Radiosurgery and Laser in Zoological Practice: Separating Fact from Fiction

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Abstract

With increasing equipment acquisition by private practitioners, laser and radiosurgery units can no longer be considered as advanced tools of the referral veterinarian. Unfortunately, much of the marketing, lay publications, and conference presentations surrounding these instruments have been based on anecdote and opinion rather than science. This review aims to re-address the balance by consolidating and presenting the scientific literature on CO_2 laser and 4.0-MHz radiosurgery, in particular by citing those studies that have directly compared these surgical devices side by side. It is hoped that this information may provide the veterinarian with objective criteria that may be helpful when considering such a major equipment purchase. Copyright 2008 Elsevier Inc. All rights reserved.

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Over the past 10 years, there has been a dramatic increase in advanced technologies and their adoption in veterinary practice. One area that has seen an almost meteoric rise is the application of surgical devices such as lasers and radiosurgery units.[1-5] Unsubstantiated claims and marketing have played significant roles in persuading practitioners to purchase many of these devices, especially laser units; and, indeed, many practices have in turn used the laser in their marketing strategies to clients, while some have even adopted the term "laser" in their practice name. Many individuals and practices have invested in the laser phenomenon despite a lack of credible data to support their popularity. The author's first experiences with laser were with an 810-nm diode laser while in private practice in England in 1997. At that time, this was most likely the first veterinary laser used in practice in the United Kingdom. Today, at the University of Georgia, as with many university hospitals and referral centers, surgeons have access to multiple lasers (diode, CO_2, and neodymium-yttrium-aluminum garnet [Nd-YAG]), as well as 3.8-MHz and 4.0-MHz radiosurgery devices. However, these devices are no longer restricted to the referral specialist, with many private practices boasting of a CO_2 laser and/or radiosurgery unit among their inventory.

Intrigued by the upsurge in general interest and veterinary magazine publications hailing the benefits

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Disclaimer: All laser and radiosurgery equipment used at the University of Georgia's Veterinary Teaching Hospital has been paid for, and none was donated or loaned by interested companies. In keeping with the Royal College of Veterinary Surgeons' (London, UK) guidelines for professional conduct, the author does not endorse any particular product or company.

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of CO_2 lasers and radiosurgery in companion animal practice, a detailed review was undertaken. There is little peer-reviewed veterinary literature and not much more from our human counterparts when comparing surgical tissue reaction between that of laser and radiosurgery technologies. This article compares and summarizes the methodologies, tissue effects, healing, and postoperative pain associated with CO_2 lasers and 4.0-MHz radiosurgery units, and briefly reports on the findings of comparative veterinary studies involving dogs, pigeons, and green iguanas. It is hoped that this information will enable practitioners to make more informed decisions regarding the purchase of expensive surgical equipment.

Physics

Radiosurgery

Electrical current has been used in medical equipment for over a century. Traditional electrocautery and low-frequency electrosurgery consists of a platinum wire heated with an electric current, and has the ability to both cut and coagulate tissues. Further development led to the advent of alternating current and transformer circuitry, which could produce high-electric currents that were used in medicine to coagulate, cut, and destroy tissues. In 1978, Maness and colleagues discovered that high radiowave frequencies (3.8 MHz) were preferred for cutting soft tissues.[6] This frequency served as the starting point for modern radiosurgery units, but has subsequently been surpassed by the development of 4.0-MHz units. Surgery performed with a modern radiosurgical unit should not be confused with the results obtained with electrocautery, low-frequency electrosurgery, diathermy, spark gap generators, or partially rectified devices that do not provide surgical cutting waveforms. The modern radiosurgery units discussed here use ultra-high frequencies to vaporize intracellular water, which accurately destroys cells with minimal collateral damage.

Laser

The term *laser* stands for "light amplification by the stimulated emission of radiation" and relies on the production of electromagnetic radiation in response to photon emission by the lasing medium.[2] Photons are directed from the optical laser chamber as coherent, monochromatic electromagnetic radiation. These photons are transmitted, via a series of lenses and delivery fibers, in a focused and controlled manner called a laser beam (Fig 1). The wavelength and frequency of this radiation are peculiar to the specific lasing medium. CO_2 units selectively vaporize intracellular water and destroy cells with minimal collateral damage, whereas diode lasers are more selective for pigments (especially melanin and hemoglobin), may be less effective in pale or avascular tissues, and tend to provide deeper penetration with greater collateral damage when used in noncontact mode.

