Comparison of the Carbon Dioxide Laser and the Radiofrequency Unit for Feline Onychectomies

This study compared the collateral tissue damage and incisional bridging with granulation tissue via histopathological examination following feline onychectomy performed by radiofrequency (RF) and carbon dioxide (CO_2) laser. Two cats were euthanized, and their digits were harvested for histopathological evaluation on days 1, 3, and 7 post-onychectomy. Each digit was evaluated for total lesion width, total necrosis width, and degree of edema, hemorrhage, and inflammation. This study found few significant differences in collateral tissue damage between RF and CO_2 laser, but more incisional bridging by granulation tissue was noted with RF for feline onychectomies. These results indicate that RF for feline onychectomy is a reasonable alternative to CO_2 laser in regard to collateral tissue damage and bridging of the incision by granulation tissue. In addition, RF is not accompanied by the strict safety considerations and initial expense of acquisition of a CO_2 laser. **J Am Anim Hosp Assoc 2010;46:375-384.**

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Introduction

Feline onychectomy is a common surgical procedure performed in small animal practice. Onychectomy is indicated in the treatment of severe follicular infections and nail bed neoplasms;[1,2] however, it is also performed as an elective procedure to prevent undesirable scratching behavior in cats that are unresponsive to environmental manipulation and/or behavior modification.[3-5]

Traditional methods of performing feline onychectomy include resection of the third phalanx using a scalpel blade or nail clippers (guillotine method). Short-term complications of both techniques include hemorrhage, swelling, and clinical signs of pain.[5] One study compared complications and discomfort after feline onychectomy using the carbon dioxide (CO_2) laser or the scalpel technique. The CO_2 laser provided excellent intraoperative hemostasis and lower discomfort scores on the first postoperative day.[1] Another study measured peak vertical forces and vertical impulses in cats undergoing CO_2 laser versus scalpel onychectomy and found significantly higher values (more weightbearing) in the CO_2 laser group on days 1 and 2 postsurgically.[4]

The CO_2 laser delivers a large amount of energy via an intense beam of light that can be focused on a small area of tissue, permitting a precise incision without physical contact with the tissue. The released energy instantly heats the intracellular water above the boiling point, which vaporizes cells. Rapid and precise vaporization limits thermal damage to surrounding tissues. Blood vessels, nerves, and lymphatics are presumably sealed as the CO_2 laser makes the incision, thereby decreasing hemorrhage, pain, and swelling.[1-6]

While a CO_2 laser can be an excellent tool for feline onychectomy, the safety considerations and initial price of acquisition of a CO_2 laser have limited its widespread use in veterinary medicine. The radiofrequency

(RF) unit reportedly produces a similar margin of tissue injury compared to the CO_2 laser in human medicine.[7-10] A recent study in the veterinary literature by Silverman and others reported that RF caused less lateral thermal damage than the CO_2 laser or monopolar electrocautery when used for canine skin biopsies.[11]

Radiofrequency technology delivers radiowave energy at a low temperature, low voltage, and high frequency (4.0 MHz) directly to the tissues. The energy passes from an active, hand-held electrode with a metallic tip to a passive electrode located beside or beneath the animal. The tissue is heated by molecular friction caused by ionic agitation of the cells because of tissue resistance to radiowave transmission at the tip of the active electrode.[11,12] Heat is generated within the tissues and not from the active electrode itself. Lateral tissue damage can be minimized by decreasing tissue contact time of the active electrode while utilizing the lowest-effective power setting.[11,13]

The CO_2 laser and RF technologies both utilize heat to incise tissue. Dissipation of the thermal energy into adjacent tissues must be considered, as it may lead to delayed healing or increased risk of infection.[11] The purposes of this study are to evaluate and compare the collateral tissue damage created by RF and the CO_2 laser in elective feline onychectomy on days 1, 3, and 7 following surgery. A comparison between the two modalities is also made in regard to the degree of incisional bridging by granulation tissue on day 7 postsurgically. To the authors' knowledge, no prior reports have compared histological evaluation of collateral tissue damage and incisional bridging by granulation tissue associated with RF and CO_2 laser for feline onychectomies. The authors hypothesize that no difference in collateral tissue damage or incisional bridging by granulation tissue exists between these two techniques.

Materials and Methods

Case Selection

This protocol was approved by the University of Georgia Institutional Animal Care and Use Committee. Six healthy, mature, domestic shorthaired cats were obtained from a commercial breeder. A normal physical examination was required for enrollment in the study. Each cat underwent onychectomy of all four limbs. A total of 12 limbs (54 digits: 30 front and 24 rear) on the right side had onychectomy performed with RF. A total of 12 limbs (54 digits: 30 front and 24 rear) on the left side were operated upon using the CO_2 laser.

