Rev Fish Biol Fisheries (2011) 21:11–24
DOI 10.1007/s11160-010-9184-4

RESEARCH PAPER

Training considerations for the intracoelomic implantation of electronic tags in fish with a summary of common surgical errors

Steven J. Cooke · Glenn N. Wagner ·
Richard S. Brown · Katherine A. Deters

Received: 22 April 2010 / Accepted: 17 September 2010 / Published online: 8 December 2010

Abstract Training is a fundamental part of all scientific and technical disciplines. This is particularly true for all types of surgeons. For surgical procedures, a number of skills are necessary to reduce mistakes. Trainees must learn an extensive yet standardized set of problem-solving and technical skills to handle challenges as they arise. There are currently no guidelines or consistent training methods for those intending to implant electronic tags in fish; this is surprising, considering documented cases of negative consequences of fish surgeries and information from studies having empirically tested fish surgical techniques. Learning how to do fish surgery once is insufficient for ensuring the maintenance or improvement of surgical skill. Assessment of surgical skills is rarely incorporated into training, and is needed. Evaluation provides useful feedback that guides future learning, fosters habits of self-reflection and self-remediation, and promotes access to advanced training. Veterinary professionals should be involved in aspects of training to monitor basic surgical principles. We identified attributes related to knowledge, understanding, and skill that surgeons must demonstrate prior to performing fish surgery including a "hands-on" assessment using live fish. Included is a summary of common problems encountered by fish surgeons. We conclude by presenting core competencies that should be required as well as outlining a 3-day curriculum for training surgeons to conduct intracoelomic implantation of electronic tags. This curriculum could be offered through professional fisheries societies as professional development courses.

Keywords Biotelemetry · Biologging · Suturing · Training · Surgical error

S. J. Cooke (✉)
Fish Ecology and Conservation Physiology Laboratory, Department of Biology, Carleton University, 1125 Colonel By Drive, Ottawa, ON K1S 5B6, Canada
e-mail: steven_cooke@carleton.ca

G. N. Wagner
EDI Environmental Dynamics Inc., Suite 780-1100 Melville Street, Vancouver, BC V6E 4A6, Canada

R. S. Brown · K. A. Deters
Ecology Group, Pacific Northwest National Laboratory, 902 Battelle Boulevard, P.O. Box 999, MSIN K6-85, Richland, WA 99352, USA

Background

Biotelemetry and biologging have become important tools for fisheries professionals in recent years. Each year, tens of thousands of electronic tags are surgically implanted in the coelomic cavity of fish. Nowhere are more tags deployed than in the Columbia Basin of the Pacific Northwest. Here, thousands of telemetry transmitters per study are deployed over a several-week period to evaluate hydropower infrastructure and operations (e.g., Keefer et al. 2004; Schreck et al. 2006; Caudill et al. 2007; Naughton et al. 2007). With multiple research organizations (e.g., US Fish and Wildlife Service, Pacific Northwest National Laboratory, US Geological Survey, National Marine Fisheries Service, state natural resource agencies), academic institutions, tribal organizations, and environmental consultants each implanting electronic tags into fish, there is a great need for consistency in terms of the surgical procedures. Given that many of these studies are conducted to comply with regulatory requirements, the data they generate can undergo intense scrutiny, including legal challenges. Therefore, there is a long-standing interest in ensuring that surgical procedures and the presence of the electronic tag do not alter fish condition, behavior, or survival. Consistent surgical procedures also would improve comparisons among years of the same study and between different studies. Currently, these comparisons are unreliable. Here we discuss the topic of training individuals to become qualified for intracoelomic surgical implantation of acoustic telemetry transmitters into salmon smolts. However, the material is equally applicable to other fish species and life stages as well as to different biotelemetry or biologging devices. We also present an overview of common surgical errors in an attempt to emphasize undesirable outcomes and the need for training.

The importance of training

Training is a fundamental part of all scientific and technical disciplines. This is particularly true for surgeons, whether working on humans or other animals. For surgical procedures, a number of skills are necessary to reduce the likelihood for mistakes. Trainees must be provided with the most extensive yet standardized set of problem-solving skills and technical skills to deal with challenges that can arise. In medical and veterinary contexts, surgeons also must operate under a legal framework. Failure to achieve a specific outcome for a patient, particularly if based on negligence, can result in malpractice litigation. When dealing with fish surgery to implant electronic tags, however, the context is somewhat different.

In fisheries-related research, the primary legislative bodies responsible for outcomes and approving procedures are the institutional animal care and use committees (often referred to as IACUCs in the United States). Although once limited to higher vertebrates in academic settings, IACUCs now cover all vertebrates (including fish) and extend toward many state and federal government agencies, reflecting increased interest and concern for animal welfare (DeTolla et al. 1995; see discussion in Mulcahy 2003a). Although IACUCs wield little legal power, they can withhold research funding and levy academic misconduct charges to ensure compliance with their guidelines or decisions. For some agencies and organizations, project funding cannot be released until approval has been granted by an IACUC (note that this varies between agencies). Prior to being granted IACUC permission to conduct a procedure such as transmitter implantation on a fish, the applicant (or those who will be involved in the procedures) must be able to document proficiency. Compliance typically is obtained by simply participating in generic animal care training delivered by the IACUC on topics such as ethics and animal welfare. Rarely are there training materials or performance evaluations specific to fish surgery. In some cases, individual IACUCs have attempted to regulate or standardize procedures for fisheries research (Borski and Hodson 2003). However, because most fish telemetry and biologging research is not performed by veterinarians and occurs under field conditions, it has been difficult to develop guidelines that are useful and appropriate for fisheries scientists (Mulcahy 2003a, b). Many of the existing documents have been written by veterinarians (e.g., Stoskopf 1993a, b; Harms and Lewbart 2000; Mulcahy 2003a). These sources provide important veterinary rigor, but that rigor is not always transferable to wild fish in field environments (Stoskopf 2003).