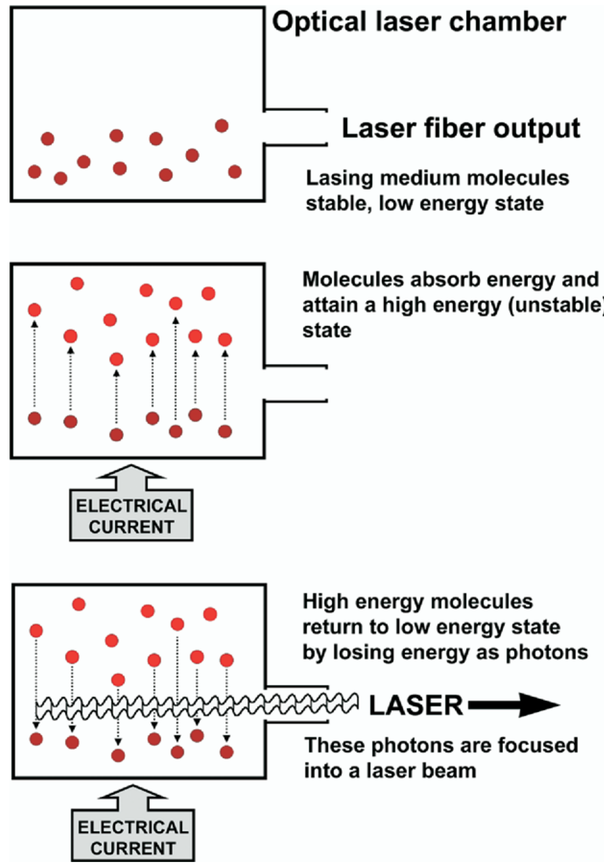

Figure 1. Diagrammatic representation of laser. The top diagram demonstrates the resting lasing medium molecules within the optical laser chamber. As energy in the form of electrical current is applied, these molecules attain a higher energy level and become unstable (*middle*). There is a constant effort to return to a more stable state, and the molecules achieve this by losing energy in the form of photons (*bottom*). These photons leave the optical chamber via the laser fiber output as a monochromatic laser beam.

Equipment

Radiosurgery

There is only one manufacturer of veterinary equipment and 2 models available; the long-established 3.8-MHz and the more advanced and expensive 4.0-MHz dual radiofrequency units (Fig 2). Both of these units offer monopolar/bipolar applications with foot-pedal/finger switch control for several waveforms (Fig 3):

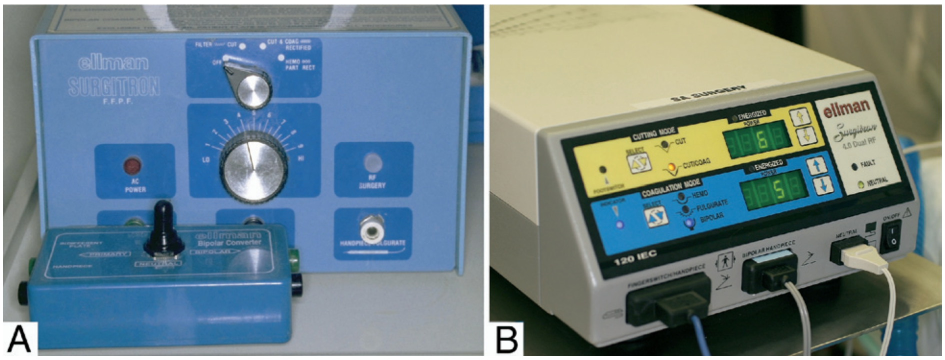

Figure 2. (A) 3.8-MHz and (B) 4.0-MHz radiosurgery units.

1. Pure filtered waveform (pure micro-smooth cutting): for skin incisions and wire loop excisions where hemostasis is not expected to be a problem; creates minimal thermal damage, comparable to focused small-spot CO_2 laser incisions.[7-9]
2. Fully rectified waveform (blended cutting and coagulation): used where bleeding might be expected; cuts as well as coagulates small blood vessels and gives slight lateral heat to the tissues.
3. Partially rectified waveform: primarily used for hemostasis; not used for cutting but is excellent for coagulation.
4. Fulguration (spark-gap tissue destruction): similar to the unipolar diathermy and gives superficial tissue damage by holding the needle electrode close to the tissue and allowing a stream of sparks to burn the tissues; suitable for superficial hemostasis and destruction of cysts and superficial neoplasms.
5. Bipolar coagulation: precise hemostasis using bipolar forceps; each blade is connected to the radiosurgery unit so that the current passes between the points of the forceps.