Anesthesia and Surgery

Each cat was anesthetized using the same protocol. Meloxicam[a] (0.3 mg/kg) was administered orally followed by an intramuscular injection of 0.1 mg/kg butorphanol[b] combined with 0.05 mg/kg acepromazine.[c,14,15] Each cat was anesthetized 45 minutes later with isofluorane[d] in oxygen (5 L per minute) administered via an induction box. Anesthesia was maintained with isofluorane in oxygen delivered via a rebreathing system following intubation of each cat.

Onychectomy on the front digits was performed by a single, experienced general practitioner (Mauck). The same procedure was performed on the rear digits by a small animal surgery resident (Burns). The three surgical coauthors monitored all of the procedures. No tourniquet was used for either treatment method in any of the six cats.

The same procedure was performed regardless of the treatment modality. A circumferential incision was made at the haired margin of the distal phalanx. The common digital extensor tendon and dorsal elastic ligaments were transected. The joint capsule was incised, following the contour of the joint with transection of collateral ligaments as they were encountered. The deep digital flexor tendon was exposed by flexion and distal retraction of the third phalanx and was subsequently transected to allow removal of the third phalanx. The edges of the skin incision were apposed, and one to two drops of tissue adhesive[e] were applied to the skin, taking care to avoid adhesive entrance into the wound. Bandages were only used for postoperative hemorrhage as judged necessary by the primary observer (Burns).

The CO_2 laser[f] was used to perform the onychectomies on the left forelimbs and hind limbs. A 0.25-mm ceramic tip[g] was used and positioned 1 to 2 mm away from the tissue to be incised. The recommended power settings of 3 to 4 watts in the continuous wave mode was adjusted to 4 to 6 watts based on the level of tissue dissection and amount of char formation.[16] Sterile, saline-soaked gauze sponges were used as backstops during dissection and to remove carbonized debris as needed throughout the procedure. Standard safety protocols, including protective eyewear and use of a smoke evacuator, were implemented during use of the CO_2 laser.

Radiofrequency[h] was used for the onychectomies on the right forelimbs and hind limbs. The wave form, power settings, and type of electrode used were based on the manufacturer's recommendations. The "cutting" mode, in which the waveform is fully filtered (90% cutting and 10% coagulation), was recommended for the skin; the "blend" mode, in which the waveform is fully rectified (50% cutting and 50% coagulation), was recommended for the remainder of the dissection. The initial power setting recommendations were adjusted based on the amount of tissue drag, hemorrhage, and/or char formation during dissection; the setting ranged from 8 watts in the cutting mode to 35 watts in the coagulation mode. The handpiece and a 36-gauge A-series wire tip[i] were used. The passive electrode was placed beneath the cat at the level of the thorax. Subjective observations regarding the differences between each treatment modality were recorded by both surgeons immediately after surgery. Observations included the presence and amount of char in the surgical field, amount of hemorrhage, ease and accuracy of dissection, and ability to control the depth of dissection.

Postoperative Evaluation

Postoperative analgesia consisted of a single intramuscular injection of 0.01 mg/kg buprenorphine[j] prior to extubation. Rescue buprenorphine[j] (0.005 mg/kg) was available if deemed necessary by the primary observer.

Case nos. 1 and 2 were euthanized on day 1 postsurgically; case nos. 3 and 4 were euthanized on day 3 postsurgically; and case nos. 5 and 6 were euthanized on day 7 postsurgically. The distal limbs were harvested intact and submitted for histopathological evaluation. Thus, four limbs (18 digits) were collected for each surgical modality (RF and CO_2 laser) at each time period (i.e., days 1, 3, and 7) following surgery.

The distal limbs were fixed in 10% buffered formalin. For each digit, sections were made perpendicular to the plane of surgical excision. These sections were embedded in 1.5% agarose to maintain orientation of the surgical margins during routine processing and paraffin embedding for histology. Segments (5 μm) were cut and stained with hematoxylin and eosin. Digital images were captured, and total lesion width (TLW) and total necrosis width (TNW) were measured using Image Pro Plus[k] for each digit on days 1 and 3 following surgery, as defined in Table 1 and Figure 1. The TLW was determined for each digit on day 7 postsurgically by averaging three separate distance measurements across the entire bed of granulation tissue filling the lesion [Figure 2]. Necrosis could not be measured linearly on day 7; therefore, necrosis was subjectively scored (necrosis score; NS) on a scale of 0 to 3 [Table 1].

