SPECIAL REPORT

Guidelines for animal surgery in research and teaching

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EXECUTIVE SUMMARY

The direct or delegated authority for activities involving animals used in research and teaching programs lies with the attending veterinarian. These duties and responsibilities cannot be abrogated by others in the organization. The veterinarian is the single individual with the broadest range of knowledge of animals used in biomedical research, testing, and teaching. Federal regulations and policy require that the Institutional Animal Care and Use Committee (IACUC) ensure that the use of animals will be ethically justifiable and humane and that all individuals who perform surgery on animals will be appropriately qualified and trained. The attending veterinarian also has specific responsibilities under law and must take an active role in providing this assurance. In recognition of this, the Council on Research of the AVMA created a Panel on Animal Surgery in Research and Teaching[a] to develop a report on guidelines for performing animal surgery in a research or teaching setting. Drafts of the panel report were sent through an extensive review process that included representative groups in veterinary medicine, human health, government, biomedical research, and animal welfare.

The report of the panel was referred to the American Society of Laboratory Animal Practitioners (ASLAP). As an organization, the major focus of which is the role of the veterinarian in research using animals, it is appropriate that the ASLAP further refine this report into a set of guidelines for the research community. The ASLAP committee[b] wishes to acknowledge the AVMA for recognizing the need for these guidelines and providing the financial support to convene the initial panel.

This document was compiled with expectations for change in future revisions. Intended to complement other pertinent guidelines and regulations on animal surgery, these guidelines are designed to help individuals charged with the stewardship of animals used in research and teaching.

PREFACE

These guidelines focus on the major components associated with the conduct of surgery in research and teaching settings. The purpose is to offer guidance, not regulations. These guidelines are not intended to supersede federal laws and regulations on animal care or state veterinary practice acts that regulate surgery performed by licensed veterinarians on animals owned by clients. They are not intended to be encyclopedic; an appropriate but limited bibliography is provided. The contents are intended to serve as general guidelines for the conduct of surgery on mammals, but the basic principles contained in these guidelines should be generally applicable to all vertebrate species used in research, teaching, and testing. Where special considerations are appropriate (eg, with respect to certain aspects of surgery performed on rodents or agricultural animals), they are mentioned.

While meeting the research or teaching objectives, animal surgery should be ethical and humane. It should be performed, using sound professional and scientific knowledge and judgment.

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This document is based on the premise that the process of development and approval of a research or teaching proposal has examined the rationale for the use of the animal, the appropriateness of its use as a model, the number of animals to be used, and related matters of animal use. Although the aim of the guidelines is responsible surgical care for animals used in teaching and research, factors such as practicality, cost, and effects of the procedure on scientific or instructional objectives are worthwhile considerations.

The following points are important to readers:

The report presents a set of guidelines. On the basis of knowledge, experience, and circumstances, interpretations of the guidelines can differ and should not be automatically considered deviations from sound surgical practice. Professional judgment is essential in any application of these guidelines. Different interpretations of the guidelines need to be addressed by the IACUC. Responsible care and use of the animal is always the primary objective.

These guidelines and the state of knowledge of surgery on animals in research and teaching laboratories continue to evolve. Changes should be expected and encouraged through support of research on surgical procedures. Research will hasten this evolution to the benefit of animals and humankind alike.

The attending veterinarian should serve as a source of information and can provide valuable assistance in locating agencies and organizations that can provide guidance on matters related to surgery on animals used in teaching and research.

INTRODUCTION

The requirements for successful survival surgery, whether it is performed on human beings or animals, are similar. In addition to adequate surgical skills, knowledge of procedures to ensure aseptic results is crucial. Familiarity with the anatomy, physiology, pharmacology, anesthesia, and basic care of the species undergoing surgery also is necessary.

Programs for teaching or research involving surgery on animals should focus on all elements of the perioperative care of the animal, not just on the technique itself. Without a program of pre- and postoperative management, the teaching or research activity is incomplete. Pre- and postoperative management programs promote the success of surgical procedures and influence animal comfort and well-being during the immediate and extended recovery period. During the surgical procedure, general anesthetics, other sedatives and analgesics, and muscle relaxants are administered as needed. A multidisciplinary approach, with pertinent veterinary medical advice, is recommended so that all operative procedures are planned appropriately and performed humanely.

Definitions

Aseptic surgery—Surgery performed in ways and by means sufficiently free from microorganisms so that appreciable infection or suppuration does not develop.

Distress—A state in which the animal is unable to adapt to an altered environment or to altered internal stimuli.[1]

Field or production surgery—Any surgery performed on farm or free-ranging wild animals residing in their natural or production habitat.

Institutional Animal Care and Use Committee (IACUC)—A committee whose existence is required by the USDA and the Department of Health and Human Services at institutions conducting research on animals. The committee consists of veterinarians, practicing scientists, nonscientists, and individuals not affiliated with the institution. The committee is responsible for evaluating the institutional animal care and use programs and making recommendations to the administration of the institution. The committee ultimately is responsible for approving or disapproving the use of animals in research at the institution on a case-by-case basis.

Major surgery—Any surgical intervention that penetrates and exposes a body cavity; any procedure that has the potential for inducing permanent physical or physiologic impairment; and/or any procedure associated with orthopedics or extensive tissue dissection or transection.

Minor surgery—Any surgical intervention that neither penetrates and exposes a body cavity nor induces permanent impairment of physical or physiologic function. Examples are laparoscopy, superficial vascular cutdown, and percutaneous biopsy.

Nonsurvival/nonrecovery surgery—A surgical procedure performed under general anesthesia at the conclusion of which the animal is euthanatized without regaining consciousness.

Pain—Perception of an unpleasant sensory or emotional experience that results from potential or actual tissue damage.[2]

Perioperative—All events associated with a surgical procedure.

Stress—The effect induced by external (eg, physical or environmental) events or internal (eg, physiologic or psychological) factors, referred to as stressors, that induce alteration in an animal's biologic equilibrium.[3]

Surgery—The act of incising living tissue; an operative procedure; and/or the room or facility where an operative procedure is done.

Surgical facility—a group of interrelated rooms specifically designed for the conduct of surgery as well as pre- and postoperative functions associated with the conduct of surgery in animals.

Survival/recovery surgery—A surgical procedure from which the animal recovers from the effects of general anesthesia and becomes conscious.

Regulations

Two principal federal government agencies regulate the use of animals in research and teaching programs: The USDA and the Department of Health and Human Services (DHHS). Other federal, state, and

local agencies also might have some regulatory powers.

The USDA—The USDA's Animal and Plant Health Inspection Service (APHIS), through its Regulatory Enforcement and Animal Care (REAC) unit, is responsible for administration of the Animal Welfare Act (AWA[4]; PL 89-544; amended in 1970, PL 91-579; amended in 1976, PL 94-279; amended in 1985, PL 99-198). The Act establishes minimal standards for the care and use of animals in research, teaching, testing, and experimentation. The regulations include requirements for pre- and postoperative care and minimizing or eliminating signs of pain or distress in animals covered by the AWA. Investigators must consider alternatives to painful procedures and ensure that the work is not unnecessarily duplicative. The Act covers all warmblooded animals used for these purposes, with the exception of farm animals used for agricultural purposes or agricultural (animal science) research. The regulations that promulgate the Act currently exempt rats of the genus *Rattus,* mice of the genus *Mus*, and birds.