Furthermore, there seems to be much variation among the standards employed by different agencies, jurisdictions, and employers. Professional fisheries societies, including the American Fisheries Society (AFS), American Institute of Fisheries Research Biologists (AIFRB), the American Society of Ichthyologists and Herpetologists (ASIH), and the Fisheries Society of the British Isles (FSBI), have developed guidelines intended to improve the welfare of fish used in research (ASIH et al. 1987, 1988; FSBI 2002;

AFS et al. 2004). These general guidelines include sections on surgical implantation of electronic tags, but, as Mulcahy (2003a) noted, there is very little detailed or standardized information concerning the development of guidelines for training and regulation of fish surgery. This paucity of information is particularly surprising, considering documented cases of negative consequences arising from surgery on fish (see Bridger and Booth 2003; Mulcahy 2003b; Welch et al. 2007) and the presence of information from studies having empirically tested fish surgical techniques (see reviews by Jepsen et al. 2002; Mulcahy 2003b; Wagner and Cooke 2005).

The relationship among training, experience, and outcome: perspectives from medical and veterinary sciences

In medical and veterinary science, training of the surgeon and the volume of procedures conducted have been deemed important in the outcome of surgical procedures (Califf et al. 1996). An expanding body of literature suggests that despite receiving formal surgical instruction and clinical experience, veterinarians and physicians still exhibit significant differences in surgical aptitude (Sosa et al. 1998; Freund et al. 1999). Research in medical and veterinary science has shown that novice medical surgeons have reduced dexterity compared to more experienced surgeons which affects not only the accuracy of the suture placement and the degree of suture holding, but also the time required to complete the surgery (Annett 1971; Engelhorn 1997). It should not be surprising that surgical skills, including manual dexterity, have been shown to be strongly correlated to the outcome of medical procedures (see Table 1) (Szalay et al. 2000). Research into this topic has grown, reflecting genuine care and concern for the well-being of patients and an increase in professional responsibility (Califf et al. 1996).

Although this strong correlation between skill level and success of surgical outcome is based on evidence from human and veterinary medicine, surgical skill level is of importance in fisheries surgery as well. 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, Cooke and Wagner (2004) submitted that there is greater opportunity for increased variation in fish surgeon ability. Therefore, there is a strong likelihood that fish surgeons experience greater variation in dexterity, precision, and surgical outcome than their medical and veterinary counterparts. Longer surgeries on fish translate into extended anesthetization and thus potential delays in recovery, which is problematic when releasing the implanted fish (particularly smolts) into the wild.

Experience and surgical outcome for fish

To date, very little work has been performed on the effects of surgical expertise on the outcome of transmitter implantations. In fact, most data come from a single study comparing two surgeons with different levels of experience (Cooke et al. 2003) and from a survey of fish surgeons of ranging levels of experience (Cooke and Wagner 2004).

Cooke et al. (2003) used an expert and a novice surgeon in their study. Both surgeons had been trained by individuals noted as experts in the field of fish tagging, although none of those trainers was a qualified veterinarian or physician. The expert surgeon had been conducting fish surgeries for 6 years and had completed more than 1,150 surgeries on several different fish species. Those surgeries included tag implantation and the surgical attachment of cardiac output monitoring devices. It was estimated that during those 6 years, the expert surgeon had administered more than 5,000 individual sutures.

The novice surgeon was taught how to conduct surgeries by the expert in a manner similar to that by which the expert had learned to perform surgeries. Prior to instruction, the novice read a commonly used text reference (Summerfelt and Smith 1990) on conducting surgery on fishes. Formal instruction included the novice first observing the expert perform surgeries, then practicing sutures and incisions on foam and moribund fishes, and finally practicing on live specimens under the guidance of the expert. This level of training was very representative of typical fish surgical training in North America. During this training, the novice surgeon successfully completed surgeries on five largemouth bass and afterwards

Table 1 Examples of correlations between surgical skills and surgery outcomes in medicine

Summary	Reference
Individual surgeon experience is significantly associated with complication rates and length of stay for thyroidectomy (i.e., less experience leads to more complications and longer stays)	Sosa et al. (1998)
Patients of surgeons with higher average annual caseloads of total shoulder arthroplasties and hemiarthroplasties have decreased complication rates and hospital lengths of stay compared with the patients of surgeons who perform fewer of these procedures	Hammond et al. (2003)
Surgeon volume and carotid endarterectomy outcome are correlated positively (i.e., greater surgical volume leads to more favorable outcome)	Feasby et al. (2002)
Surgeon volume and certification (i.e., specialized training and evaluation) are significantly related to better outcomes for patients who undergo vascular surgery procedures. Surgeons with high surgery volumes demonstrated consistently lower mortality and morbidity rates than did surgeons with low volumes	Pearce et al. (1999)

indicated feeling satisfied with the level of knowledge attained. Total training time for the novice was 5 h.

Despite having received the basic training prior to the actual experiment, the novice surgeon took longer to complete the surgeries, had reduced suture precision, and experienced higher fish mortality relative to the expert surgeon (Cooke et al. 2003). During the surgery day, the expert surgeon exhibited consistently rapid surgery times, whereas the novice surgeon exhibited significantly improved speed as the number of completed surgeries increased. Details on the outcome of the experiment are provided in Table 2.

The importance of feedback in surgical outcome

The ability of surgeons to observe the surgical sites on their fish in the days and weeks following surgery provides immediate feedback, enabling surgeons to modify their procedures and conduct improved surgeries (Deters et al. 2010). While evaluating different suture types for implanting acoustic transmitters into juvenile Chinook salmon *Oncorhynchus tshawytscha*, Deters et al. (2010) found differences in the surgical outcomes among four experienced surgeons (all who previously had implanted transmitters into hundreds or thousands of fish). Deters et al. (2010) concluded that the opportunity of two of those surgeons to monitor the healing progression of their surgeries over time during laboratory-based studies was beneficial to the surgical outcome of their fish. Surgeons who obtained feedback had higher suture retention, lower incision openness scores, and higher transmitter retention. This finding indicates that having a large quantity of surgical experience may be important, but a feedback process also is important so surgeons can see the outcomes of their surgeries and improve their techniques. Surgeons should receive feedback and observe the surgical sites externally (e.g., suture retention, incision condition, and tag loss). However, it may be more valuable to have the trainees perform necropsies on each of their practice fish to examine the internal condition (e.g., wound healing from inside-out, nicking/snagging or cutting of organs, depth of sutures).