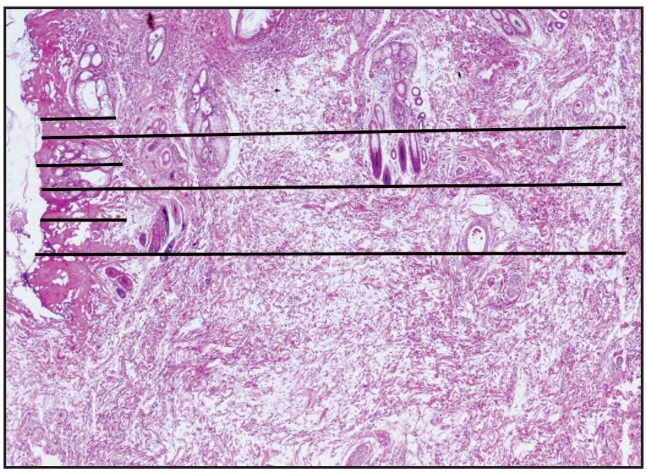

Figure 1—Days 1 and 3: Total lesion width was the distance from the cut edge of the incision to the edge of all induced changes (long bars). Total necrosis width was the distance from the cut edge of the incision to the edge of the necrosis surrounding the incision (short bars). Three separate length measurements were made and averaged for each image.

In addition, an edema score (ES), hemorrhage score (HS), and inflammation score (IS) were made by a single pathologist on days 1, 3, and 7 after surgery. Bridging of the incision by granulation tissue (granulation score; GS) and degree of reepithelialization (reepithelialization score; RES) were also scored [Table 1]. The GS and RES were assigned values so that more bridging equaled lower scores to contribute to a lower overall total score (TS). A TS was determined for each day [Table 1].

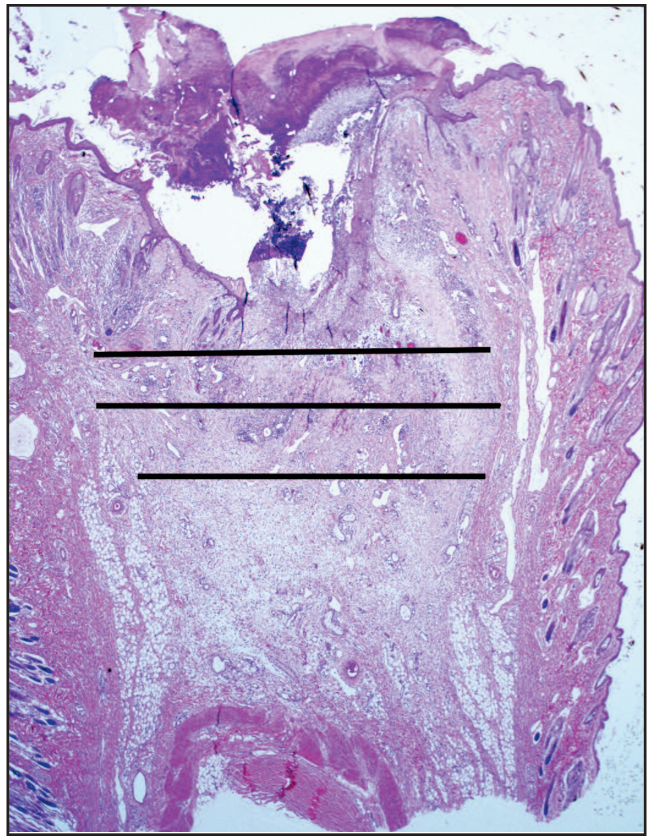

Figure 2—Day 7: Total lesion width was determined for each digit by measuring across the entire bed of granulation tissue that was filling the lesion (bars). Three separate length measurements were made and averaged for each image.

Statistical Analysis

All analyses were performed using SAS V 9.1.[l] Treatment differences were evaluated using an analysis of variance (ANOVA). Factors included in the model were treatment, cat, and front/back (confounded with surgeon effect) and all two-way and one three-way interaction effects. The ANOVA was implemented in PROC GLM in SAS V 9.1.

If significant two-way treatment interactions (either treatment versus cat or treatment versus front/back) were present, it would indicate that the treatment effect was not consistent among cats or between surgeons (front and back). In this case, separate ANOVAs were performed for front and back or for each cat, depending on which interaction effect was significant. The separate ANOVAs included factors for treatment and either front/back or cat and a treatment by front/back or cat interaction effect. A P value <0.05 was considered statistically significant.