The DHHS—The DHHS, through the Office for Protection from Research Risks of the National Institutes of Health (NIH), has the authority to establish guidelines for regulating the care and use of vertebrate animals at institutions that receive United States Public Health Service (USPHS) funds in support of research, teaching, or testing. The Health Research Extension Act of 1985 (PL 99-158) mandated that "appropriate pre-surgical and post-surgical veterinary medical and nursing care for animals in research" be covered in the guidelines. The guidelines, referenced in PHS Policy on Humane Care and Use of Laboratory Animals are published as the *Guide for the Care and Use of Laboratory Animals*[5] (also known as the *Guide*), developed by the National Research Council, National Academy of Sciences. The PHS policy requires that institutions use the *Guide* in developing and implementing their animal care and use programs. It should be noted that, in contrast with current USDA regulations, the PHS policy covers all vertebrate animals at institutions with PHS-funded projects.

Because they are ultimately responsible to ensure that the research facility is in compliance, the institutional official, the attending veterinarian, and the IACUC need to have a working knowledge of these regulations and guidelines. A brief summary of these regulations, as they pertain to surgical research and teaching, follows.

Protocol—The first, and often the most important step in establishing a research, teaching, or testing program is to develop a protocol. A protocol for an operative procedure must be developed by the principal investigator (PI) and approved by the IACUC. Federal regulations require procedures that may cause more than momentary or slight pain or distress to involve, in their planning, consultation with the attending veterinarian.[4] To ensure that adequate veterinary care is provided, the PI must consult with the attending veterinarian during the planning of any procedure that could cause the animal pain or distress. The protocol must then be reviewed by the IACUC, whose approval is necessary before the project can begin. The protocol must state the rationale for the animal-use study and describe the operative procedures. The animal study proposal must include a justification of the species and the approximate number of animals to be used. The institution must ensure that professionally acceptable standards governing the care, treatment, and use of animals will be followed, including appropriate aseptic technique and appropriate use of anesthetic, analgesic, and tranquilizing drugs. If drugs cannot be administered during pain-causing procedures, the protocol must include a scientific justification, which must be approved by the IACUC before the study can begin. Use of paralytic drugs without animals being under general anesthesia for procedures that may cause more than momentary or slight pain or distress is prohibited under the AWA.

Personnel—Under the AWA, the institution has the ultimate responsibility to ensure that the attending veterinarian has the authority to ensure provision of adequate veterinary care. If the veterinarian is a part-time employee, there must be a written program of veterinary care that provides for regularly scheduled visits available to the USDA for inspection. The veterinarian must have reasonable access to the animals and ensure that daily observations of the animals are performed by qualified individuals.

Major survival surgery—Major survival surgery, with the exception of procedures performed on rodents or farm animals used in agricultural research, should be performed in facilities specifically designed, operated, and maintained for that purpose. These facilities should be maintained and operated to ensure cleanliness. For rodent and food animal surgery, as well as minor procedures, separate dedicated facilities might not be required; however, facilities should be clean, and aseptic technique should be used. Professional judgment should be exercised when making such determinations.

Use of an animal in multiple major survival surgeries must comply with existing regulations. If such procedures are to be done as related components of a protocol for scientific reasons, they must be justified in the protocol and approved by the IACUC. Cost savings is not an acceptable justification for multiple major survival surgeries.

Determination that a procedure constitutes major surgery is usually made before the surgery. However, existence of permanent effects may not be recognized until after the procedure is performed. If it is determined by the IACUC, the attending veterinarian, or the PI that the procedure is major surgery, the animal(s) cannot be used for another recovery procedure unless it is required as part of the same research protocol as approved by the IACUC. Special circumstances are considered by the Administrator of APHIS on an individual basis. A second major procedure is not considered to be multiple major sur-

gery if it is nonsurvival. However, an animal should not be allowed to recover from a major surgical procedure for the sole purpose of being used in another unrelated nonsurvival procedure.

Minor survival surgery—For minor survival surgery procedures, there is no prohibition against multiple procedures. However, the animal needs to recover physically and physiologically from the effects of any prior surgical procedure before any subsequent procedure is performed. Good professional judgment should be used to limit the number of minor surgical procedures performed on a single animal.

SURGICAL PERSONNEL

It is the responsibility of the research or teaching institution to ensure that all personnel, regardless of academic degrees, are qualified and trained to conduct surgical procedures. Personnel who perform surgery, as well as staff members who manage the operating rooms, must be qualified and trained for the assigned procedures or functions. The institution, acting through the attending veterinarian, is also responsible for conduct or supervision of all presurgical and postsurgical care in accordance with established medical standards and for provision of adequate veterinary care. The institution must provide appropriate facilities, personnel, equipment, and services for the surgical procedures performed.

Regardless of the complexity of the procedure, a multidisciplinary approach is most likely to produce the best results. A multidisciplinary approach could include the following categories of personnel, modified from recommendations by the Academy of Surgical Research[6]:

Scientist—A person with a degree in any of a number of disciplines who plans and conducts the study. The scientist may or may not participate in the performance of the the surgical procedures.

Laboratory animal veterinarian—Provides veterinary oversight at the institution and ensures adequate veterinary care for the animals.

Perioperative care technician—Prepares the animal and monitors it throughout the surgery and recovery.

Anesthetist—Person administering anesthetic agents during the procedure and monitoring the animal to ensure adequate analgesia and physiologic homeostasis.

Surgeon—Person performing the operation.

Each component of the team may involve one or more persons and, in some instances, one person may perform more than one task (eg, the laboratory animal veterinarian may also be the surgeon). Use of trained technicians from AVMA-accredited programs is encouraged.

State governments have established licensing requirements to ensure that veterinarians who perform surgery on client-owned animals are competent to do so. The necessary qualifications and training programs for individuals involved in the use of animals in research and teaching are addressed in regulations issued by USDA and USPHS and might not require licensure.

The AWA places the responsibility on the research institution to ensure that all scientists, research technicians, animal technicians, and other personnel involved in animal care, treatment, and use are qualified to perform their duties. This responsibility can be fulfilled, in part, through provision of training for these individuals. Training and instruction should be made available, and the qualifications of personnel should be reviewed, with sufficient frequency to fulfill the research institution's responsibilities under the AWA.

The AWA requires that training include the following:

Humane methods of animal maintenance and experimentation, including basic needs of each species of animal; proper handling and care; proper pre- and postsurgical care; and aseptic surgical methods and procedures.

The concept, availability, and use of research or testing methods that limit the use of animals of minimize animal distress (reduction, refinement, and replacement).

Proper use of anesthetics, analgesics, and tranquilizers.

Methods of reporting deficiencies in animal care.

Use of information services to provide information on animal care and use, alternatives, intent of the AWA, and information that could prevent unnecessary duplication of research involving animals.

Ultimately, responsibility for ensuring competence of individuals involved in surgical research and teaching is that of the institution. To assist attending veterinarians and animal care and use committees at research institutions, The Academy of Surgical Research has developed and published "Guidelines for Training in Surgical Research in Animals."[6] These guidelines can be helpful for development of institutional surgical teaching and research programs. A brief review of considerations for institutional training programs follows.

Personnel Requiring Training

Veterinarians—Veterinarians have received training and have experience in surgical procedures, methods of anesthesia, and postoperative care techniques in animals. However, few have received such training in experimental surgical techniques or in laboratory animal species. Veterinarians who have received training or certification in laboratory animal medicine, surgery, or anesthesiology are most likely to have appropriate experience.

Veterinarians should be included in a team approach to minimize complications. Their contributions can include consultation in anatomic, anesthetic, surgical, and postoperative techniques, even though

they may not be competent in the actual performance of the specific experimental procedures. Veterinarians who are requested to perform complex surgical procedures (eg, organ transplantation, cardiopulmonary bypass) on laboratory animals for which they do not have training or experience should seek training before performing the particular procedure.