Table 2 Summary of differences in surgery outcomes between novice and expert surgeons for largemouth bass tagged with dummy radio transmitters (Cooke et al. 2003)

Metric	Expert	Novice
Survival of tagged fish	High	Moderate
Suture retention (5 days)	High	Moderate
Suture score[a]	High	Moderate
Speed: incision (s)	36	54
Speed: transmitter insertion (s)[b]	53	68
Speed: suturing (s)	161	190
Speed: total surgery time (s)	250	312

[a] Higher suture score implied better suture placement and less inflammation

[b] Radio transmitters were used, so the time for insertion included making a hole for external exit of antenna

The state of training and evaluation in medical and veterinary science

Each medical and veterinary school seems to use different techniques for surgical training and evaluation. These differences may reflect the fact that surgical training has undergone many changes in the last decade (Bradley 2006). In particular, one trend, not yet uniformly accepted, is the development of surgical skills through different simulation techniques. Torkington et al. (2000) suggest that practicing surgical procedures on simulated human (or other animal) tissue, if perfect, could enable complete transfer of techniques learned in a skills laboratory directly to the operating theater. Simulation techniques currently used in human medicine include artificial tissues, animal models, and virtual reality computer simulation.

In fish surgery, one of the more technical aspects of the procedure is the suturing. This skill is important also in medical and veterinary practices. In a microsurgical department in Spain, students are advised to perform 1,000–1,500 microsurgical stitches (which represents around 40 to 50 h of practice) to attain expertise in microsuturing (Uson and Calles 2002). Although this high number initially was viewed as excessive, the instructors (through student feedback) agreed that the techniques could be mastered only after much practice. Uson and Calles (2002) surveyed their students, and 98% favored training first on nonliving models prior to switching to live animal models.

Starkes et al. (1998) also assessed suturing performance for 13 novice microsurgeons throughout a 4- to 5-day microsurgical training course. At the beginning and end of each training day, time to complete a suture (from needle insertion to completion of tie-off) was assessed on a standardized suture task using simulated tissue as well as actual tissue. An average learning curve for suturing performance on the standardized test was developed and demonstrated significant performance improvement in the suturing of actual tissue. Thus, the use of standardized tests appears to reflect actual suturing performance and to be sensitive to improvements in suturing skill that result from practice.

In a survey of all 31 veterinary schools in the United States and Canada, Bauer (1993) revealed that models were frequently used to teach suturing, general psychomotor skills, knot tying, and hemostasis. Indeed, globally there is a trend toward no longer using live animals for surgical technique training classes in veterinary science (Silva et al. 2007). Ideally, training would include a combination of core skills that are initiated on models and subsequently applied to living organisms. This training method is particularly relevant for fish research in which the surgeon is responsible also for handling, anesthetization, and recovery of the patient.

The state of training in fish science

Currently, there are no standardized or official training methods or guides for the implantation of transmitters into fish; the majority of fish surgeons learn their craft from direct observation, mentoring, and the literature (Cooke and Wagner 2004). Conversely, Bauer (1993) reported that 37% of veterinary schools in North America used a standardized process to evaluate the surgical skills of students in the laboratory training environment prior to their transitioning to work on live animals. In a survey of fish surgeons, Cooke and Wagner (2004) revealed a lack of clear consensus on the need for international standards for intracoelomic surgery for tag implantation within the fish surgery community. However, many of the survey respondents stated that some minimum standards are needed to ensure that fish exposed to surgery have a reasonable chance of recovery and survival. The majority of respondents also stated they work in a jurisdiction or for an employer that does not require a minimal level of training or proficiency prior to conducting fish surgery. In the instances in which training was required, a veterinarian or other appropriate official within an IACUC often simply observed the surgical approaches used on fish, providing guidance and eventual approval to work independently. Some individuals surveyed by Cooke and Wagner (2004) indicated they were required to demonstrate competence in surgical technique and speed on nonliving specimens coupled with survival of trial organisms in the laboratory. However, government agencies in Europe (e.g., the UK Home Office) regulate surgical activity on all vertebrates, including fish, and in Iceland, the Fish Disease Officer must approve all fish surgeons. To our knowledge, similar levels of training or certification are not required in any jurisdiction in North America. Cooke and Wagner (2004) asked whether respondents had taken any university or college courses for credit that included instruction on surgical techniques. Only 12% of respondents participated in university-level course work that included such instruction, and of those, only one-half included experience focused specifically on fishes. The majority (88%) of respondents had not participated in any academic credit-based courses that included instruction on surgical techniques. Some schools with veterinary programs now include graduate courses involving surgery for research; these courses are relatively new and are unlikely to include modules or content on fishes. If there is a component on fish surgery, it would likely focus on tumors and general health assessment rather than transmitter implantation.

When Cooke and Wagner (2004) queried as to the potential of an Internet portal to serve as a resource for training surgeons, the results were mixed. Overall, more respondents disagreed (41.0%) than agreed (16.3%) that an Internet portal could provide enough information to train fish surgeons. Another 35.5% were neutral to the idea. Few respondents indicated they strongly disagreed or strongly agreed. Although the survey results reflected general apprehension to the idea, the Internet still could serve as a resource for communication among fish surgeons. An Internet portal could provide a venue for exchange of information on surgical techniques and species-specific insights, as well as provide opportunities for less-experienced surgeons to identify and connect with potential mentors.

Cooke and Wagner (2004) also asked respondents about what they believed would be the most effective means of learning fish surgery. Mentoring in a laboratory was identified as one of the key strategies. However, many respondents also recognized the need for complementary training in a classroom environment (see Table 3). A combination of these approaches would likely be ideal, as it would join theory with practice.