Results

Intraoperative observations of CO_2 laser onychectomy made by both surgeons included char in the surgical field with no hemorrhage; difficult dissection because of manipulation of the ceramic tip so that the second phalanx was not damaged; and, yet, easier control of incisional depth. Intraoperative observations of RF onychectomy made by

Table 1

Definitions of Terms for Objective and Subjective Measurements/Scoring for Days 1, 3, and 7 Post-onychectomy

Parameter	Measured	Definition
Total lesion width (TLW)	Days 1, 3, 7	Objective measurement in microns (from the edge of the incision to the delineation between normal and abnormal tissue)
Total lesion width score (TLWS)	Days 1, 3, 7	Conversion of TLW from a range of microns to a whole number (1= 0-400 microns; 2 = 400-800 microns; 3 = 800-1200 microns; 4 = >1200 microns)
Total necrosis width (TNW)	Days 1, 3	Objective measurement in microns (from the edge of the incision to the far edge of necrosis that surrounded the incision)
Total necrosis width score (TNWS)	Days 1, 3	Conversion of TNW from a range of microns to a whole number (1 = 0-400 microns; 2 = 400-800 microns; 3 = 800-1200 microns; 4 = >1200 microns)
Edema score (ES)	Days 1, 3, 7	Subjective scoring (0-4) based on degree of edema (0-none; 1=minimal; 2=mild; 3=moderate; 4=severe)
Hemorrhage score (HS)	Days 1, 3, 7	Subjective scoring (0-4) based on amount of hemorrhage (0-none; 1=minimal; 2=mild; 3=moderate; 4=severe)
Inflammation score (IS)	Days 1, 3, 7	Subjective scoring (0-4) based on degree of inflammation (0-none; 1=minimal; 2=mild; 3=moderate; 4=severe)
Necrosis score (NS)	Day 7	Subjective scoring (0-3) based on amount of necrosis (0-none; 1=mild; 2=moderate; 3=severe)
Granulation score (GS)	Day 7	Subjective scoring (0-3) based on amount of bridging by granulation (0 = complete bridging; 1 = ≥75%; 2 = 25%-75%; 3 = <25%)
Reepithelialization score (RES)	Day 7	Subjective scoring (0-3) based on amount of reepithelialization (0 = complete epithelialization; 1 = ≥75%; 2 = 25%-75%; 3 = <25%)
Total score (TS) for digits harvested on days 1 and 3 post-onychectomy	Days 1, 3	Sum of TLWS, TNWS, ES, HS, and IS Total possible score = 20
Total score (TS) for digits harvested on day 7 post-onychectomy	Day 7	Sum of TLWS, NS, ES, HS, IS, GS, and RES Total possible score = 25

both surgeons included a clean surgical field with minimal hemorrhage, quick and accurate dissection with the wire tip, but difficult control of incisional depth.

All 12 limbs operated with RF had clinical hemorrhage that required bandages immediately after cats recovered from general anesthesia. In contrast, none of the CO_2 laser limbs required bandages. Five bandages were removed prematurely by case nos. 1 (hind limb), 3 (forelimb), 5 (forelimb), and 6 (both limbs) on the day of surgery. Case no. 5 required replacement of the bandage on day 2 postsurgically because of continued hemorrhage. All other bandages were removed the morning of the first postoperative day without complication. Rescue buprenorphine was not required for any cat following surgery.

Histopathology

Day 1 Post-onychectomy (Case Nos. 1, 2). No significant difference was seen in TLW between RF and CO_2 laser on day 1 post-onychectomy [Table 2]. All incisions were surrounded by a rim of coagulative necrosis. No significant difference was seen in TNW between the two modalities. Necrosis was variable in width for both modalities, but it was more difficult to discern between normal and necrotic tissue in RF digits compared with CO_2 laser digits. While the rim of necrosis with the CO_2 laser was well demarcated, the distinction between normal and necrotic tissue was less obvious with RF.

For both treatment modalities, the dermis surrounding the area of necrosis was typically edematous, with loosening and separation of collagen fibers and occasional accumulation of lightly staining proteinaceous fluid. The mean ES was greater with the CO_2 laser than with RF. The area of edema for both RF and CO_2 laser had variable amounts of hemorrhage and neutrophilic infiltration. The RF digits had a greater HS compared to CO_2 laser digits. While the IS was greater with the RF digits compared to the CO_2 laser digits, the difference was not consistent between surgeons [Table 3]. The TS also differed between surgeons. The TS was

Table 2

Comparison of Means±Standard Deviations for Various Parameters Between CO_2 Laser and Radiofrequency (RF) on Day 1 Post-onychectomy*

Parameter	CO_2 Laser	RF	*P* Value
Total lesion width (microns)	1484.9±621.8	1504.7±708	0.960
Total lesion width score	3.5±1.2	3.4±1.5	0.653
Total necrosis width (microns)	517.4±322.7	373.0±241.3	0.095
Total necrosis width score	1.6±0.6	1.4±0.5	0.211
Edema score†	2.8±0.9	2.2±0.8	0.042
Hemorrhage score†	0.6±1.2	2.0±1.6	0.005
Inflammation score†	1.3±0.5	1.8±0.8	0.030
Total lesion score	9.8±2.8	10.8±3.2	0.360