Physicians—Not all physicians have been trained in surgery on animals, because of the differences in curriculum requirements between medical schools. Physicians have at least received didactic surgical training and have observed surgery on human beings. Physicians trained in surgical specialties should be considered to be competent in their particular field of expertise. However, such person may not be knowledgeable in interspecies variations in anatomy, anesthesia, analgesia, and postoperative care methods. For survival surgical procedures, a team approach is recommended. This should include consultation and oversight of operative technique, anesthetic and analgesic selection, and postoperative care supervised by a veterinarian. If support services are provided by competent personnel, the need for a formal training program could be waived.

The experience and background of physicians should be taken into account when evaluating their ability to perform a particular surgical protocol on laboratory animals. If they participate in a multidisciplinary team approach with persons who are qualified by experience or training to work with animals, this should be taken into consideration to negate any lack of experience they may have with a particular species or procedure. Similarly, if physicians have previously performed the experimental surgical protocol successfully, including management of anesthesia as well as postoperative care, and have done so without any suggestion of unusual operative or postoperative complications, there should be no need for additional training.

Dentists—Dentists and oral surgeons generally do not receive training in surgical procedures on laboratory animals. However, they receive didactic and operative training in dental and oral surgical procedures on human beings. Although dentists are considered competent in their area of expertise, they might require training in anatomy, anesthesia, analgesia, and postoperative care for animals being used for experimental surgical procedures. This training requirement could be waived if they select a multidisciplinary approach to performance of surgical procedures on animal species with which they are unfamiliar. Similarly, if dentists have previously performed the experimental surgical protocol successfully, including management of anesthesia as well as postoperative care, and have done so without any suggestion of unusual operative or postoperative complications, there should be no need for additional training.

PhDs—Few persons with graduate degrees from even biomedical research programs have received formal training in experimental surgery on laboratory animals. However, all scientists who have had appropriate training or who have become competent in particular surgical procedures through previous experience and have a documented history of minimal operative and postoperative complications should be recognized as competent to perform those procedures without further training. Graduate students performing surgery in animals in the course of their research should be subject to the same requirements as persons with a PhD degree.

It is recommended that doctoral degree scientists be required to have formal training in proper surgical techniques, including successfully performing the designated procedure, before undertaking experimental surgical protocols. The need for formal training might be waived by taking a multidisciplinary collaborative approach with persons who are qualified by experience and training to perform the particular experimental surgical protocol on laboratory animals.

Technical staff—Nondoctoral degree personnel may perform experimental surgical protocols on laboratory animals only under the direction of investigators qualified to perform animal surgery. Personnel in this category can have a wide variety of backgrounds, including certification as a technician in various fields. Regardless of the background, they should not be considered qualified in the area of experimental surgery without documentation of previous training and experience. Technical staff can be valuable participants of a team approach to experimental surgical protocols in the areas of aseptic preparation, anesthesia, surgical assistance, and postoperative care. Personnel in this category should be allowed to perform survival surgery on animals only after successfully completing a formal training program, including successfully performing the designated procedure, or by having documented experience performing a particular procedure with minimal operative and postoperative complications. In either instance, it is advisable for the veterinarian, on behalf of the IACUC, to observe and evaluate the actual performance of a procedure to verify competency.

Training Programs

Institutions involved in surgery on animals must provide the necessary expertise and support for training of personnel. Several levels of training programs should be created to suit the diverse group of individuals involved in research and teaching. In addition, training should include didactic instruction, as well as laboratory instruction. On-the-job training in the form of observation and occasional assistance with others experienced in the surgical manipulations should not be substituted for a more-formal presentation and appropriate hands-on experience.

Institutional experimental animal surgical training programs should be comprehensive and include subjects such as humane methods of animal experimentation, interspecies variations in anatomy, analgesia and postoperative care, aseptic technique, as well as a variety of other subjects that might be ap-

propriate.[6] It is important that all such training programs focus on the need to provide the necessary didactic and, where appropriate, hands-on training, to enable surgery on animals to be successfully conducted with a minimum of complications, while ensuring the highest standards of comfort and well-being that can be provided within the context of the surgical protocol.

Laboratory instruction is a vital part of surgical education. It should be provided by qualified veterinarians and/or other competent instructors. One method of developing basic surgical techniques is through the use of nonrecovery animals, cadavers, and non-animal alternatives. However, training is not complete until the trainee successfully performs the designated procedure.

Evaluation of Surgical Competence

The institution is responsible to ensure that all personnel are well-trained and competent to perform animal surgery. In practice, this responsibility is often given to the IACUC and may subsequently be delegated to the institutional veterinarian. The attending veterinarian must have the authority to take the corrective measures necessary to discharge these responsibilities.

FACILITIES

The type and extent of facilities needed depend on the animal species and complexity of the surgery. For example, a more-extensive facility is needed for performing orthopedic surgery than for just suturing skin wounds. It is generally agreed that rodent surgery does not require the extensive facilities needed for larger animals. In addition, appropriate facilities for field surgery may not meet the guidelines of this section. The *Guide for the Care and Use of Laboratory Animals*[5] states:

> Aseptic technique must be used on most animals, including lagomorphs, that undergo major survival surgery. This technique includes wearing of sterile surgical gloves, gowns, caps, and face masks; use of sterile instruments; and aseptic preparation of the surgical patient. Major survival surgery is defined as any surgical intervention that penetrates a body cavity or has the potential for producing a permanent handicap in an animal that is expected to recover. Survival surgery on rodents does not require a special facility, but should be performed using sterile instruments, surgical gloves, and aseptic procedures to prevent clinical infections.

Most surgical facilities will be used for a wide range of surgical procedures with various animal species and need to be designed with this in mind. If inhalation anesthetic agents are to be used, a mechanism for scavenging waste gases must be provided.

All surgical rooms should use appropriate air-filtering systems, and operating rooms should have positive pressure in relation to other areas of the facility. By decreasing airborne contamination, the risk of intraoperative contamination and postsurgical infection is reduced. The surgical suite should be outside the main traffic pattern of the teaching or research facility. The *Guide*[5] states:

> Functional areas for aseptic surgery should include a separate support area, a preparation area, the operating room or rooms, and an area for intensive care and supportive treatment of animals. The interior surfaces of this facility should be constructed of materials that are impervious to moisture and easily cleaned. The surgical support area should be designed for storing instruments and supplies and for washing and sterilizing instruments. Items that are used on a regular basis, such as anesthetic machines and suture materials, can be stored in the operating room.

To reduce contamination of the surgical environment, animals are initially prepared for surgery in an area separate from the operating room. Final preparation can be made when the animal has been anesthetized and properly positioned for surgery. Anesthesia should be induced in the most appropriate location for the animal and the surgical procedure.

According to the *Guide*,[5] a preparation area should exist for surgical personnel. The area should be equipped with surgical sinks and be close to, but apart from, the operating room. A dressing area needs to be provided for personnel to change into surgical attire.

The surgery facility's walls, ceiling, and floor should be constructed of materials that are impervious to moisture and easily cleaned. Facilities used principally for food animals and horses should be adequately designed to avoid standing water. A nonskid floor in such facilities is desirable for safety of personnel and animals. Floor drains in surgical facilities are generally discouraged because they can serve as a source of bacterial contamination and noxious gases. In certain situations involving large domestic farm animals, floor drains might be required; however, a rigorous sanitation program, including frequent flushing is essential.

The surgical facility also needs to have adequate light for conducting surgery and for adequate cleaning. In addition to general room lighting, the operating room usually requires supplemental surgical lighting to ensure sufficient illumination of the surgical field. There are many ways of providing supplemental surgical lighting, including fixed, track, and portable lights. Surgical lights of one of these types, equipped with removable, sterilizable handles that can be used by the surgeon to adjust the light, are commonly chosen.