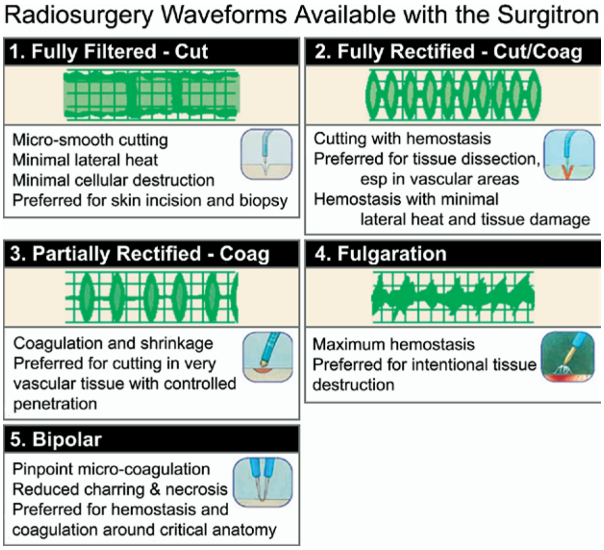

Figure 3. The different radiosurgery waveforms and their surgical uses (photo courtesy of Ellman International, Inc., Hewlett, NY USA).

All the above selections are effected through buttons and displays, which give the operator feedback of the unit's operating status. The power level for each mode is indicated by front-panel digital displays (4.0-MHz unit), which also indicate self-test and monitoring modalities. The final output power control is made through foot and/or hand switches. Monopolar cutting needles are typically used for dissection, wire loops for tissue biopsies or tissue debridement, and bipolar forceps for sealing blood vessels (Fig 4). In addition, a wide variety of soft tissue, dental, microsurgical, and endoscopic instruments are available for use with the radiosurgery unit, which makes it versatile for a range of applications in veterinary practice. Radiosurgery requires tissue contact and provides tactile feedback, but it is important to keep the electrode clean to avoid tissue drag.

Laser

There are a variety of lasers available, but CO_2 models (10,600 nm) are probably most common in veterinary medicine today, largely because they offer the advantages of minimal tissue penetration and a reduced collateral thermal injury when compared with diode lasers (Fig 5, *A*).[1] CO_2 lasers consist of a base unit and a delivery arm. The base unit may be tabletop or on wheels, and permits the surgeon to choose the power output and wave form:

1. Continuous: laser energy is supplied as a continuous beam.

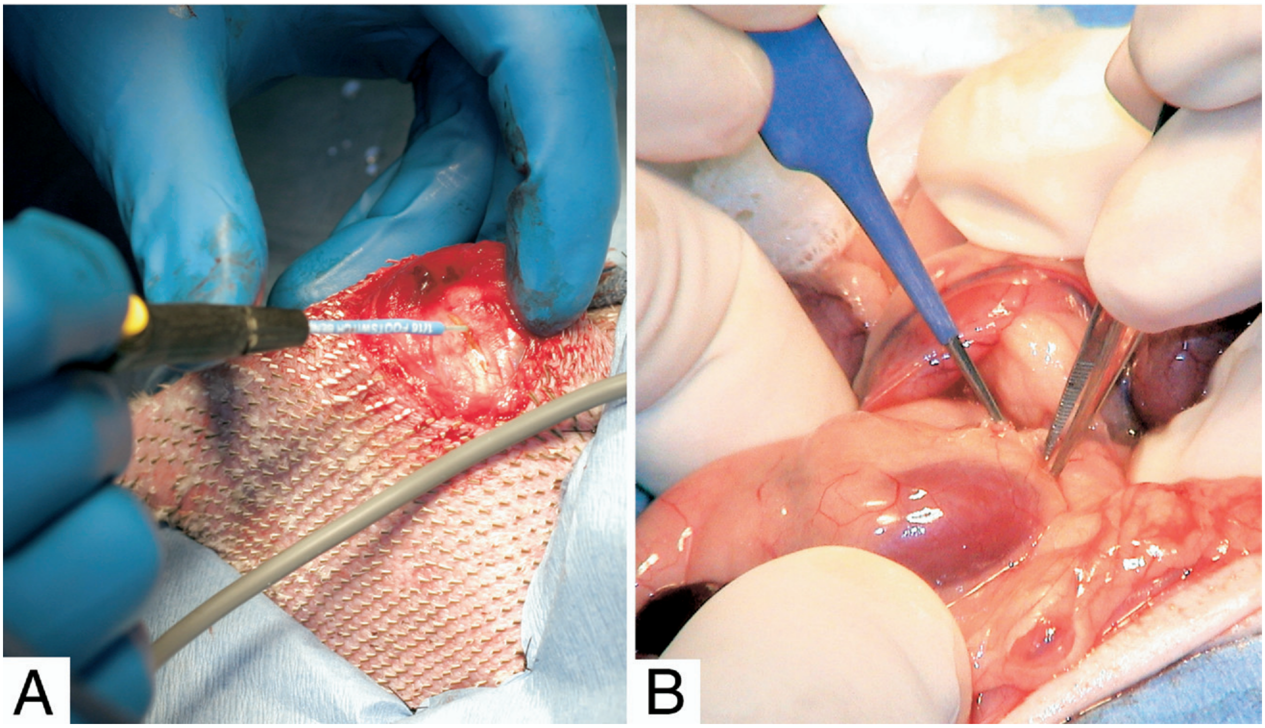

Figure 4. Radiosurgery in practice. (A) Radiosurgical arthrotomy incision into the stifle of a black-footed penguin. (B) Adrenal gland isolation using bipolar dissection and hemostasis in a ferret.

