomach or pyloric caecae from the initial incision despite using shields. Because the short-term mortality could all be attributed to violations of viscera, this appears to be an important component of the surgery that requires practice, caution and perhaps the development of alternative techniques. Mortality following the 5 day recovery period could be attributed to the presence of the transmitter, the antenna or the surgery. These factors may have altered swimming performance or behaviour thus increasing mortality risk. In this study, antennas were trimmed as has been suggested by Brown *et al.* (1999). Although this will result in reduced detection range, other studies have documented tangling of transmitters in 'debris' and increased predation risk in small fishes (Adams *et al.*, 1998*b*).

Although increases in both the L_T and mass of fish were observed in all three treatment groups, only fish in the novice group experienced a significant increase in growth between the initiation and completion of the study. Other studies of small fishes after intraperitoneal implantation have also noted very minor disparities in growth among treatments (Adams *et al.*, 1998*a*; Martinelli *et al.*, 1998). Although no size-specific mortality was observed in the first 5 days of the study (unpubl. data), it is possible that smaller fish implanted by the novice surgeon died more frequently than larger individuals. Because 17 fish from the novice group had died by the conclusion of the study and because the control and expert fish were similar in size, the significant increase in length observed in the novice group was probably a result of a size-specific mortality favouring the survival of the larger individuals. Although this size-specific mortality was not evident by day 5, it may have become an issue during the remainder of the study. Smaller fishes are more challenging for surgical procedures and the size of the transmitter is larger, relatively, in smaller fishes. In this study the generally accepted '2% rule' (Winter, 1996; Brown *et al.*, 1999) for the transmitter mass in water was adhered to and was only violated slightly for the transmitter mass in air. The transmitters fitted in the coelom and did not create undue pressure on the wound or on the viscera.

Although the initial intention of this study was not to focus on the experience level of the surgeon (as evidenced by pseudoreplication in the experimental design) the results highlight the importance of surgical experience. In medicine, surgical skill, including manual dexterity and the outcome of a procedure are strongly correlated (Szalay *et al.*, 2000; Datta *et al.*, 2002). It is therefore not surprising that fish surgeons may also experience variation in dexterity, precision and outcome. The novice surgeon in this study was taught by the experienced surgeon and practised for 1 h prior to initiating this study, but received a total of 5 h of instruction. This level of instruction is common for researchers implanting transmitters in fishes (Winter, 1996). For surgeries on most higher vertebrates, such little experience would be considered unethical. In fisheries research this level of training, however, is typical. These results suggest that surgical experience may play a major role in determining the outcome and that researchers intending to conduct surgeries on fishes should consider using veterinarians or experienced fish surgeons. It is currently difficult to determine at what point a fish surgeon becomes 'experienced'.

The timing of the surgery varied substantially among surgeons in this study, with the experienced surgeon consistently quicker than the novice while creating smaller incisions and exhibiting better suture placement. Again, these results all point toward the need for more practice for the novice surgeon. Seki (1987) reported that accuracy of suture placement in human subjects by physicians improved with more experienced surgeons, however, all of the surgeons he studied had considerable experience. Suture practice in veterinary education is used to strengthen motor skills and increase confidence and efficiency (Smeak, 1999). Undoubtedly, practicing surgical techniques on models or dead fishes is an effective means for developing and improving surgical skills. Even within a day of surgery, improvement can be noted. A significant decrease in total surgery time was observed for the novice during the day as he acquired both experience and numbers of surgeries. The experienced surgeon also experienced a decreasing trend in surgery time during the day. Although this was not significant, it suggests that even experienced surgeons increase proficiency as they become more familiar with the specific surgery they are conducting (*e.g.* transmitter size and type and species of fish).

In medical and veterinary education, assessment is incorporated into the training programme. Such assessment is rarely incorporated into fish surgery training although this varies among countries. In some countries (*e.g.* U.K.), individuals intending to conduct surgical transmitter implantation on fishes require specific licences administered by government agencies (*e.g.* U.K. Home Office). Licensing requires successful completion of courses as well as demonstration of competency for specific skills relevant to the intended procedure. In other jurisdictions (*e.g.* North America), only individuals associated with academic institutions are subject to regulations of animal care committees. These regulations vary widely among jurisdictions and institutions, but generally require some written confirmation that the surgeon has some level of unspecified 'expertise'. It is reasonable to presume that in some studies, different individuals have participated in surgery but have not considered this to be a factor or potential source of variation. Indeed, for some it may not be. Individuals embarking on surgical experiments involving fishes should nonetheless invest substantial time in practicing different procedures or solicit the services of a trained (in fish surgery) veterinarian or 'experienced' fish surgeon.

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