Ground fault circuitry is generally advisable in areas where water is likely to be used, including the material preparation area, animal preparation area, and the surgical scrub area. All wall-mounted electrical outlets should have moisture-resistant covers to prevent dust buildup and to guard against shock hazard during cleaning.

Provision for scavenging of anesthetic gases is necessary to address health and safety concerns re-

garding short-term acute, as well as long-term chronic exposure to these agents. Anesthetic gas-scavenging is best accomplished, using a separate exhaust system that directly vents to the outside, although portable gas-scavenging canisters are commercially available.

Use of flammable and explosive agents in most surgical programs has been eliminated because of safety concerns and availability of nonflammable, nonexplosive alternatives. In the absence of explosive anesthetics, most modern operating rooms do not require specialized conductive flooring, which greatly increases construction costs and requires specialized receptacles, as well as grounding of all personnel and equipment.

Surgical equipment located or used in the surgical facility should be designed for removal and/or easy cleaning and disinfection. Equipment should be kept physically clean, and only equipment that is used regularly should be kept in the surgical facility. The operating room and support areas should be cleaned at frequent intervals to keep potential microbiological contaminants at a minimum.

The recovery area should be located so that the animal can be monitored regularly by trained personnel. The recovery area needs to have emergency supplies readily accessible. Confinement during recovery should be appropriate for the species and the surgical procedure. The animal's cage or stall is acceptable if clean, segregated from other animals, adequate in size, and maintained at an appropriate temperature to prevent overheating or hypothermia during recovery.

Situations occasionally arise in which all the attributes of a standard experimental animal surgical facility might be unnecessary by virtue of it not improving the well-being of the animal or improving success of the outcome, as measured by lack of postoperative complications, improved surgical survival, or minimized pain and stress. Moreover, in some instances where surgery is done on free-living wild animals for experimental purposes, bringing such animals into a more-controlled surgical environment might not only be unwarranted, but could prove detrimental to the survival and well-being of the animals. In all instances, professional judgment must be exercised to optimize the circumstances under which surgery is conducted and to fit the environment in which the surgery is being performed, including the techniques used. Any decision to perform surgery outside of the usual surgical facilities must be authorized by the IACUC. It is not uncommon, however, not to require separate dedicated facilities for rodent surgery and for minor surgical procedures (such as castration of immature animals and wound suturing). Similarly, field surgery on agricultural animals in production facilities or on free-living wild animals in their natural habitats could be performed in settings used in clinical veterinary practice. However, the techniques used should ensure aseptic results.

Emergencies requiring surgery on animals used for teaching and research can occur. When possible, the animal should be moved to a surgical facility. However, the surgery might have to be performed in an area not specifically designed for that purpose, if moving the animal to a surgical facility is detrimental to the animal, such as wound dehiscence in a large animal.

PRINCIPLES OF PREOPERATIVE MANAGEMENT

The well-being of the animal and validity of the study are enhanced by proper management of the animal before the operative procedure and by implementation of preoperative strategies designed to avoid potential problems during the surgical procedure.

Animal health status—The health status of animals should be assessed prior to their inclusion on an experimental protocol and certainly before undergoing a surgical procedure. Unlike animals in a clinical practice that might require surgery immediately to correct a life-threatening illness, surgery conducted on animals used in teaching or research can usually be scheduled to allow time to conduct the necessary clinical and laboratory examinations to ensure that the animals are not affected by conditions or organisms that could affect the outcome of the surgical procedure or cause long-lasting harm to their well-being.

Health assessments are usually conducted during a quarantine period when the animals are kept separate from conditioned animals of known health status. Even animals that are purposefully bred for laboratory use under defined conditions also might require quarantine, isolation, health assessment, and a period of adaptation. Every effort should be made to obtain complete and reliable health information from animal suppliers, especially in the case of rodents in which extensive health testing by serologic or other means conducted by the supplier on colony members can be valuable as an adjunct in assessing the general health of individual animals.

In some instances, medical and vaccination histories of individual animals also can be helpful in evaluating their health status. When random-source animals are acquired, they should be immunized against common infectious diseases.

Conditioning—It is important that animals be provided a period of adaptation prior to undergoing surgical procedures. This period of adaptation is needed to allow the animal's physiologic and metabolic systems to stabilize to a new environment, thereby minimizing risk of complications. Furthermore, this stabilization period will increase the likelihood that the results obtained from the experimental protocol will not be compromised by uncontrolled environmental influences. Investigators should consult their attending veterinarian for appropriate methods and periods of stabilization.

Physical and laboratory examination—All animals to be used in research or teaching should receive a physical examination on arrival. For laboratory rodents or other small species, a visual examination should be performed when the animals are received.

Serologic testing is available and can be useful for detecting viral infections in rodents without clinical signs of disease. Such infections can cause clinical disease in rodents that have undergone surgery and can result in increased mortality during anesthesia.[7]

Laboratory evaluation of blood, urine, and feces can be helpful in assessing the health status of animals. The need for laboratory evaluation is determined by the animal species, research protocol, and health history of the animal or colony. Investigators might also wish to conduct such tests if long-term studies are contemplated. Diagnostic modalities, such as radiography, ultrasonography, and computed tomographic imaging might occasionally be warranted.

Animal stress—Investigators and veterinary care personnel should be familiar with the normal behavior of the animal species being used and recognize abnormal behavior in these animals.[3] Responsible animal care includes awareness of the effects of stress on the animal, as well as its potential for influencing experimental results and compromising welfare of the animal. These factors should be considered in the experimental design.

Investigators and veterinary care personnel should develop a proactive stress-reduction plan for all experimental animals under study. Of particular importance are pre- and postoperative stresses associated with survival surgery. The stress of prolonged studies, confinement, and chronic or acute pain can inflict undue distress on the animal and alter experimental results. One of the surgical team's goals is minimization or elimination of the pain and stress of surgery.

Proper handling and restraint—Because proper handling and restraint will help prevent injury and minimize stress to the animal and to personnel, it is essential that investigators, technicians, and other personnel be trained in proper restraint methods for the animal species used. Consultation with the attending veterinarian is advised when chemical restraint is needed to protect the animal or handler.

Antimicrobial prophylaxis—Indiscriminate use of antimicrobial agents should be avoided. Antimicrobial agents might be indicated prophylactically for certain surgical protocols or when known breaks in sterility occur, but should not be used as a substitute for proper aseptic techniques. Their use should be discussed with the attending veterinarian and be part of the IACUC-approved protocol.

PRINCIPLES OF ANESTHETIC MANAGEMENT

Prevention of perceived pain during surgery is the primary function of anesthesia. Anesthesia also enables humane restraint, improved safety, and increased technical efficiency. This section, by necessity, provides only a brief overview of the principles of anesthetic management of animals. Detailed information on anesthetic agents and techniques, as well as the suitability of various anesthetics for application in specific animal surgical procedures, is well beyond the scope of these guidelines. Many excellent texts and articles in peer-reviewed publications cover this subject in the detail necessary to allow successful management of anesthesia in laboratory animals.[8-13] The Institutional Laboratory Animal Veterinarian, as well as other qualified veterinary professionals, can serve as valuable resources for acquiring the necessary information.

Anesthesia can be induced by chemical and nonchemical means, or a combination of these. Nonchemical techniques, such as hypothermia, may be appropriate in certain investigative circumstances. Hypothermia reduces the requirement for anesthetic drugs. In addition, deliberate hypothermia may help to reduce the likelihood of ischemic damage to tissues during surgical studies (eg, of the heart or brain).[14-17] The following information focuses on techniques for which drug-induced anesthesia is required. Information on other drug uses is provided elsewhere.[8-13,18-22]

No anesthetic regime is suitable for all surgeries. The agent and technique chosen should be based on knowledge of the procedure(s) requiring anesthesia, biological characteristics of the species of animal selected, good understanding of the actions and properties of the anesthetics available, prior experience with the anesthetic in the species of animal being anesthetized, and available equipment and facilities. It is recognized that some animal species are anesthetized in groups rather than as individuals (eg, rodents vs larger animals), which may influence the choice of anesthetic technique. The compatibility of the anesthetic with the experimental design should be considered; however, the overriding concern should be well-being of the animal.