* Three-way analysis of variance, treatment main effect type III *P* value
† Significant findings

Table 3

Treatment Differences Listed as Means for Parameters With Significant Surgeon Interactions for Digits Harvested on Day 1 Post-onychectomy

	Forelimb Surgeon		Hind-limb Surgeon	
Parameter	CO_2 Laser	RF*	CO_2 Laser	RF*
Inflammation score	1.0	2.1†	1.6	1.5
Total lesion score	8.2	11.2†	11.8	10.4

* RF=radiofrequency
† $P<0.05$

greater with RF for the forelimbs but not for the hind limbs; however, the difference did not interfere with the overall treatment effect. Regardless of the treatment modality or surgeon, differences between the digits of the two cats (case no. 2 digits were greater than case no. 1 digits) were seen for TNW, NS, and TS, but these differences did not interfere with the overall treatment effect.

Day 3 Post-onychectomy (Case Nos. 3, 4). No significant difference in TLW between RF and CO_2 laser for postsurgery on day 3 was seen [Table 4]. For both modalities, the lateral edges of the incisional defects were surrounded by a rim of coagulative necrosis that was variable in width (being wider near the epidermal surface). Overall, TNW was not significantly different between RF and CO_2 laser; however, this finding was not consistent between cats [Table 5]. The TNW score (TNWS) was greater with the CO_2 laser for case no. 4 but was not different between the two treatment modalities for case no. 3.

The surrounding dermis for all incisions had variable degrees of edema, hemorrhage, and neutrophilic infiltration. The edema was characterized by loosening and separation of the dermal collagen fibers. Stainable proteinaceous fluid was often present. Unlike on day 1 postoncychectomy, the ES was greater with RF compared to CO_2 laser; however, the difference was not consistent between cats. The difference between the two treatments for case no. 3 was not significant, but the ES for case no. 4 was higher with RF than with CO_2 laser.

Overall, a greater HS was associated with RF compared to the CO_2 laser; however, this was not consistent between surgeons or cats. The HS was greater with RF in the thoracic limbs, but the difference was not significant between the two treatments in the pelvic limbs. Case no. 3 had no significant difference in HS between RF and CO_2 laser on day 3; however, case no. 4 had significantly greater HS with RF.

The difference in the IS with RF was significantly greater than with the CO_2 laser. The TS was not significantly different between RF and CO_2 laser. Regardless of the treatment modality or surgeon, a significantly greater TNW was present for case no. 3 than for case no. 4, but this difference did not interfere with the overall treatment effect.

Day 7 Post-onychectomy (Case Nos. 5, 6). As with days 1 and 3, no significant difference was seen in TLW between RF and CO_2 laser for day 7 postsurgery [Table 6]. No significant difference was present in overall NS between RF and CO_2 laser; however, this was not consistent between cats. Case no. 5 had a greater NS with the CO_2 laser compared to RF, but case no. 6 had no significant difference between treatment modalities [Table 7].

The tissues had variable amounts of edema (more severe around the incision) that was typically infiltrated with numerous neutrophils and lesser numbers of macrophages. On day 7 following surgery, the ES with the CO_2 laser was greater than with RF. Hemorrhage was variably present in the tissue. When present, it was accompanied by erythrophagocytosis and hemosiderosis. No significant difference was seen in the HS between RF and CO_2 laser. The IS was greater with RF compared to CO_2 laser.

Granulation tissue partially or completely bridged all incisions and infiltrated surrounding tissues. Of the 18 digits removed via RF, only 17 were evaluated for bridging of granulation tissue and reepithelialization because of damage

Table 4

Comparison of Means±Standard Deviations Between CO_2 Laser and Radiofrequency (RF) for All Given Parameters on Day 3 Post-onychectomy*

Parameter	CO_2 Laser	RF	*P* Value
Total lesion width (microns)	1490.8±527.6	1449.9±412.6	0.924
Total lesion width score	3.6±1.0	3.4±0.8	0.784
Total necrosis width (microns)	712.2±244.5	622.1±433.5	0.288
Total necrosis width score	2.1±0.6	2.0±0.8	0.473
Edema score†	1.3±0.7	1.8±0.9	0.049
Hemorrhage score†	1.1±1.3	2.2±1.7	0.020
Inflammation score†	1.4±0.6	2.1±0.6	0.006
Total lesion score	9.5±3.0	11.4±2.8	0.080

* Three-way analysis of variance, treatment main effect type III *P* value
† Significant findings

Table 5

Treatment Differences Listed as Means for Parameters With Significant Interactions for Data Collected on Day 3 Post-onychectomy