2. Pulse: laser energy is supplied as high-amplitude, short-duration pulses, followed by short pauses during which tissue is allowed to cool.
3. Superpulse: high-pulse frequencies, around 200 per second, permit primary incisions while maintaining lower tissue temperatures.

The laser beam is activated by a foot pedal and transferred from the base unit to the ceramic hand piece by either an articulated arm or a flexible waveguide. The characteristics of the laser beam as it emerges from the ceramic hand piece can be controlled in 2 ways:

1. The size of the ceramic tip can range from 0.25 to 1.0 mm, although 0.8 mm appears to be most popular in veterinary medicine. The smaller the tip, the smaller the focused spot size of the beam.
2. The laser beam can be focused to create a point (similar in diameter to the ceramic tip size) at the tissue interface for cutting, or defocused by moving the tip further away from the tissue to create a larger diameter at the tissue interface for thermal damage and ablation.

CO_2 laser hand pieces and ceramic probes do not contact the tissue, and therefore there is no tissue

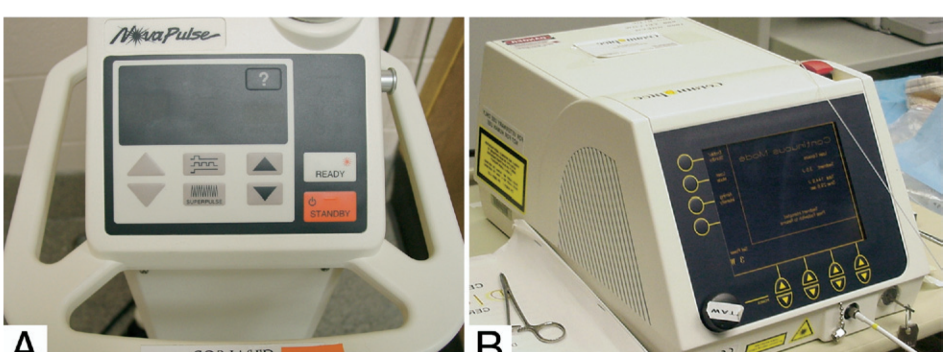

Figure 5. (A) CO_2 laser. (B) 980-nm diode laser.

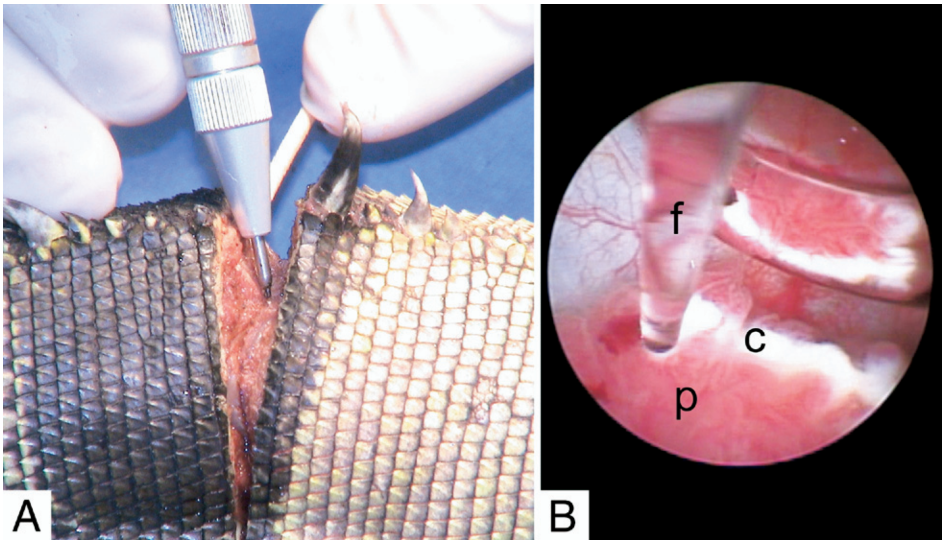

Figure 6. Laser surgery in practice. (A) Proximal tail amputation in a green iguana using CO_2 laser. (B) Endoscopic diode laser coagulation of cloacal papilloma in a macaw; the diode laser is delivered by an optical fiber (f), and coagulated tissue (c) is clearly demarcated from the unaffected papilloma (p).

drag but a lack of tactile feedback (Fig 6, *A*). Unlike radiosurgery and diode lasers, CO_2 units cannot be used in a liquid medium. There are few terminal attachments for the CO_2 laser, and, although there is a probe available for the 2.7-mm telescope, their use endoscopically is generally impractical.