General anesthesia provides overall insensitivity and unconsciousness. Localized insensitivity in awake or mildly sedated animals can result from topical application or injection of appropriate anesthetics in the region of the surgical incision (local anesthesia), injection in proximity to nerve trunks (nerve block), or injection into the subarachnoid or epidural spaces (regional anesthesia).

Local and Regional Anesthesia

Local or regional anesthesia is useful for several reasons. The cost of drugs and equipment is low. The animal's need for special postanesthetic care is minimal. Pain relief also can be conveniently and easily extended into the immediate postoperative period. Most undesirable complications that can accompany unconsciousness and recumbency are avoided by use of local or regional anesthesia. They include regurgitation and aspiration of gastric contents, inefficiency of respiratory gas exchange, traumatic complications associated with recovery from general anesthesia, and especially in larger species, myopathy.

However, local or regional anesthetic techniques have several disadvantages. Because consciousness is not lost, some degree of animal cooperation is necessary. The surgical technique and

requirement for extended anesthetic duration can preclude use of local or regional anesthetic techniques. Tissue damage (with or without infection) beyond normal surgical trauma has been associated with some techniques in which a large volume of anesthetic agent (ie, field blocks) is injected in a localized area. Finally, rapid absorption or inadvertent intravascular injection of large quantities of anesthetic agents can cause life-threatening reactions.

General Anesthesia

General anesthesia is a state induced by one or a combination of agents to provide controlled, reversible depression of CNS function, including unconsciousness. Basic elements of general anesthesia as applied to human patients include unconsciousness or sleep, amnesia, analgesia, muscle relaxation, diminished motor response to noxious stimuli, and reversibility. These same elements also are considered desirable for anesthetic management of animals. Maintaining vital life-support functions (eg, cardiovascular, respiratory, and renal function) throughout the course of general anesthesia is obviously important.

Techniques of general anesthesia are categorized as progressive CNS depression caused by a single drug or injection of a drug combination, and balanced depression (so-called balanced anesthesia), which includes multiple drugs usually given in low dosage, with each drug selected and given for a specific purpose. Balanced depression is intended to reduce undesirable depression of homeostatic mechanisms induced by large doses of a single drug. However, this technique often is complex and requires experienced personnel. A specific anesthetic plan is developed after pharmacologic requirements are considered, major drug classes are reviewed, and specific drugs are selected from the class(es) that best fulfill the surgical and patient needs.

Anesthetics for general anesthesia are administered by a variety of routes. Although IV or inhalation administration may be preferred because the dose-effect relation and the time course of effect are more predictable, other routes may be acceptable and used when appropriate in the wide spectrum of circumstances in animal anesthesia. They include IM, SC, oral, per rectum, and intraperitoneal routes. The following is a brief review of characteristics of the drug classes of importance in veterinary general anesthesia. More directed and species-specific information is given elsewhere.[8-13,18-20]

Inhalation anesthetics—Inhalation anesthetics are gaseous or volatile agents administered, usually by use of specialized equipment, via the respiratory tract. Inhalation anesthetics usually simplify control of anesthetic depth. Controlling the concentration of the animal's respiratory gas tensions in blood typically is easier when inhalation anesthetics are used. Disadvantages include need for specialized delivery equipment and potential toxicosis to human beings chronically exposed to anesthetic vapors.

Tracheal intubation facilitates effective and safe delivery of many inhalation anesthetics. Knowledge of specific species-related anatomy and practice is important to prevent undue trauma to individual animals when using tracheal intubation.

Injectable anesthetics—Animals, especially those used in research and teaching, are frequently anesthetized by injection of drugs. Such drugs can serve as the sole anesthetic agent or can be used to induce anesthesia before inhalation anesthesia and as a supplement to inhalation (eg, balanced anesthesia) or regional anesthesia. To minimize the chance of drug overdose and to reduce local drug-related tissue damage, drugs used for anesthesia of the smaller laboratory animals may have to be diluted.

Hypnotic/sedative drugs likely are the most widely used injectable drugs for inducing or managing general anesthesia in animals. They induce a dose-dependent spectrum of CNS depression, from sleep to deep general anesthesia, and in higher doses cause medullary paralysis, respiratory arrest, and death.

Dissociative drugs are the second most popular class of injectable drugs for inducing a state that enables restraint and surgery. They induce analgesia, have short duration of action and wide safety margin, and cause minimal cardiopulmonary depression. They usually are used with supplemental drugs (eg, hypnotics, tranquilizers, or α_2-adrenergic receptor (agonists) to decrease frequency and severity of undesirable actions (eg, muscle hypertonus and emergence delirium).

Tranquilizers, also known as ataractics and neuroleptics, have no prominent analgesic action themselves, but frequently potentiate the pain relief afforded by other drugs (eg, opioids). When administered to human beings, they relieve tension and anxiety and induce sleep. In animals, they decrease curiosity, aggression, and mobility, but often do not cause sleep.

Opioids are drugs that bind reversibly to multiple types of opiate receptors to cause profound analgesia. Although increasingly used in large doses as part of a balanced approach to general anesthesia, opioids are not anesthetics, per se, and do not predictably cause unconsciousness. In general, they depress respiration and have benign effects on circulation. Their actions are reversible by administration of naloxone. In some species (eg, dogs), opioids can induce a calming effect and sleep. In others (eg, mice, cats, pigs, and ponies), comparable doses of opioids can cause restlessness or excitement. In at least some species, opioids have been used successfully to induce regional analgesia via, for example, epidural administration.

α_2-Adrenergic receptor agonists are drugs with tranquilizing, sedative, and potent analgesic properties.

Muscle relaxants are classified as being predominantly central- or peripheral-acting. The peripheral-acting drugs in particular are devoid of sedative and analgesic properties. These drugs, when used during surgery, must be administered only in conjunction with general anesthetics to provide muscular relaxation and to facilitate surgical manipulation.

Use of muscle relaxants requires increased

awareness on the part of the PI of the animal's inability to respond with purposeful movement to noxious stimulation. Thus, the animal must be closely monitored (eg, heart rate, arterial blood pressure) to ensure adequate general anesthesia. Clinical signs of inadequate general anesthesia include salivation, sweating, and/or rapid or focal change in such variables as heart rate, blood pressure, body temperature, and pupil size.[22-26] Ventilation must be controlled, because satisfactory spontaneous ventilation is impaired or prevented during neuromuscular blockade.

PRINCIPLES OF PERIOPERATIVE MANAGEMENT

In nonsurvival surgery, the extent of animal and instrument preparation depends on the animal species and the surgery being performed; however, at minimum, the hair over the surgical site should be clipped, the surgeon should wear gloves, and the instruments and surrounding area should be cleaned.

Instrument sterilization—The USDA regulations[4] and the *Guide*[5] require that all instruments used in survival surgery be sterilized. In general, packs of instruments or other materials that have been sterilized and are to be stored for long periods should be double-wrapped. Materials used for wrapping packs of instruments or supplies should be impermeable to water or should indicate water strike-through (ie, colored water stain develops on exposure to water). Regardless of how materials are wrapped and sterilized, they must be inspected for damage prior to use. Wrapped and sterilized materials do not remain sterile indefinitely. The duration that materials remain sterile depends on factors such as type of wrapping material, conditions of storage, and type of materials being stored.[27] Limits for storage of sterilized materials should be determined on an institutional basis. Sterilization indicators should be used to verify that materials have undergone a sterilization process; however, sterilization equipment should be regularly validated because these indicators do not ensure that sterility has been achieved. All wrapped materials should have the date of sterilization clearly marked on the outer wrapper.