	Forelimb Surgeon		Hind-limb Surgeon	
Parameter	**CO_2 Laser**	**RF***	**CO_2 Laser**	**RF***
Hemorrhage score	0.2	2.3†	2.3	2.0

	Case No. 3		Case No. 4	
Parameter	**CO_2 Laser**	**RF***	**CO_2 Laser**	**RF***
Necrosis score	2.1	2.5	2.2†	1.4
Edema score	1.6	1.4	1.0	2.2†
Hemorrhage score	1.5	1.2	1.0	3.1†

* RF=radiofrequency
† $P<0.05$

Table 6

Comparison of Means±Standard Deviations Between CO_2 Laser and Radiofrequency (RF) for All Given Parameters on Day 7 Post-onychectomy*

Parameter	CO_2 Laser	RF	*P* Value
Total lesion width (microns)	2896.7±897.6	2951.7±1068.5	0.913
Total lesion width score	5.9±1.3	5.8±1.2	0.764
Necrosis score	1.8±1.1	1.6±0.9	0.262
Edema score†	1.7±0.9	1.0±0.8	0.004
Hemorrhage score	1.4±0.8	1.6±1.0	0.593
Inflammation score†	2.5±0.9	3.1±1.0	0.011
Granulation score†	1.8±0.9	1.1±1.1	0.027
Reepithelialization score	1.1±0.3	0.8±0.7	0.136
Total lesion score	16.1±3.0	15.0±3.7	0.129

* Three-way analysis of variance, treatment main effect type III *P* value
† Significant findings

to one digit during processing. Of the 17 digits evaluated, six (35.3%) had complete bridging of the incision with granulation tissue, six (35.3%) had >75% bridging across the incision, two (11.8%) had 25% to 75% bridging, and three (17.6%) had <25% bridging. Of 18 CO_2 laser digits, one (5.6%) had complete bridging, five (27.8%) had >75% bridging across the incision, eight (44.4%) had 25% to 75% bridging, and four (22.2%) had <25% bridging. The GS for RF digits was lower than that for CO_2 laser digits, indicating more bridging of the RF digits by granulation tissue;

Table 7

Treatment Differences Listed as Means for Parameters With Significant Case Interactions

	Case No. 5		Case No. 6	
Parameter	CO_2 Laser	RF*	CO_2 Laser	RF*
Necrosis score	2.5†	1.6	1.2	1.5
Granulation score	2.1†	0.6	1.5	1.5
Total lesion score	16.3†	12.8	15.8	16.5

* RF=radiofrequency
† $P<0.05$

however, this was not consistent between cats. Case no. 5 had significantly lower GS (i.e., more granulation) with RF than with CO_2 laser, whereas case no. 6 had no significant difference between the two treatment modalities.

The epidermis at the edge of the incision was typically hyperplastic and starting to migrate over the lesion for both modalities. Six (35.3%) of 17 RF digits had complete reepithelialization by day 7 post-onychectomy, but reepithelialization was not complete for any of the CO_2 laser digits. Reepithelialization scores were not significantly different between RF and CO_2 laser. Variable amounts of necrotic tissue were trapped in the healing incisions for both modalities. Along the unhealed margins of the CO_2 laser incisions, unlike the RF incisions, the tissue was pale and hyalinized with necrotic vessels.

The mean TS was not significantly different between RF and CO_2 laser; however, this was not consistent between cats. Case no. 5 had significantly greater TS with CO_2 laser compared to RF, whereas case no. 6 showed no significant difference between the two treatments. Regardless of the treatment modality or cat, greater NS, ES, HS, and TS were present for the thoracic limb digits than for the pelvic limb digits. Regardless of the treatment modality or surgeon, significant differences between the two cats were seen for NS, IS, and HS. Case no. 5 had a greater NS, whereas case no. 6 had a greater IS and HS.

Discussion

In this study, onychectomy performed by RF had similar collateral tissue damage compared to that with the CO_2 laser. Radiofrequency onychectomies demonstrated more tissue bridging with granulation tissue 7 days following surgery, and more inflammation was identified at all time intervals with RF compared to the CO_2 laser.

Edema was increased on day 3 with RF, whereas on days 1 and 7 edema was increased with the CO_2 laser. One limitation of the study was the inability to follow each cat from days 1 through 7 post-onychectomy. This made it difficult to evaluate the progression of each parameter over time and to determine its relationship to healing, if any. Inherent differences exist among cats regarding temperament, response to pain, and ability to heal. Therefore, to directly compare the edema between the different time intervals was difficult, because it was observed in different cats. For example, case nos. 3 and 4 possibly did not have as much edema on day 1 as case nos. 1 and 2.