Table 3 Methods of learning surgical procedures on fish identified as most effective for training future fish surgeons

Method of learning	Total responses (%)
Mentoring in a laboratory	26.6
Continuing education courses/workshops at professional conferences	22.1
Handbook	17.5
Academic instruction	12.6
Internet portal	12.0
Sessions provided by animal care councils or government	5.1
Other	4.0

Methods were reported by 171 fish surgeons surveyed by Cooke and Wagner (2004). Respondents were able to identify more than one method

Development of important skills

Although many surgical skills (for health care professionals) require technical expertise, these skills form only one component of a complex picture of training for fisheries researchers that includes general knowledge of fish and the project (Kneebone 2003). In terms of fish surgery, this means ensuring that the surgeon is aware of basic principles of fish biology and surgery and understands the purpose of the study for which the surgery is being done. Having surgeons with a background in the biological or physiological sciences will increase the likelihood that they will be familiar with the physiology of the study animals. Furthermore, surgeons who are brought in from within the field of study may feel like they have a larger stake in the success of the project and may be more motivated to conduct high-quality surgeries. Such an integrated approach should yield highly trained surgeons who feel like part of the overall research team and are committed to ensuring that the project is a success.

In addition to motivation, one of the most important components of surgical training is the development of precise and controlled hand movement. In medicine, it is well known that deliberate practice is important to achieve expert performance (Ericsson et al. 1993; Ericsson 2004). Simply learning how to do fish surgery once is insufficient for ensuring the maintenance or improvement of surgical skill. Therefore, such proficiency must be achieved before an individual is allowed to progress to practicing on a live fish. Body positioning also must be comfortable, and the instruments must be handled firmly but gently. Instructors can provide ways to make slight changes to the trainee's technique to improve efficiency and dexterity. While it is important to note that the surgery speed is not a competition, it is imperative that the surgery be done in the least amount of time possible to enable the fish to recover quickly. These steps are important for surgical procedures and to maintain the comfort of the surgeon across multiple surgeries often lasting hours to days.

Evaluation of surgical experience

In medical and veterinary education, assessment of surgical skills is incorporated into the training program. Such assessment is rarely incorporated into fish surgery training, with the exception of a few countries (e.g., the United Kingdom, Germany). The medical professional competence standards developed by Epstein and Hundert (2002) state that evaluation of surgical ability and outcomes is important for several reasons. From the perspective of the trainee, evaluation provides useful feedback about individual strengths and weaknesses—feedback that guides future learning, fosters habits of self-reflection and self-remediation, and promotes access to advanced training. From the perspective of the curriculum and the training program, evaluation enables instructors to respond to lack of demonstrated competence, fosters course or curricular change, and certifies the competence of graduates. As well, there is the opportunity for self assessment of the need for additional practice, which can be relevant when switching between organisms or adapting to a change to the surgical procedure, or after long periods of surgical inactivity.

Suture practice in veterinary education is used to strengthen motor skills and increase confidence and efficiency (Smeak 1999), but it is difficult to determine at what point a fish surgeon has gained enough experience. Although an experienced fish surgeon has been shown to be consistently quicker, with smaller incisions and better suture placement than a novice (Cooke et al. 2003), the accuracy of suture placement in human subjects has been shown to improve with experience among already experienced surgeons (Seki 1987). Unfortunately, the majority (93%) of fish surgeons have not been formally tested or evaluated to determine their level of surgical proficiency (Cooke and Wagner 2004). Clearly this pattern needs to change in order to elevate the quality of fish surgery for the sake of fish welfare and the integrity of scientific research.

Feedback, or the ability to monitor the progression of surgical incision healing, can improve surgical outcome (Deters et al. 2010). Surgeons who previously took part in research projects that involved post-surgery examination of study animals were associated with better surgical outcomes, such as higher suture and transmitter retention. To provide feedback within a surgery training program, we suggest that surgeons first be allowed to view examples of poor techniques that can manifest into significant problems several days or weeks later (examples are shown later in the paper). As part of the surgeon evaluation, images of practice fish should be taken on the day of surgery and at other times within approximately 2 weeks of surgery, before the incision location begins to heal considerably. Images taken after 2–3 weeks post-surgery may not provide the surgeon with optimal feedback because problems associated with poor technique may be concealed by the advancement in healing, possibly leading to the false impression that no negative issues were associated with the surgical technique. For this reason, it is suggested that images be taken both immediately following surgery and during the first few weeks of the healing process (7 and 14 days after surgery, for example).

Delivery of fish surgery training

It is crucial that the individuals delivering the training are themselves experts in surgical procedures and fish care. Therefore, veterinary professionals should be involved in at least some aspects of training to ensure that basic surgical principles (related to tissue and tool handling and cleaning) are observed. This may be as simple as having the surgical instructor conduct a surgery in the presence of a veterinarian while asking for guidance on technique. Often, the IACUC panels that approve animal care permits include veterinarians who are happy to provide advice. However, it should be noted that most veterinarians are familiar with terrestrial animals, not fish. This difference in patient experience may lead to large variations in animal-handling and surgical techniques.

Veterinary involvement in training may help to avoid situations where incorrect surgical procedures are taught, such as using hands rather than surgical tools to drive suture needles, doing surgery with the entire fish out of water, and suggesting the use of surgical gloves is unnecessary. Such information learned at surgical workshops and seminars is dangerous because it can be further disseminated through word of mouth. Along with veterinary consultation, a benefit to the instruction team would be the presence of experienced fish surgeons who have worked on a number of species and are familiar with the latest advances in fish (and other wildlife) surgery.

Defining attributes for fish surgeons

One way forward in fish surgical training is to identify a set of attributes related to knowledge, understanding, and skill that surgeons must demonstrate prior to engaging in fish surgery. Indeed, such an approach has been used to define a series of attributes that are expected of graduating veterinarians (Walsh et al. 2001; Zemljic 2004). Such an approach can be used to develop an outcomes assessment to evaluate whether fish surgeons are meeting these expectations (Walsh et al. 2002). Typically these outcomes assessments are performed by surveying recent graduates (Tinga et al. 2001), which could easily be adapted for fish surgeons. The three sets of attributes listed in Table 4 provide an example of the competences required of a surgeon implanting electronic tags into fish.