Sterilization kills or renders inactive all microbial organisms. The five categories of sterilization methods are heat (dry or steam), gas (usually ethylene oxide gas), radiation, chemical, and physical (filter sterilization of liquids). Chemicals used for sterilization can yield unsatisfactory results if the manufacturer's recommendations for use, including dilution recommendations and contact times, are not followed carefully. If chemical residues are not removed from the material being sterilized, they can lead to chemical burns or even can be toxic to the patient. Gas sterilization or γ-radiation may be used for sterilization of materials that are thermolabile. Instrument and material sterilization can be performed at some distance from the surgical facility if the products are transported to the surgical facility in a manner that will ensure that sterility has not been broken.

All materials and devices used in survival surgery, such as catheters, flow probes, and electrodes should be sterilized appropriately regardless of the species of animals in which they will be used. All fluids used for flushing or for other parenteral use also should be sterile. Fluids can be sterilized by membrane filtration. Special care is needed to ensure that multiple-use solutions for parenteral medications are maintained in a sterile state and are free of pathogens.

Animal preparation—Because ways to prepare a surgery site are many, the attending veterinarian should be consulted regarding appropriate techniques to use for the species and circumstances. Bathing some animals before preparation of the surgical site might be necessary to remove excess dirt and hair and might be done the day before the scheduled surgery. On the day of surgery, hair over the surgical site should be clipped and the skin should be washed in a preparation area physically separate from the location where the surgery will be performed. Depending on the circumstances and the species, the animal's rectum and bladder can be evacuated to avoid contamination of the surgical field. It might be preferable to prepare the animal for surgery before anesthesia, because prolonged anesthesia time may add to peri- and postoperative complications; however, often an animal's temperament will not allow this and will require that it be anesthetized before hair clipping and skin washing.

Hair removal from the operative site should be done carefully to avoid causing small skin abrasions that could become infected. The loose hair can be removed by use of a vacuum cleaning system or other suitable means. In most instances, hair is removed over a liberal area to anticipate any surgical emergency and minimize wound contamination from adjacent areas. Because small animals can experience excess heat loss from wide hair-free areas, only hair over the surgical site is clipped.

After clipping of the hair, the surgical site is washed with a solution containing antiseptic surgical soap to remove remaining hair and dirt. Once this initial cleaning has been accomplished, the animal should be anesthetized, if not done previously, and positioned for surgery.

When animals are placed directly on metal surgery tables, body heat is lost. Depending on the anticipated duration of surgery, as well as size and species of animal, warming devices or insulating materials should be placed between the table and the animal to prevent loss of body heat. Circulating warm water heating devices, warm water bottles, or heat lamps should be used rather than electrically heated pads. Electric heating pads are more likely to cause burns because the animals cannot move away from them. In all instances, caution is needed to prevent thermal injury.

After the animal is positioned for surgery, the final preparation of the surgical site is done. Although components of this final preparation might vary, it will include application of an antiseptic to the surgical site. The surgical site is usually draped to isolate the surgical field from the surrounding areas. Drapes

are positioned and often fixed with towel clamps and should not be dragged across unsterile areas onto the surgical field.

Surgeon preparation—A surgical cap, mask, and sterile gloves and gowns must be worn during major survival surgery on most animals. For rodent surgery, surgical gloves and aseptic procedures also are important. Gowns and caps are not required, but might be advisable. Anything that comes in contact with internal body tissues of any animal should be kept in suitably decontaminated condition to maintain asepsis. Scrubbing hands prior to gloving is highly recommended and should precede any major surgical procedure. Although a surgical scrub does not render the surgeon's hands sterile, it reduces the risk of contamination if the gloves are punctured.

PRINCIPLES OF OPERATIVE TECHNIQUE

Proper surgical technique is important in preventing wound infection, promoting wound healing, and ensuring likelihood of a satisfactory outcome of the surgical procedure. Maintaining tissue viability is the essence of proper surgical technique. Good surgical technique includes gentle tissue handling, effective hemostasis, maintenance of sufficient blood supply to tissues, asepsis, accurate tissue apposition, proper use of surgical instruments, appropriate use of monitoring equipment, and expeditious performance of the surgical procedure. Good surgical technique is especially important during implantation procedures.

The belief that rodents are not affected by surgical infections or that they are more resistant than are other laboratory animals has not been supported.[3] In fact, rodents often serve as animal models for studying bacterial infections. It is true, however, that surgical procedures usually performed on rodents require a small incision, usually are of short duration, and often do not require extensive tissue dissection, therefore minimizing exposure of tissues to contamination. Thus, some of the precautions and techniques that apply when conducting similar procedures on larger animals might not improve surgical results, postoperative infection rate, or well-being when they are applied to rodents. The extent to which these techniques must be applied in rodent surgery is dependent on the circumstances and should be evaluated by the IACUC. In all instances, however, appropriate precautions need to be taken to prevent surgical wound infections.[28]

Good tissue-handling techniques should be used. Tissue should not be cut or separated without reason. Tissue dissection is usually done along natural fascial planes. Major nerves and vessels are retracted carefully and preserved when possible. Because prolonged retraction can lead to ischemia, retracted tissue needs to be evaluated periodically during the procedure to be sure it is not being damaged. Exposed tissue should always be protected from drying and contamination. Appropriate handling of the tissues will also help minimize postsurgical pain.

Hemostasis preserves the circulating blood volume and allows visualization of the surgical field. Hemostasis is achieved by ligation, pressure, electrocoagulation, and avoiding damage to major vessels. Only the vessel to be occluded should be incorporated in a ligature or vascular clip. The appropriate size and type of suture material needs to be used.

In using electrocoagulation, a high-frequency current is applied to a small area of tissue (the bleeding vessel) and electric energy is converted to heat, resulting in coagulation of tissue and sealing of the vessel. To avoid excessive tissue damage, only the vessel to be occluded is in contact with the electrode. Electrocoagulation can be used for minor hemorrhage; large vessels should be occluded by ligation.

Retraction and dissection of tissue can produce pockets known as dead space. Large areas of dead space can delay healing and serve as a site for bacterial growth and fluid accumulation. As tissues are returned to their normal positions, large areas of remaining dead space need to be obliterated. This may be done by careful suture placement in the dead space to appose tissue and/or for placement of drains to prevent fluid accumulation.

As a procedure is concluded, tissues are returned to their normal anatomic positions. Accurate apposition of tissue enhances healing and promotes rapid return to normal function. Most tissues should be apposed with a minimal amount of tension. Suture material of appropriate size and type maintains the tissue in the desired position.

Depending on location and size, absorbable or nonabsorbable suture material can be used for vessel ligation; however, apposition of tissues is most commonly done, using absorbable suture material. Monofilament nonabsorbable suture usually is used to maintain apposition of vital structures or tissues that regain strength slowly. Sutures for apposition should not devitalize the tissue in which they are placed.

Type of suture material and pattern to be used will be dictated by the tissue involved and forces, such as animal activity, that are applied to those tissues. Behavior of animals also might influence the choices, because some animals are more prone to chew or remove certain types of suture materials or devices such as surgical staples.

Proper use of surgical instruments minimizes trauma. Experienced surgeons know how to use the proper instrument in the appropriate situation. Vascular forceps, for example, are used to occlude blood vessels when flow is to be reestablished. Hemostatic forceps, which have a more crushing effect on tissue, are applied to vessels through which blood will no longer flow. In the manipulation of friable tissue, such as a lung lobe, special instruments are needed to avoid damage to these tissues.