Diode lasers are less common and generally cheaper to purchase. They are also composed of a base unit that provides a laser beam of 810 or 980 nm (Fig 5, *B*). This lower wavelength is absorbed preferentially by pigmented tissues (e.g., hemoglobin and melanin), but can traverse liquid environments. The beam is activated by a foot pedal and transferred from the base unit to the hand piece by a flexible quartz fiber ranging from 200 to 1000 μm in diameter. The flexibility of the fibers makes this laser much more versatile with regards to use via the instrument channel of most rigid and flexible endoscopes (Fig 6, *B*). The diode laser can be used in continuous or pulse modes in 2 ways:

1. Noncontact mode: the laser beam emanates from the end of the fiber and continues until it is absorbed by pigment; as a result, the beam may travel up to 4 mm into tissue and can cause significant damage below the tissue surface. However, diode lasers are also able to seal larger blood vessels than other lasers, up to 2 mm in diameter.
2. Contact mode: the terminal end of the fiber is coated with a fine layer of carbon (most easily accomplished by activating the laser beam while holding a tongue depressor against the terminal tip); the laser beam is completely absorbed at the carbon-coated tip, which becomes super heated and can be used to ablate tissue; the advantage here is that there is no laser penetration into the tissue, but thermal collateral cellular damage is greater.

Staff Safety

To prevent retinal damage to personnel in the operating room, it is essential that protective glasses be worn at all times when lasers are in use.[10] The safety glasses need to be appropriate for the wavelength of the laser being used (Fig 7, *A*). Likewise, the patient's eyes should also be protected by gauze or drapes, unless specifically operating on the ocular tissues. Finally, windows in the operating room should be covered to prevent potential damage to nonsurgical personnel outside of the operating suite. All CO_2 and diode lasers come with emergency cut-off switches that can be operated by persons in the room, or when a door is opened.[10] No such ocular health issues exist with the use of radiosurgery.

The use of laser or radiosurgery on biological tissue produces a smoke plume that may contain pyrolysis products that are known to be cytotoxic.[11,12] This smoke, which can contain viable bacterial, viral, or patient DNA, should always be evacuated with a filtered vacuum from the surgical site (Fig 7, *B*).

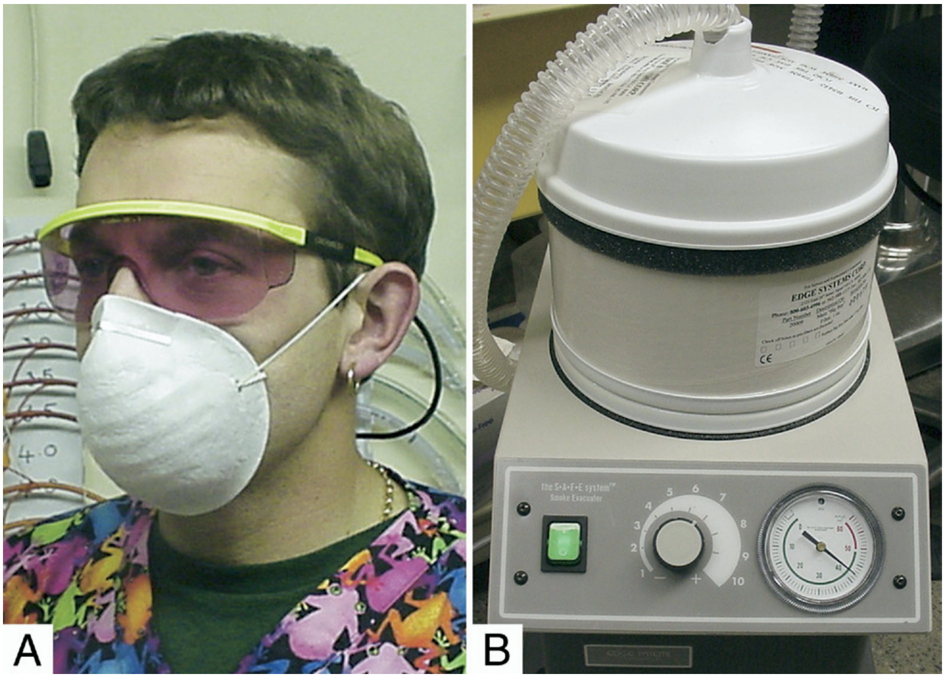

Figure 7. Occupational safety. (A) Appropriate protective glasses and face masks are required when working with lasers. (B) Smoke evacuation devices are required when using laser or radiosurgery.

Purchase Costs

Table 1 details the purchase costs obtained from the sole radiosurgery distributor and one of many veterinary laser distributors in the United States.