Proposed curriculum for surgical training related to fish

To date, we are unaware of any published curricula developed specifically for training surgeons to conduct intracoelomic implantation of electronic tags in fish. Here we provide a proposed 3-day curriculum for fish surgical training as a guide for instructors. Our hope is that this curriculum will be used to advance the area of surgical training for fish biologists. Included is a combination of classroom instruction with hands-on trials and mentoring using models and real animals.

To ensure that knowledge is maintained, each individual should be subjected to routine evaluation and provided with occasional refresher training. Furthermore, there should be some expectation that each trainee will engage in deliberate practice throughout his or her career.

Guiding principles

The goal is to develop a standardized training program that leads to a high level of surgical proficiency and knowledge of fish biology and handling necessary for the intracoelomic implantation of electronic tags in fish. Such training should yield standardized approaches to surgery across studies as well as enhance the welfare, condition, and survival of tagged fish. Each participant should be provided with a manual covering the key learning objectives listed below, as well as photographs and/or a CD/DVD with short video clips of surgical procedures.

Another goal of training is to identify individuals who require additional study or do not have the dexterity (i.e., innate talent) to be involved in surgical procedures. Identification of those unable to learn or demonstrate the necessary skills to ensure successful surgery is an important general preventive measure in animal care.

Learning objectives

At the end of the training period, the trainee should:

- recognize and understand the importance of conducting surgery in a manner that puts the fish on a trajectory to survive with negligible sublethal impairments;
- understand basic information about fish biology and surgical techniques (including principles of sterilization) needed to properly handle and care for fish during surgery;
- exhibit proficiency in fish surgical procedures, including the handling and use of tools and completion of all phases of the surgical procedure;
- exhibit proficiency in data registration/dictation, to become accustomed to “multitasking” while performing surgery;
- understand body positioning and posture needed to reduce surgical fatigue and reduce chances of worker injury or exhaustion; and,
- recognize the types and level of practice needed to maintain skills and be willing to subject themselves to testing (surgical evaluation).

Training program example

Details of the schedule for our proposed 3-day training in fish surgical techniques are presented in

Table 4 Essential competences of the fish surgeon

Knowledge and understanding
Graduates will be able to demonstrate knowledge and understanding of
Scientific method at a level adequate to provide a rational basis for fish surgery practice and the purpose of telemetry/biologging studies, and to assimilate the advances in knowledge that will occur over their working life
The basic structure (anatomy), function and development of fish, their interactions with their environment (e.g., physiochemical), and the factors that may disturb these (e.g., stressors)
The underlying basis of health and disease in fish
The fish welfare and animal care policy environment
Skills
Graduates should have developed the skills to
Acquire information from and about fish and fish telemetry/biologging and perform a basic examination of fish
Collect, organize, and analyze information in relation to specific problems that may be encountered during fish surgery or in determining the best surgical procedures to use, assess the validity of information, and reach probabilistic judgment
Successfully select and use anesthetics, surgical tools, and surgical procedures necessary to implant transmitters into fish (including hemostasis and suturing)
Maintain a "clean" surgical environment that reduces opportunity for infection, cross-contamination, or other sterility or biosecurity concerns
Perform basic diagnostic and therapeutic procedures associated with fish care and recovery, including particular emphasis on water quality
Work and communicate effectively with colleagues
Perform effectively in a workplace, including an understanding of organizational systems, human and physical resource management, performance indicators, occupational health and safety, knowledge management, and quality control
Attitudes affecting professional behavior
During fish surgical training, students should become familiar with professional standards which are regarded as fundamental to surgical practice on fish
An appreciation of the complexity of ethical issues, the diversity of stakeholder perspectives, and the range of cultural values associated with conducting surgery on fish
A desire to promote animal welfare
An ability to recognize when there is a need for practice or further professional development to ensure that skills and knowledge are maintained and enhanced
An appreciation of the need to recognize when a clinical problem exceeds their capacity to deal with it safely and efficiently and of the need to refer the patient for help from others when this occurs
A willingness to work effectively in a team with other relevant professionals, including respect for the role of veterinary and fish health professionals in fish telemetry/biologging projects

Adapted from Australasian Veterinary Boards Council Inc. (2006, p. 25)

Table 5. Each training day is subdivided into a morning and an afternoon session, and each session has a specific focus. We acknowledge that this format is an example and that different organizations and institutions may have slightly different requirements regarding the duration of different course components and the number of practice surgeries conducted. For evaluation, we are proposing a sample size of 75 fish. However, the minimum number of total surgeries performed would exceed 100 over the 3-day training course.

Completion of the practical examination does not signify approval to perform surgery on a project. Training culminates with a final evaluation (based on timing, quality of wound closure, care with internal organs, transmitter placement) and includes a feedback report. The final evaluation should be determined as soon as possible after the 2-week holding period. Trainees should not be scheduled to perform surgeries for a project until they have been approved as a qualified surgeon in the final evaluation. For this reason, funding agencies should be made aware of