Intraoperative patient support and monitoring—Accepted surgical protocol requires repeated assessment of the physiologic status of the animal throughout the surgery. Circulatory and respiratory function, as well as core body temperature, need to be monitored during the anesthetic and surgical ep-

isodes. The degree of monitoring sophistication depends on the species undergoing surgery, the extent and duration of the surgical procedure, and whether it is a survival or terminal procedure. Monitoring anesthetic depth is especially important when neuromuscular blocking agents are used. In species such as rodents, sophisticated monitoring might not be practical.

Monitoring anesthetic level and vital organ function—Intermittent or continuous measurement of specific physiologic functions can be used to monitor an animal's condition. Because most anesthetics depress the function of the cardiovascular and respiratory systems, these systems must be monitored to accurately balance the need to provide sufficient anesthesia to prevent pain perception while limiting total dose of anesthetic. The extent of monitoring undertaken must be evaluated with respect to potential complications associated with anesthetic regimen, surgical procedure, and animal species. Vital time for resuscitation can be lost by failure to properly notice life-threatening physiologic or metabolic problems. For this reason, adequate consideration must be given to monitoring these systems throughout the anesthetic period. Depending on the situation, expensive or complex monitoring equipment is not always necessary to adequately monitor vital body functions.

Monitoring can be qualitative, using the anesthetist's sense of touch, sight, and hearing to evaluate the patient, or quantitative, using instruments for periodic measurement of specific vital organ performance. The extent of quantitative monitoring is dictated by the physical status of the animal undergoing surgery or the magnitude of the physiologic insult to be inflicted during the course of surgery. Qualitative monitoring can usually be applied to all patients and can be particularly important in some species such as rodents, in which sophisticated monitoring may not be practical or possible.

Monitoring the patient is also essential for evaluating the adequacy of the anesthetic regimen. It is seldom possible to ascertain the precise concentrations of anesthetic in various tissues throughout the course of a surgical procedure. Even if such information is available, the effects induced by such concentrations on physiologic and metabolic processes including degree of pain perception and/or consciousness can vary appreciably among animals as well as among species. Similarly, the perception of noxious stimuli, as well as the responses to such stimuli, also can vary with individuals, making assessment of pain perception difficult. Some classic descriptions of biological responses to certain anesthetics in specific species can be found and serve as general guidelines in evaluating the anesthetic status of an animal patient. However, simple description of an animal's response to a particular anesthetic that is applicable to all conditions and all individuals within that species does not exist. Each animal, therefore, should be addressed individually, and the anesthetic regimen must be controlled by graded administration of anesthetic drugs on the basis of monitoring of clinical signs and certain vital parameters. This monitoring is essential to successful outcome of the surgery and is a dynamic equilibrium requiring that administration of anesthetic drugs be titrated in a manner so that the sum total of anesthetics in the body at any given time induces a stage of depression or anesthesia that just meets surgical needs. To conduct this successfully, it is assumed that the anesthetist has sufficient training and experience to evaluate the results of monitoring various clinical signs and vital organ functions. This evaluation must be integrated with the degree of applied surgical stimulus as well as the physiologic or clinical responsiveness by the animal to this stimulus in a way that the anesthesia administered is adequate to allow surgery to be performed while rendering the animal free of pain.

The anesthetic record can be an important part of the operative protocol. It provides a detailed account of the course of anesthesia and intraoperative events. The anesthetic record can be useful for subsequent assessment of the success of the procedure as well as be a means for developing improvements in surgical technique and the anesthetic management plan. The extent of record-keeping depends on circumstances and the species. For example, brief records are suitable when regional anesthesia or short-term general anesthesia is administered to small rodents. By contrast, during general anesthesia for major surgical procedures, especially in larger laboratory animals such as dogs and cats, the anesthetic records might be more complex, with more observations being made.

Vital organ support—Support of vital organ functions is an integral part of any surgical and anesthetic management plan. Many procedures and devices are available to support the function of vital organs, but they are not all applicable, practical, or possible for use in all species and under all conditions. For example, IV administered fluid therapy can be easily applied to many larger animal species, but can be difficult to use in mice or other small rodents. Other routes of administration of fluids or other strategies can be more appropriate for supporting circulating blood volume in these species.

Food and often water are commonly withheld before induction of general anesthesia in many species of animals. The duration that these items are withheld may be dictated by circumstances required to prevent vomiting and aspiration of stomach contents during surgery. In some instances, nonfeeding might be advantageous in stabilizing the rate of uptake of anesthetic administered by routes other than IV, as is the case of rodents, which do not vomit and might otherwise not benefit from withholding of food or water. Because nonfeeding can result in unreplaced solute and water loss, administration of fluids during surgery might be considered so that intra- and extravascular fluid volume will be maintained at a level that provides optimal blood pressure, cardiac output, and urinary flow. There are many possible choices for fluid replacement, with normal (0.9%) saline or balanced electrolyte solution, such as lactated Ringer's, being most commonly chosen. The

duration that fluids are administrated and rate of their administration are governed by a variety of factors including size of the animal, type of operative procedure, preoperative physiologic condition, and extent of blood loss. Monitoring rate and amount of urine production, as well as subjective assessment of blood loss, and capillary refill time of the oral or unpigmented mucus membranes can provide some indication of the adequacy of fluid volume and blood circulation. A variety of techniques exist to assess cardiovascular function, including capillary refill time, heart-rate monitoring, use of Doppler flow probes, ECG, as well as palpation of apical or femoral pulse, and use of esophageal or conventional stethoscopes.

General anesthesia interferes with body temperature regulation. An animal's body temperature decreases during the course of surgery and anesthesia, especially if a major body cavity is opened. In the case of small animals, heat is often lost into surrounding materials including the surgical table and instruments, resulting in rapid decrease in body temperature. Body temperature can be measured, using thermometers placed in the rectum or the esophagus. Every effort should be made to combat hypothermia, which will, in turn, markedly reduce morbidity and mortality associated with anesthesia and provide a more-predictable course of anesthesia throughout the operative procedure. Body temperature can be maintained by use of circulating warm water blankets, application of insulating materials such as drapes or pads, and use of warm water bottles or heat lamps. Electric heating pads are discouraged because of their high operating temperatures and the inability of animals to move away from these heat sources while anesthetized.

Wherever possible, it is appropriate to support function of the respiratory system during anesthesia and surgery. This can be done by use of simple procedures such as appropriate positioning of the animal to ensure an unobstructed airway, use of tracheal intubation, or provision of supplemental oxygen through techniques such as insufflation. In some instances, mechanical ventilation also might be desirable or necessary.

PRINCIPLES OF POSTOPERATIVE CARE

Adequate postoperative care enhances the animal's recovery by improving its physiologic status and minimizing pain and distress. The principles of a postoperative care program are summarized in these guidelines. Portions of this section are condensed from *Essentials for Animal Research.*[29] More detail about the various aspects of a postoperative care program can be found elsewhere.[29-31]

The postoperative period consists of 3 overlapping phases: recovery from anesthesia, acute postoperative care, and long-term postoperative care. The specifics of postoperative care for each protocol are assessed by the IACUC as an integral part of the overall review process. The attending veterinarian must have appropriate authority to ensure continued provision of adequate veterinary care during all phases of the postoperative period. Evaluation of the postoperative program should be an ongoing part of the institution's overall animal care program.