Subjective evaluations of minimal intraoperative hemorrhage with RF and (more importantly) the postoperative hemorrhage requiring a bandage as opposed to the CO_2 laser led to the conclusion that RF is less efficient in hemostasis than the CO_2 laser. Therefore, it was not surprising on days 1 and 3 to find that the RF digits had significantly more hemorrhage histopathologically than CO_2 digits.

With increased hemorrhage, one would expect increased inflammatory mediators to incite inflammation, which is the first phase of healing leading to granulation and epithelialization. Inflammation was increased at all time intervals with RF. Another factor that may have affected the amount of inflammation was the experience of the two surgeons. Differences will exist between surgeons regarding experience and surgical technique. For all parameters where significant interaction was found between surgeons and treatment modalities (i.e., day 1 IS and TS and day 3 HS), the forelimb surgeon and the CO_2 laser had consistently lower ISs than RF. In the authors' experiences, pelvic limb declaws are subjectively more challenging to perform than thoracic limb declaw procedures, which may have confounded the differences between surgeons. The increased difficulty with pelvic limb declaws may or may not be related to the frequency of performing elective thoracic limb versus pelvic limb declaw procedures or possible anatomical differences between the two sites. Both surgeons were properly trained to use CO_2 laser and RF for feline onychectomy prior to the study; however, the forelimb surgeon had more clinical experience with CO_2 laser than with RF, and the hind-limb surgeon had only a modest amount of clinical experience with both devices. The decision to use two surgeons was based on evaluation of whether or not surgeon experience would play a major role in the collateral tissue damage between RF and CO_2 laser. No major confounding interactions affected overall treatment differences between the two surgeons in this study.

Incisional bridging by granulation tissue was significantly increased with RF compared to the CO_2 laser on day 7; however, because of the lack of further evaluation at a time period following healing, no direct conclusion can be made about healing. The majority of RF limbs required bandaging postoperatively. Bandages can decrease arterial blood supply and venous return by creating a tourniquet-like effect. In addition, they can also increase local wound temperature, creating a positive environment for healing. Although the bandages were only placed on the limbs for a short period of time, they may have confounded the overall results in healing.

Silverman *et al* reported that RF surgery resulted in the least amount of coagulation artifact when compared to other heat-generating devices (laser and monopolar electrocautery) used for canine skin biopsies.[11] Lesions in that study were classified based on the amount of "char penetration." In the present study, the collateral tissue damage was broken down into specific characteristics describing the lesions (i.e., edema, hemorrhage, inflammation, necrosis). The TLW and TS were not significantly different between RF and CO_2 laser for any of the days evaluated in the current study.

A study by Rizzo *et al* reported that the depth of thermal injury created by the CO_2 laser for canine skin biopsies was 0.31 to 0.41 mm.[17] In the Silverman *et al* study comparing heat-generating devices for canine skin biopsies, the lateral tissue damage was 0.215 mm with the CO_2 laser and 0.154 mm with RF.[11] The extent of lateral tissue damage (i.e., TLW) in the present study was 1.48 mm on day 1, 1.49 mm on day 3, and 2.90 mm on day 7 post-onychectomy with the CO_2 laser; with RF, the extent of TLW was 0.37 mm on day 1, 0.622 mm on day 3, and 2.95 mm on day 7 post-onychectomy. These distances are greater than previously reported for either modality and may be the result of surgical procedure (skin biopsy versus onychectomy), surgeon experience, pathologists' interpretation, timing of specimen collection, power settings, tissue contact time (hand speed), or type of electrode/tip used. The histopathological descriptions in the two previously mentioned studies evaluated depth of char and coagulative necrosis; however, it is difficult to determine whether or not the lesions in those studies included the surrounding inflammatory changes as well.

Another factor to take into consideration is timing of the specimen collection. The first collection of the digits in the present study occurred 24 hours following surgery, whereas in previous reports the collection of biopsy specimens was immediate, and the portion evaluated was the excised tissue. The delay in collection in the present study may have allowed more time for further inflammation and necrosis to occur prior to histopathological evaluation. Also, in this study, topical tissue adhesive was used for closure of the onychectomy incisions. Because tissue adhesive is not sterile or absorbable, a foreign body reaction may have occurred if any of the adhesive entered the wound from the surrounding skin, thereby confounding the study results. No evidence of foreign material was seen in the histological sections, and since both treatment modalities were closed in the same manner, any confounding histopathological results would likely affect both treatment groups to a similar degree.

Power settings, tip size, and mode for the CO_2 laser have been reported, but no "gold standard" has been established for use when performing a feline onychectomy. When utilizing the CO_2 laser, the power settings are adjusted based on the hand speed of the surgeon and the amount of carbonization or char formation produced during the procedure. The combined experiences of the authors have shown that most elective declaw procedures on younger cats require lower power settings than what is required for more mature cats. Because this study involved adult cats, the power settings were adjusted to optimize ease of dissection and minimize char formation.