Table 5 Sample schedule for proposed 3-day surgical training

Morning	Afternoon
Day 1	
Trainees observe lectures and/or videos on topics such as the reasons for surgical implantation of transmitters into fish how and for what the data from studies are used (trainees engaged in a project will have greater interest in improving skills) basic principles of biotelemetry and biologging basic principles of fish biology (anatomy, physiology, environmental relations) fish identification specific to the project Instructors can provide reading materials on these subjects to the trainees in advance of Day 1, to save time and costs	Trainees observe lectures on the principles of fish handling, surgical techniques, and fish stressors. Lectures should be delivered by a highly experienced fish surgery instructor and/or veterinarian. Topics to be addressed include animal welfare fish holding conditions and basic handling (netting) identification of diseased states at time of surgery (e.g., bacterial kidney disease, BKD) sterilization/disinfection water conditioners anesthetics and antibiotics surgical principles and tools, including transmitter implantation and wound closure techniques pictures/list of good and bad suturing techniques and the outcomes of each This training session should end with a demonstration of fish surgery that brings together the topics covered
Day 2	
Quiz on topics covered on previous day. Focus on development of skills involving practice of the following techniques: knot-tying using rope incisions and sutures on bananas or other fish alternative incisions and sutures on dead fish Instructors should circulate during training periods to ensure trainees are handling tools properly. Throughout the morning, trainees should be evaluated for preliminary surgical proficiency to identify individuals who require additional training. At the end of the morning, the trainees should be timed and scored on suturing skills	If competency has been demonstrated, the trainee will move on to practice the entire surgical procedure (including fish handling, water quality monitoring, transmitter insertion, and so on) with live fish. Toward the end of the day, surgery times should be monitored. Trainees with surgery times averaging more than 5 min should attain additional training and practice before moving to the next steps. A subset of fish should be necropsied to provide immediate feedback. Some practice fish can be held overnight to monitor survival
Day 3	
Continued practice on live fish for trainees with overnight fish mortality, slow surgery times, or any other deficiencies; commencement of the surgical implantation practical examination for all others. For the practical examination, each trainee will perform intracoelomic transmitter implantation surgery on 75 live fish (will require instructor to provide assistance and constant feedback, or 2 days may be required to complete 75 fish). The incisions of the last 20 fish will be photographed immediately following surgery to aid in evaluation of the wound closure technique and re-evaluated at 24 h. All 75 fish should be held for 2 weeks, to allow poor surgical techniques to manifest themselves in lost sutures and transmitters, abnormal irritation to the fish, mortality, or other symptoms	Completion of the practical exam

this time requirement, to allow potential surgeons to be trained before the project starts. Additional time should be allocated in case trainees do not pass the final evaluation. This time provides the opportunity to retrain and retake the exam. However, instructors should identify individuals with an obvious lack of skill because it may be more cost-effective to train a new surgeon with more innate ability.

Beyond this type of 3-day training program, novice fish surgeons should further practice their learned surgical skills to continue to improve timing, incision and suture placement, and fish recovery. More experienced and expert surgeons should retrain with a small number of fish when working with a new species, when the procedure has been modified, or after a length of surgical inactivity.

Because the success of electronic tagging studies depends on the retention of transmitters and high survival of study fish, it is important that the final evaluation of the trainee include a collection of data not limited to percentages of fish mortality, transmitter retention, suture retention, or wound healing and appearance. Evaluations of photos taken a few times post-surgery (24 h, 1 and 2 weeks are commonly used) provide the information necessary to assess the surgical proficiency of the trainees. By taking photographs of the incision at a number of days post-surgery, instructors and trainees will be able to observe which aspects of the surgery may be causing detriment to the fish. Indeed, photographs are essential for identifying common errors in surgical technique that may not manifest themselves immediately. For example, photographs and visual inspection several days post-surgery can provide information related to how tight the knots are pulled (Fig. 1), knot technique (Fig. 2), tissue handling (Fig. 3), tissue

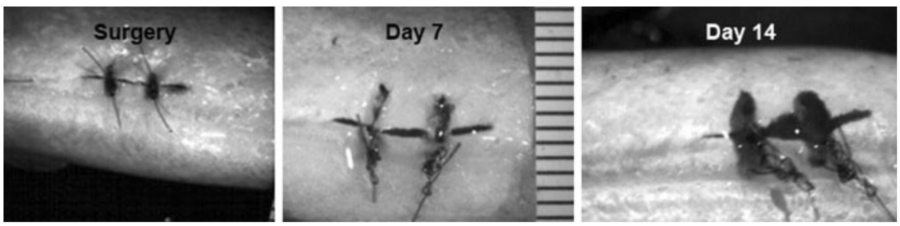

Fig. 1 Sutures that are pulled too tightly restrict blood flow to the underlying tissue and do not allow proper apposition of tissue layers. Over time, this may lead to necrosis of the tissue as shown in the day 14 picture above. This process often results in sutures pulling through the body wall and eventual suture loss. Some sutures that are tied too tightly will tear through the body wall before necrosis of the tissue occurs

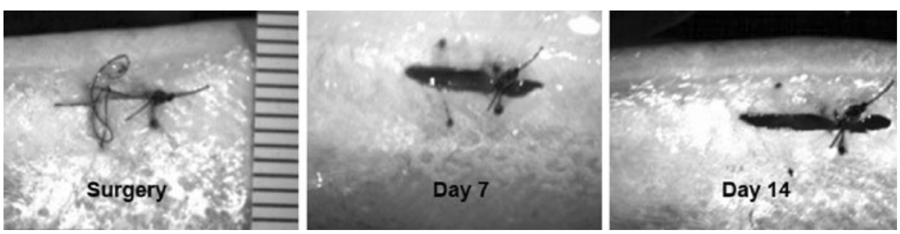

Fig. 2 Achieving perfectly tight knots on sutures tied with monofilaments is sometimes difficult. However, it is important that each throw be locked into position by the next throw in the alternate direction. Sutures tied so that the successive throws do not lock into position are more likely to untie. Over time, with fish movement and obstacles, the suture may untie completely and fall out, as shown in the day 7 and 14 pictures above, resulting in the reopening of the incision

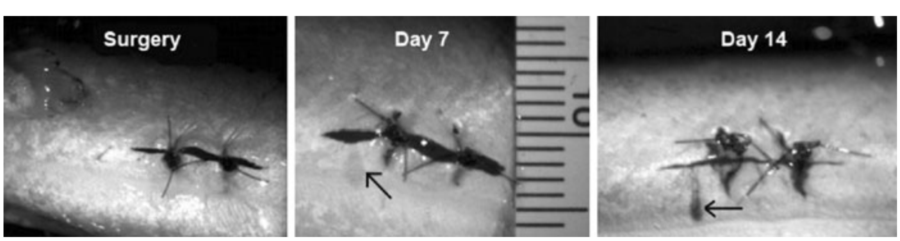

Fig. 3 Some poor surgical techniques are not noticeable on the day of surgery. Above is an example of one problem that can manifest over time. In this case, the trainee grasped the skin too tightly with forceps, causing tissue necrosis. Instead, the skin should have been lifted with forceps