Tissue Effects

All CO_2 lasers and radiosurgery units cause cellular destruction in the same way—the vaporization of intracellular water. The way this energy is delivered to cause vaporization differs, but the end result is the same. It should, therefore, come as no surprise that the tissue effects are very similar—an immediate area of vaporization, surrounded by a zone of irreversible coagulative necrosis, and a further zone of reversible edema and inflammation (Fig 8).

With proper technique, collateral damage is minimal with both small-spot focused CO_2 lasers and micro-fiber radiosurgery set to pure cut mode. Ul-

Table 1. Current sources and list prices for radiosurgery and laser units in the United States

Ellman International, Inc. 3333 Royal Ave Oceanside, NY 11572 USA Tel: 1-800-835-5355, ext. 6512 Fax: 1-516-569-0054 www.ellman.com	3.8-MHz Surgitron radiosurgery unit, $4,300 4.0-MHz Surgitron radiosurgery unit, $18,000
Lumenis, Inc. (AccuVet) 5302 Betsy Ross Dr Santa Clara, CA 95054 USA Tel: 1-877-586-3647, ext. 3997 Fax: 1-800-783-5671 www.lumenis.com	Diode 980 nm 15 W, $16,995 Diode 980 nm 25 W, $19,995 CO_2 laser 12 W, $21,000 CO_2 laser 20 W, $29,000 Nova pulse CO_2 laser 20 W with superpulse, $33,500

Prices were obtained from a company representative in November 2007.

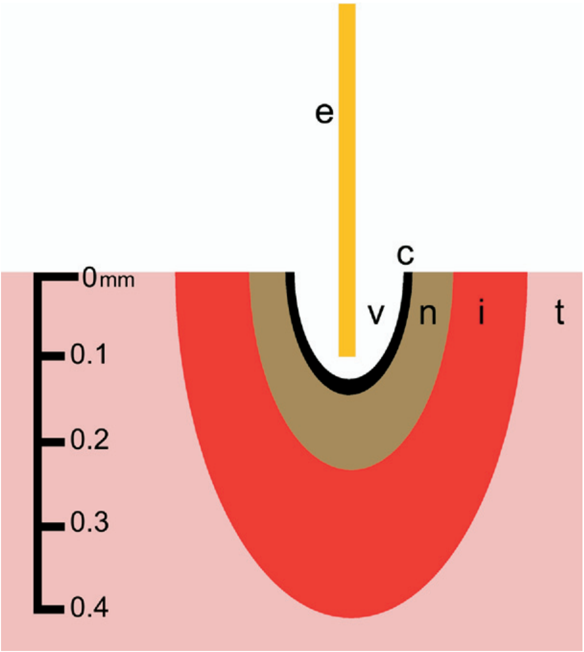

Figure 8. General effects of laser or radiosurgery on soft tissue (t). Energy provided by the laser beam or radiosurgical electrode (e) causes intracellular water to vaporize, which causes cellular ablation (v). A thin layer of char (c), may be present and is surrounded by an area of irreversible coagulative necrosis (n). The combined thickness of char and necrosis equates to the collateral thermal damage caused by the device during surgery. A larger zone of reversible edema and inflammation (i) develops within minutes or hours of surgery but later resolves.

trafine incisions permit delicate and precise dissection with reduced tissue damage and less postoperative inflammation. However, despite the suggestion that radiosurgery and lasers can be used to harvest tissue biopsies, there will always be a degree of coagulative artifact that may hinder the histopathological evaluation at the biopsy margins.[13] In cases where margin evaluation is critical (e.g., tumor resection), the use of the scalpel to collect biopsy samples may still be preferred. At the extreme of minimal damage, surgical devices are less effective at maintaining hemostasis (the least damaging incisional device is the scalpel blade, which is well known to cause hemorrhage). Conversely, diode lasers can seal vessels up to 2 mm in diameter by virtue of their greater collateral damage. Therefore, the benefits of minimal collateral damage must be weighed against the need for hemostasis. For example, greater collateral damage and cellular destruction would be preferable when dissecting through vascular tissue or ablating neoplastic cells. This can be achieved with radiosurgical coagulation or fulgaration modes, or by using the defocused CO_2 laser beam.

In general, radiosurgical and CO_2 laser incisions cause less collateral damage than cryosurgery, electrocautery, and diode lasers. However, an experienced surgeon using a scalpel blade or electrocautery could produce superior results compared with an inexperienced surgeon using CO_2 laser or radiosurgery. No amount of advanced technology can make up for lack of training, surgical skill, or experience.

Research and Peer-Reviewed Literature

There is a plethora of scientific reports, case reviews, and research studies that have looked at the effects of an individual surgical device. However, there are very few studies that have objectively and directly compared laser and radiosurgery.