The initial waveform, power settings, and type of electrode used for RF were based on the manufacturer's recommendations. The power intensity was adjusted to minimize the amount of tissue resistance (identified with too low of a power setting) and carbonization of tissue causing sparking (identified with too high of a setting). According to the manufacturer, the passive electrode (also known as the antenna) only needs to be near the patient and not in direct contact with the skin of the patient; however, the closer the passive electrode is to the surgical site, the less power is required to achieve the desired results, thereby decreasing lateral thermal damage.[8]

In this study, the plate was placed under the thorax to minimize and equalize the distance for radiowaves to travel through the forelimbs and hind limbs. The types of waveforms range from cutting to fulguration of tissue. The cutting mode is fully filtered (restricts passage of certain frequencies) and fully rectified (converts radiowaves to electrical current), which allows 90% cutting and 10% coagulation. This mode results in micro-smooth cutting, negligible lateral heat, and good cosmetic results with faster healing compared to the cut/coagulation mode. The cut/coagulation (blend) mode is an unfiltered but fully rectified waveform that results in 50% cutting and 50% coagulation. This mode is ideal for subcutaneous tissue dissection; it is appropriate for vascular areas, as it produces minimal amounts of lateral heat and tissue damage while promoting superior healing. The coagulation mode is an unfiltered and partially rectified waveform that results in 10% cutting and 90% coagulation. This mode is ideal for controlled penetration with hemostasis and does not create charring or necrosis of tissue. Fulguration is designed for maximum penetration and hemostasis and is ideal for intentional tissue destruction. Because of hemorrhage and tissue resistance initially identified in the cutting mode, the blended mode was used for the majority of the digits in this study. The coagulation mode was occasionally used to provide adequate hemostasis when vessels were identified during the dissection. The wire tip, with its small diameter, was used for accurate dissection. Despite not using the initial recommended waveform and power settings for RF, the TLW and TS in this study were comparable to those for the CO_2 laser at all time points.

The CO_2 laser is frequently used in the superpulse mode when performing skin incisions because of the intermittent tissue relaxation time that results in less collateral tissue damage. In the authors' experience, the superpulse mode is not as successful for hemostasis during onychectomy as it is with skin incisions on other areas of the body. Hemorrhage is increased with adult compared to juvenile feline onychectomy; therefore, the continuous mode was chosen, and this may have led to increased collateral tissue damage associated with the CO_2 laser. The power density is directly related to the power setting and indirectly related to the size of electrode used. The smaller the tip diameter, the more concentrated the beam of laser light, which produces a precise incision with minimal distribution of heat laterally into the tissue. While the smaller tip size was used, the initial recommended power settings were adjusted, which may have contributed to more lateral thermal damage than the recommended lower power settings.

Conclusion

The results of the current study indicate that use of RF for feline onychectomy is a reasonable alternative to CO_2 laser in regard to collateral tissue damage and bridging of the incision by granulation tissue. In addition, RF is not accompanied by the strict safety considerations and initial expense associated with acquiring a CO_2 laser. The disadvantage of RF, compared to the CO_2 laser, is the increased likelihood of a bandage being required because of hemorrhage following surgery. Despite the increased hemorrhage and inflammation identified with RF, healing did not appear to be negatively impacted. A subsequent study comparing postoperative pain and return to normal function between the use of CO_2 laser and RF following feline onychectomy is indicated to clinically compare the two treatment modalities.

Footnotes

[a] Meloxicam; Boehringer Ingleheim Vetmedica, St. Joseph, MO 64506
[b] Butorphanol; Fort Dodge Animal Health, Fort Dodge, IA 50501
[c] Acepromazine; Vedco, Inc., St. Joseph, MO 64507
[d] Isoflurane; Abbott Laboratories, North Chicago, IL 60064
[e] Nexaband S/C; Closure Medical Corporation, Raleigh, NC 27616
[f] Luxar Novapulse 20W CO_2 Laser, Model ±LX-20 SP; Luxar Corporation, Bothell, WA 98011
[g] Luxar 0.25-mm ceramic tip; Luxar Corporation, Bothell, WA 98011
[h] Ellman Surgitron 4.0 MHz Dual RF; ellman International, Inc., Oceanside, NY 11572
[i] Ellman A8 bendable electrode; ellman International, Inc., Oceanside, NY 11572
[j] Buprenorphine; Hospira, Inc., Lake Forest, IL 60045
[k] Image Pro Plus; Media Cybernetic, Inc., Bethesda, MD 20814
[l] Statistical Analysis Software V9.1; SAS Institute Inc., Cary, NC 27513

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