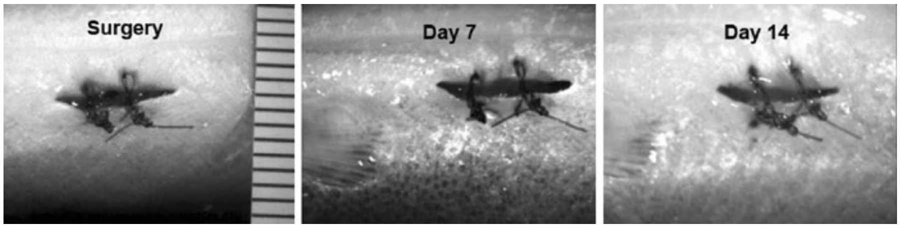

Fig. 4 Poor incision apposition can result from several bad suturing techniques. Poor apposition (illustrated above) occurs when one side of the incision slides underneath the other side, possibly due to unequal tissue bite or unequal knot tension. This may occur more often when implanting juvenile fish with very thin muscle layers. Pulling the suture too tight can also cause the skin to pucker where the skin edges meet, resulting in poor apposition. This can lead to some sections of the incision having good apposition while other sections are not apposed

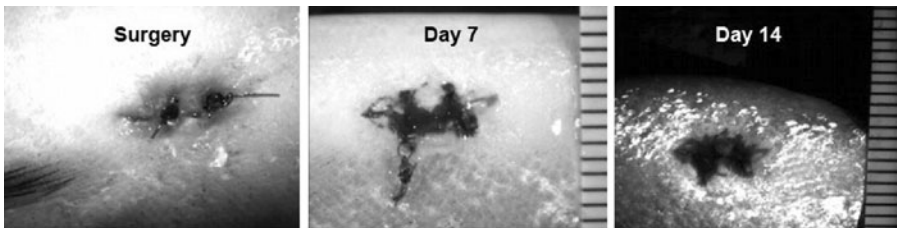

Fig. 5 It is important to take a large "bite" of skin; that is, to have the suture entry and exit points far enough from the incision ($\sim$2 mm on each side) to appose all the tissue layers and avoid suture tearing through the skin. In the pictures above, on the day of surgery, the suture entry and exit points are not visible behind the suture knot, indicative of not taking a large enough bite. Often, this poor technique is coupled with pulling the suture too tight. When the wound inflammation occurs, tension causes the skin to rip, as shown in the day 7 picture. With such a small bite of skin, the suture will rip through the entire body wall more quickly and is more likely to be lost, leading to a higher likelihood of tag expulsion

apposition (Fig. 4), and the size of the tissue bite (Fig. 5). Techniques can then be modified to improve the surgical outcome. Retraining could include surgeries on live fish only, with subsequent feedback on the surgeries.

Acknowledgments We thank Brad Eppard and the Portland District Army Corps of Engineers for supporting this project. Cooke was also supported by the Canada Research Chairs program. We thank Chris Peery, Jennifer Panther, Brad Eppard and Christa Woodley for discussions regarding training and Caleb Hasler, Karen Murchie and Edd Brooks for providing comments on the manuscript. Andrea Currie kindly assisted with formatting the article.

References

AFS (American Fisheries Society), American Institute of Fishery Research Biologists, and American Society of Ichthyologists and Herpetologists (2004) Guidelines for the use of fishes in research. American Fisheries Society, Bethesda. Available at www.fisheries.org/afs/docs/policy_guidelines2004.pdf. Accessed Apr 2009

Annett J (1971) Acquisition of skill. Br Med Bull 27:266–271

ASIH (American Society of Ichthyologists and Herpetologists), American Fisheries Society, and American Institute of Fishery Research Biologists (1987) Guidelines for use of fishes in field research. Copeia Suppl 1987:1–12

ASIH (American Society of Ichthyologists and Herpetologists), American Fisheries Society, and American Institute of Fishery Research Biologists (1988) Guidelines for use of fishes in field research. Fisheries 13(2):16–23

Australasian Veterinary Boards Council Inc (2006) Annex 2, Essential competences required of the veterinary surgeon. In: Policies, procedures and standards—Veterinary Schools Accreditation Advisory Committee. Australasian Veterinary Boards Council Inc, Melbourne, p 25

Bauer MS (1993) A survey of the use of live animals, cadavers, inanimate models, and computers in teaching veterinary surgery. J Am Vet Med Assoc 203:1047–1051

Borski RJ, Hodson RG (2003) Fish research and the institutional animal care and use committee. ILAR J 44:286–294

Bradley P (2006) The history of simulation in medical education and possible future directions. Med Educ 40: 3254–3262

Bridger CJ, Booth RK (2003) The effects of biotelemetry transmitter presence and attachment procedures on fish physiology and behavior. Rev Fish Sci 11:13–34

Califf RM, Jollis JG, Peterson ED (1996) Operator-specific outcomes: a call to professional responsibility. Circulation 93:403–406

Caudill CC, Daigle WR, Keefer ML, Boggs CT, Jepson MA, Burke BJ, Zabel RW, Bjornn TC, Peery CA (2007) Slow dam passage in adult Columbia River salmonids associated with unsuccessful migration: delayed negative effects of passage obstacles or condition-dependent mortality? Can J Fish Aquat Sci 64:979–995

Cooke SJ, Wagner GN (2004) Training, experience, and opinions of researchers who use surgical techniques to implant telemetry devices into fish. Fisheries 29(12): 10–18

Cooke SJ, Graeb BDS, Suski CD, Ostrand KG (2003) 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. J Fish Biol 62:1366–1380

Deters KA, Brown RS, Carter KM, Boyd JW, Eppard MB, Seaburg AG (2010) Performance assessment of suture type, water temperature, and surgeon skill in juvenile Chinook salmon surgically implanted with acoustic transmitters. Trans Am Fish Soc 139:888–899

DeTolla LJ, Srinivas S, Whitaker BR, Andrews B, Hecker B, Kane AS, Reimschuessel R (1995) Guidelines for the care and use of fish in research. ILAR J 37:159–173