Incisional Characteristics

Studies that have objectively assessed different surgical modalities generally do so by comparison with a gold standard that causes no collateral damage (e.g., scalpel blade incision). Unlike electrocautery and low-frequency electrosurgery, radiosurgery and CO_2 laser offer superior accuracy and reduced collateral damage. Histologic studies involving human skin peel grafts concluded that radiosurgery produces less epidermal loss, reduced zone of thermal damage, and reduced dermal fibrosis than CO_2 laser.[7] In other comparative studies including turbinate ablation and resection, biopsy collection, and effects on oviductal tissue, radiosurgery was comparable or superior to CO_2 laser.[8,9,14] In veterinary medicine, even less has been published; however, a recent publication in *Veterinary Surgery* described the collection of skin biopsies from greyhounds using scalpel, skin biopsy punch, monopolar electrosurgery, CO_2 laser, and radiosurgery.[13] This study found that collateral damage and char associated with radiosurgery was significantly less than for CO_2 laser, and concluded that radiosurgery caused less lateral thermal damage to canine skin biopsies than CO_2 laser. Studies at the University of Georgia have compared the incisional characteristics of radiosurgery and CO_2 laser on the skin and muscle of pigeons and iguanid lizards. In pigeon skin, radiosurgery caused less collateral thermal damage than CO_2 laser (94 ± 60 μm vs 150 ± 64 μm) (Fig 9).[15] The results from iguanas were similar, with both radiosurgery and laser able to produce bloodless incisions, but radiosurgery caused significantly less collateral tissue damage in skin (307 ± 94 μm vs 386 ± 108 μm) and muscle (18 ± 7 μm vs 91 ± 31 μm) compared with CO_2 laser (Hernandez-Divers, unpublished data, 2006) (Fig 10). From these veterinary studies, it appears that radiosurgery causes significantly less collateral damage than CO_2 laser.

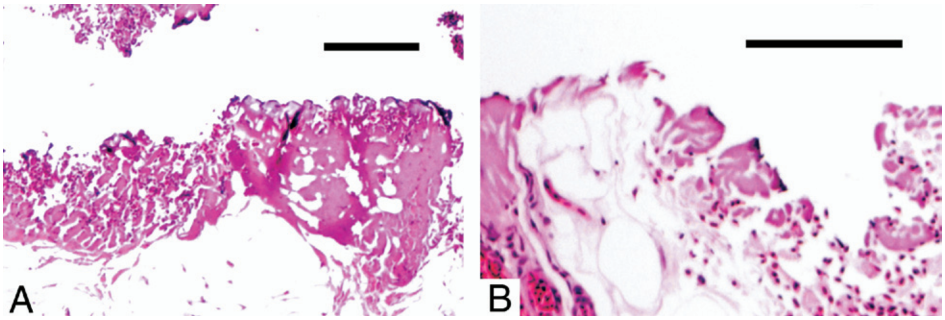

Figure 9. Comparison between CO_2 laser (A) and 4.0-MHz radiosurgery (B) skin incisions in pigeons; note the greater thickness of collateral necrosis associated with the laser. Hematoxylin and eosin (stain), bar = 100 μm.

Tissue Effects and Healing

There have been few veterinary studies to assess the healing process after their use. The effects of Nd-YAG and CO_2 laser tenotomies of flexor digitorum profundus muscles in rabbits were used to evaluate the effects of laser on collagen tissue.[16] The most consistent observation was variable carbonization (charring) in most cases. Studies on the morphological consequences of thermosurgery and carbonization in human tissue biopsies and rat organs have demonstrated areas of necrosis, coagulation, and edema, with cellular granulation predominantly by giant cells. Laser surgery on the buccal mucosa of rats was performed to assess the effects on lymphatic vessels, and whether laser tumor resection may lead to iatrogenic metastases via the lymphatics.[17] This study demonstrated that lymphatic vessels are absent from the area of carbonization, occluded by coagulation in the zone of necrosis, and dilated within the zone of edema. The authors concluded that laser resection of tumors was unlikely to result in lymphatic spread. The regeneration of lymphatics was correlated to overall wound healing, being delayed with laser (CO_2 more so than Nd-YAG) compared with conventional scalpel surgery. Other studies have confirmed this delayed primary intention wound healing after laser surgery. This delay is primarily because of the temporary postponement of inflammation, phagocytic resorption, collagen production, and re-epithelialization in the early stages of repair.[18]

Various human studies involving radiosurgery devices, particularly in dermatologic and ophthalmologic surgery, have been published.[19-25] These studies have demonstrated the atraumatic and minimal collateral damage associated with radiosurgery. Tonsilectomy using radiosurgery has been shown to cause less pain and result in faster healing than traditional surgery in human pediatrics.[24] In one study, radiosurgery was credited with reducing stump neuromas in the rat—a common complication of traditional amputation techniques.[25] In addition, veterinary texts, especially those dealing with avian and other exotic species, have advocated radiosurgery for a number of years.[5,26-28]