Communication among the postoperative care team (research and teaching personnel, animal care staff, and the institutional veterinarian) is essential to the animal's welfare. Postoperative complications are minimized by the teamwork that results from effective communication. It creates an environment in which a postoperative care program, tailored to the animal's needs and the institution's capabilities, can be managed productively. To ensure effective animal care, personnel to be involved in postoperative management need to be identified in advance of surgery. These individuals should be appropriately trained to identify and manage postoperative problems. Preplanning inclusion of the support staff, animal care technicians, research technicians, and veterinarians will help to promote prevention and/or timely treatment of complications. To facilitate development of an effective postoperative management plan, anticipated complications such as pain, vomiting, and paresis or special maintenance requirements (eg, special diets and dressing changes) need to be described thoroughly in the protocol and discussed with key staff. In addition, a secondary plan to handle the unexpected or less-likely complications should be established.

Recovery from anesthesia—Anesthetic recovery likely will be the most critical time of postoperative care, because it is a period of physiologic disturbance during which crises can arise rapidly. Therefore, frequent observation is required during anesthetic recovery.

During this period, the physiologic condition of the animal needs to be monitored regularly. Cardiovascular function can be assessed by many methods including ECG and blood pressure monitors, auscultation, and evaluation of mucous membrane color. Respiratory function can be monitored by methods such as evaluation of mucous membrane and tongue color and respiratory volume and rate. Some situations may require use of an expired gas monitor and/or blood gas analyzer.

During the recovery period, body temperature needs to be maintained. Circulating warm water heating devices, warm water bottles, or heat lamps can be used. Care should be taken to ensure that animals do not chew these devices and injure themselves as they recover. Warming fluids before IV administration might help prevent hypothermia, which is a major problem in animals, particularly small animals whose large surface area in relation to body mass results in rapid heat loss.

During anesthetic recovery, animals should be positioned in a manner to avoid compromising cardiovascular and/or respiratory function. Improper positioning can lead to aspiration pneumonia, obstruction of airways, tissue necrosis, or edema at pressure points. In most instances, until the animal has recovered from anesthesia, it should be turned from one side to the other side frequently enough to avoid dependent pulmonary edema and, thus, facilitate ventilation. Food and water intake should be

withheld until the animal is fully recovered from anesthesia.

Acute postoperative care—Recovery from surgery comprises 2 phases: acute postoperative care and long-term postoperative care. During acute postoperative care, the animal usually is maintained in the recovery area until its vital functions are adequately stabilized and it is ready to be moved to more-standard housing. Large farm animals can recover in their own cage, stall, or paddock if frequently observed.

When animals are transferred from the surgery area to the recovery area, they need to be carefully observed to prevent obstruction of the airway. As during surgery and the anesthetic recovery period, maintenance of body temperature is important during postoperative transport.

Postoperative pain can be difficult to detect because of individual and species variation. Therefore, the individual(s) monitoring recovery should be familiar with behavior of the individual animal before it undergoes surgery to more readily assess subtle changes. Typical signs of pain include guarding the painful area, vocalization, licking, biting, self-mutilation, signs of depression, grinding of teeth, restlessness, lack of mobility, failure to groom, abnormal posture, failure to be normally inquisitive, changes in sleep patterns, and failure to eat or drink. Pain can be assumed to have been present if administration of analgesics causes amelioration of these signs.

Understanding the degree of pain involved in various experimental procedures can help predict the amount of postoperative pain that an animal could experience. An important principle prepared by the Interagency Research Animal Committee and used by the USPHS is that "unless the contrary is established, investigators should consider that procedures that cause pain and distress in human beings may cause pain or distress in other animals."[32]

Relief of pain should be balanced against the possible detrimental effects caused by respiratory and/or cardiovascular depression and other interactions that could outweigh potential beneficial effects of analgesics. Use of analgesics in certain research situations might confound data obtained from the study. When considering use of analgesics, it is important to consider species differences. Nonchemical methods for reducing pain, such as use of extra bedding or bandaging and minimizing stimulation, also should be considered.

In addition, administration of antibiotics and parenteral administration of fluids might be needed during the postoperative period. Special diets could be indicated during this phase of recovery as well.

Long-term postoperative care—Long-term management programs will facilitate recovery of an animal from the trauma of surgery. Consultation with the attending veterinarian should be sought to develop strategies that will promote the animal's comfort and well-being.

Careful observation by trained and caring personnel is the key to postoperative management. Frequency of monitoring is determined by the nature of the surgical procedure and the stage of recovery. Body temperature, food intake, locomotion, behavior, and signs indicative of pain should be monitored. During this phase, postoperative procedures, such as examination of the surgical site, suture removal, and monitoring for postoperative infection, are needed. If antibiotics are indicated, dosage as well as route of administration appropriate for the species and circumstances should be outlined in the protocol and documented in the medical record.

The quantity and character of urine and feces should be monitored, because changes could indicate postoperative complications such as paralytic (adynamic) ileus, acute renal failure, or intestinal hypermotility caused by irritation. The wound should be observed for signs of infection, incision breakdown (dehiscence), or self-inflicted trauma. Elizabethan collars or bandages can help protect the surgical site from self-inflicted trauma. When bandages, collars, splints, slings, or other restraining devices are used, the staff should make certain that the animal can obtain food and water and move about to perform bodily functions. Drains, collars, and dressings should be examined and changed regularly. Cannulas and catheters should be examined regularly and cleaned as necessary. Implanted devices should be examined for proper operation and lack of interference with the animal's physiologic functions, unless otherwise designated by protocol. Special diets could be indicated during long-term recovery from surgery. Monitoring food and water intake is important to successful recovery. Oral or parenteral supplementation also could be necessary to maintain an anabolic state and normal hydration.

The actual location for postoperative recovery should be predetermined. This area should be staffed and equipped to address postoperative complications and should be easy to sanitize. Cages should be designed to avoid injury to occupants and should be sanitized between occupants. The cage size should be appropriate for the species and operative procedure. Care should be taken to separate incompatible species to minimize potential transmission of disease and to avoid stress. When there is danger of injury from other animals during recovery, animals should be housed individually.

Evaluation and summary of postoperative plan—After a surgical procedure and the subsequent postoperative periods, the postoperative plan and its implementation need to be reevaluated and changes need to be made for subsequent procedures as indicated. This evaluation should have input of the surgical team, attending veterinarian, research technicians, and animal care staff. Modifications that result from this evaluation need to be reviewed with all personnel involved and, when significant changes are to be made, with the IACUC.

An effective postoperative care program should be tailored to the procedure and individualized for the well-being of each animal. The plan is characterized by preplanning, involving all appropriate personnel, careful postoperative observation by trained

personnel during all phases of recovery, thorough and accurate documentation using medical records and logs, and regular evaluation of the postoperative program.

Disposition of animals—Euthanasia of animals must be performed when required by the experimental protocol or at the end of a procedure that would leave the animals with unrelievable, prolonged pain or distress.[3] When animals that have been exposed to biohazardous materials, such as radioisotopes and carcinogens, must be euthanatized, appropriate methods must be taken for their safe and legal disposition. Euthanasia methods should conform to the most recent *Report of the AVMA Panel on Euthanasia.*[33]

Disposal of remains, particularly animals exposed to biohazardous materials, must be in accordance with institutional, local, state, and federal regulations. In some states, animal remains can be considered biohazardous waste. The transportation and safe disposal of remains needs to be carried out in a nonoffensive and professional manner.

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Regulations

The Animal Welfare Act, 7 USC Sec 2131 et seq Title 9, Code of Federal Regulations, parts 1, 2, and 3.

Correction: In the report "Comparison of the properties and concentrations of the isoforms of retinol-binding protein in animals and human beings," by Betty J. Burri, et al (*Am J Vet Res,* August 1993, pages 1213–1220), the following correction should be made. On page 1215, Figure 2 should be turned left 90 degrees. The authors and the AJVR regret the error.