Engelhorn R (1997) Speed and accuracy in the learning of a complex motor skill. Percept Mot Skills 85:1011–1017

Epstein RM, Hundert EM (2002) Defining and assessing professional competence. JAMA 287:226–235

Ericsson KA (2004) Deliberate practice and the acquisition and maintenance of expert performance in medicine and related domains. Acad Med 79:S70–S81

Ericsson KA, Krampe RT, Tesch-Roemer C (1993) The role of deliberate practice in the acquisition of expert performance. Psychol Rev 100:363–406

Feasby TE, Quan H, Ghali WA (2002) Hospital and surgeon determinants of carotid endarterectomy outcomes. Arch Neurol 59:1877–1881

Freund D, Lave J, Clancy C, Hawker G, Hasselblad V, Keller R, Shneiter E, Wright J (1999) Patient outcomes research teams: contribution to outcomes and effectiveness research. Annu Rev Public Health 20:337–359

FSBI (Fisheries Society of the British Isles) (2002) Fish welfare. Briefing Paper 2. Fisheries Society of the British Isles, Granta Information Systems, Sawston

Hammond JW, Queale WS, Kim TK, McFarland EG (2003) Surgeon experience and clinical and economic outcomes for shoulder arthroplasty. J Bone Joint Surg Am 12: 2318–2324

Harms CA, Lewbart GA (2000) Surgery in fish. In: Bennett RA (ed) Veterinary clinics of North America: exotic animal practice. W. B. Saunders, New York, pp 759–774

Jepsen N, Koed A, Thorstad EB, Baras E (2002) Surgical implantation of telemetry transmitters in fish: how much have we learned? Hydrobiologia 483:239–248

Keefer ML, Peery CA, Bjornn TC, Jepson MA, Stuehrenberg LC (2004) Hydrosystem, dam, and reservoir passage rates of adult Chinook salmon and steelhead in the Columbia and Snake Rivers. Trans Am Fish Soc 133:1413–1439

Kneebone R (2003) Simulation in surgical training: educational issues and practical implications. Med Educ 37:267–277

Mulcahy DM (2003a) Does the Animal Welfare Act apply to free-ranging animals? ILAR J 44:252–258

Mulcahy DM (2003b) Surgical implantation of transmitters into fish. ILAR J 44:295–306

Naughton GP, Caudill CC, Peery CA, Clabough TS, Jepson MA, Bjorn TC, Stuehrenberg LC (2007) Experimental evaluation of fishway modifications on the passage behaviour of adult Chinook salmon and steelhead at Lower Granite Dam, Snake River, USA. River Res Appl 23:99–111

Pearce WH, Parker MA, Feinglass J, Ujiki M, Manheim LM (1999) The importance of surgeon volume and training in outcomes for vascular surgical procedures. J Vasc Surg 29:768–778

Schreck CB, Stahl TP, Davis LE, Roby DD, Clemens BJ (2006) Mortality estimates of juvenile spring-summer Chinook salmon in the Lower Columbia River and estuary. Trans Am Fish Soc 135:457–475

Seki S (1987) Accuracy of suture techniques of surgeons with different surgical experience. Surg Today 17:465–469

Silva RM, Matera JM, Ribeiro AA (2007) New alternative methods to teach surgical techniques for veterinary medicine students despite the absence of living animals. Is that an academic paradox? Anat Histol Embryol 36:220–224

Smeak DD (1999) Accent on an alternative: skin and suture pattern simulator. Altern Vet Med Educ Newslett 10:2–3

Sosa JA, Bowman HM, Tielsch JM, Powe NR, Gordon TA, Udelsman R (1998) The importance of surgeon experience for clinical and economic outcomes from thyroidectomy. Ann Surg 228:320–330

Starkes JL, Payk I, Hodges NJ (1998) Developing a standardized test for the assessment of suturing skill in novice microsurgeons. Microsurgery 18:19–22

Stoskopf MK (1993a) Clinical examination and procedures. In: Stoskopf MK (ed) Fish medicine. W. B. Saunders Inc., New York, pp 62–78

Stoskopf MK (1993b) Surgery. In: Stoskopf MK (ed) Fish medicine. W. B. Saunders Inc., New York, pp 91–97

Stoskopf MK (2003) All of the world is a laboratory. ILAR J 44:249–251

Summerfelt RC, Smith L (1990) Anesthesia, surgery, and related techniques. In: Schreck CB, Moyle PB (eds) Methods for fish biology. American Fisheries Society, Bethesda, pp 213–272

Szalay D, MacRae H, Regehr G, Reznik R (2000) Using operative outcome to assess technical skill. Am J Surg 180:234–237

Tinga CE, Adams CL, Bonnett BN, Ribble CS (2001) Survey of veterinary technical and professional skills in students and recent graduates of a veterinary college. J Am Vet Med Assoc 219:924–931

Torkington J, Smith SG, Rees BI, Darzi A (2000) The role of simulation in surgical training. Ann R Coll Surg Engl 82:88–94

Uson J, Calles MC (2002) Design of a new suture practice card for microsurgical training. Microsurgery 22:324–328

Wagner GN, Cooke SJ (2005) Methodological approaches and opinions of researchers involved in he surgical implantation of telemetry transmitters in fish. J Aquat Anim Health 17:160–169

Walsh DA, Osburn BI, Christopher MM (2001) Defining the attributes expected of graduating veterinary medical students. J Am Vet Med Assoc 219:1358–1365

Walsh DA, Osburn BI, Schumacher RL (2002) Defining the attributes expected of graduating veterinary medical students, part 2: external evaluation and outcomes assessment. J Vet Med Educ 29:36–42

Welch DW, Batten SD, Ward BR (2007) Growth, survival, tag retention of steelhead trout (*O. mykiss*) surgically implanted with dummy acoustic tags. Hydrobiologia 582: 289–299

Zemljic B (2004) Standards of veterinary education for the future: Preparing the profession for the new century. J Vet Med Educ 31:13–14