Few studies have directly compared the functional tissue effects and healing associated with laser and radiosurgery. One study compared radiosurgical and CO_2 laser resection of nasal turbinates in humans, and concluded that although both methodologies

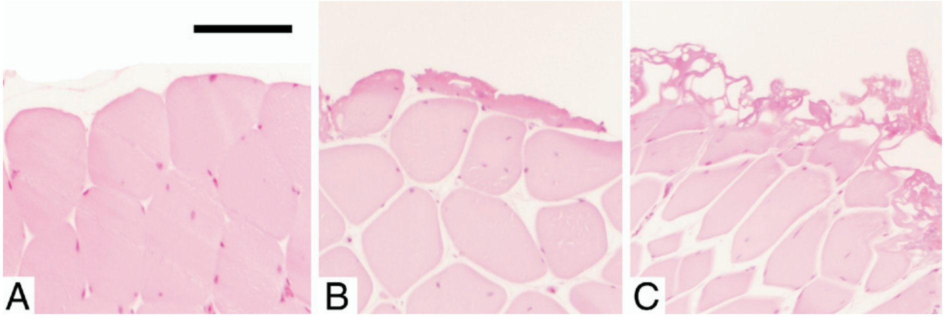

Figure 10. Comparisons between scalpel (A), radiosurgical (B), and CO_2 laser (C) muscle incisions in green iguanas; note the absence of any collateral damage in the scalpel incision and the greatest thickness of collateral necrosis associated with the laser. Hematoxylin and eosin (stain), bar = 50 μm.

Table 2. Comparison between 4.0-MHz radiosurgery and CO_2 laser

Surgical device	4.0-MHz radiosurgery	CO_2 laser
Energy provision	Ultrahigh frequency radiowaves, 3.8-4.0 MHz	LASER 10,600 nm
Incisions	Minimal trauma using filter-cut and micro-fiber electrode	Minimal trauma using focused beam and small spot size
Costs	Less expensive ($4,300-$18,000)	More expensive ($21,000-$33,500)
Occupational Safety and Health Administration regulations	Minimal: evacuation of surgical vapors	Significant: evacuation of surgical vapors, covered windows, protective glasses, and covering patients' eyes to prevent retinal damage
Available modes	Monopolar (cutting, coagulation, fulgaration) Bipolar	Focused beam Defocused beam
Ancillary equipment	Large selection of wire electrodes and devices for soft tissue, dentistry, neurosurgery, orthopedics, and endoscopic surgery	Limited number of hand pieces and ceramic tips available from 0.25-1 mm; a 2.7-mm cystoscope probe is available
Comments	Excellent results possible with training and experience Versatile for traditional and endoscopic surgery Tissue contact = good tactile feedback	Excellent results possible with training and experience Unable to use in fluid environments or in most endoscopic applications No tissue contact = no tissue drag

were equally effective at accomplishing the surgical goals and resolving nasal obstruction, CO_2 laser resulted in significantly greater disturbance of mucociliary function.[29] Another comparative study involving human oviducts revealed that radiosurgery was the least traumatic instrument used, with CO_2 laser being second.[8]

Postoperative Pain and Complications

Despite the common proclamation that CO_2 lasers result in less postoperative pain, there have been few objective comparisons between radiosurgery and laser.[30] However, 2 independent studies that evaluated pain after soft palate resection in humans both concluded that radiosurgery produced less postoperative pain than CO_2 laser.[14,31] Typically, patients who underwent radiosurgery had discomfort for 2.6 days with only 9% requiring narcotic analgesics, compared with patients who underwent laser treatment who experienced pain for an average of 13.8 days and 100% required narcotic analgesics.[31] Furthermore, postoperative side effects (e.g., trouble with smell and taste, pharyngeal dryness, globus sensation, voice change, and pharyngonasal reflux) and complications (e.g., wound infection, dehiscence, posterior pillar narrowing) were more common after CO_2 laser surgery than those when radiosurgery was used.[14]

Summary

Table 2 provides a comparative summary of CO_2 laser and radiosurgery units. Laser and radiosurgery usage is well established in veterinary medicine, and their list of surgical indications is certain to grow as this technology becomes further used within practice. In the future, those procedures already developed in areas of human medicine, including ophthalmology, gastroenterology, urology, neurology, and gynecology, will continue to filter into the veterinary profession. In an age when marketing hype can sometimes overshadow science, it is wise to fully investigate and personally evaluate equipment before making a major capital investment. The latter point cannot be overstressed because individual surgeon ability and preferences will undoubtedly have more effect on surgical outcomes than the nature of the surgical device used.

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