



Original Article

# Comparative assessment of thermal injury induced by bipolar electrocautery systems in a porcine model

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## ABSTRACT

**Background:** Bipolar electrocautery systems used during neurosurgical procedures have been shown to induce thermal injury to surrounding tissue. The goal of this study was to compare the thermal injury induced by two different systems commonly used in neurosurgical procedures (Silverglide by Stryker Corporation and Spetzler-Malis by Codman Neuro), with that of a newly introduced device (TRIOwand by NICO Corporation).

**Methods:** A farm swine underwent craniectomy and durotomy with subsequent exposure of cortical brain tissue. Electrocoagulation for the duration of 3 s was conducted with three different bipolar systems under comparable power settings. The maximal depth of thermal injury and mean area of injury in Hematoxylin and Eosin stained slides were quantified using Image J. The tissues were evaluated for vacuolization and ischemic damage. One-way ANOVA followed by *post hoc* Tukey test was utilized for statistical analysis. Alpha level was set at 0.05.

**Results:** TRIOwand lesions showed less depth of injury when compared to both Spetzler-Malis ( $P < 0.001$ ) and Silverglide lesions ( $P = 0.048$ ). Silverglide lesions showed significantly less depth of injury when compared to Spetzler-Malis lesions ( $P < 0.001$ ). The injury area induced by the TRIOwand was significantly less than that of Spetzler-Malis ( $P < 0.001$ ) and Silverglide systems ( $P < 0.001$ ). Ischemic changes and vacuolization were seen in all three groups.

**Conclusion:** Thermal damage is induced to varying extents by all bipolar systems. In this porcine model and under the conditions tested, bipolar cauterization with the TRIOwand resulted in less depth and decreased mean area of injury. Further studies are needed to characterize the injury caused by different bipolar systems with other settings and under surgical conditions in humans.

**Keywords:** Bipolar, Electrocautery, Porcine, Thermal damage,

## INTRODUCTION

Bipolar electrocoagulation is a basic technique of modern neurosurgery and has undergone significant technological improvements since its introduction in 1940 by James Greenwood.<sup>[5,8,11]</sup> Standard microsurgical dissection techniques in neurosurgery routinely involve bipolar electrocoagulation in close proximity to cranial nerves and critical cerebral vasculature. Iatrogenic collateral damage to tissue from bipolar electrocoagulation can occur and result in damage to critical structures, diminished functionality and worse patient outcomes.

Several techniques, including the use of active heat transfer and continuous irrigation have been introduced to minimize heat transfer away from the site of electrocoagulation along with

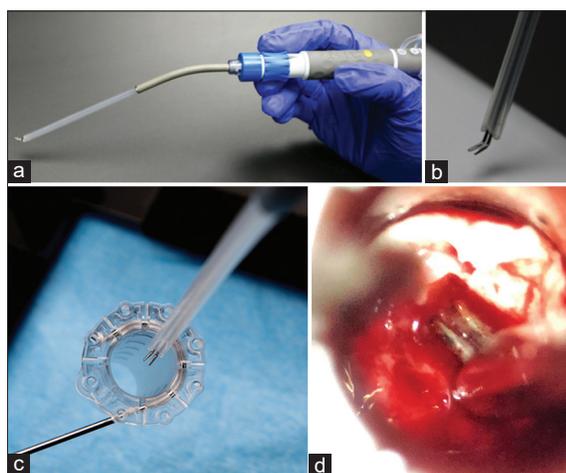
minimizing charring and tissue adherence.<sup>[2-4]</sup> The Spetzler-Malis (Codman Neuro, Raynham, MA) and Silverglide bipolar forceps (Stryker, Kalamazoo, MI) are among the most commonly used systems in cranial neurosurgery.

The TRIOwand bipolar cautery system (NICO Corporation, Indianapolis, Indiana) was recently introduced for working in narrow and deep surgical corridors that require minimal access ports for treatment of lesions located in the subcortical white matter or the cerebral ventricles [Figure 1]. To serve this purpose this system was designed with a fixed opening at the tip that reaches targets at 10 cm from the surface, it provides continuous and simultaneous suction and irrigation for maximized visibility of the bleeding source, and maintains an ergonomic profile that prevents the hand of the operator from blocking the visualization of the surgical field when working down the minimal access port. The current study was designed to assess the extent of thermal injury resulting from cortical coagulation in a live porcine brain model using the TRIOwand and to compare it to the thermal injury caused by the Spetzler-Malis and Silverglide systems under similar experimental conditions.

## METHODS

### Experimental design

Bipolar electrocautery is primarily employed for hemostasis during active bleeding, which is difficult to accurately replicate in experimental settings. Repeated measures in the same subject are required as physiological animal conditions such as blood pressure, rheology, vessel diameter, and others can vary significantly among subjects despite standardized anesthetic and surgical techniques. Thus our study focused on assessment of tissue damage due to heat transfer for a fixed duration of time under nonhemorrhagic conditions in a single subject. The frontal and parietal cortical surface of a swine was divided into three separate regions for electrocoagulation utilizing



**Figure 1:** (a and b) NICO TRIOwand for port based access. (c) TRIOwand inside the sheath (d) TRIOwand in the field.

three different bipolar systems. Region 1 was cauterized using the Spetzler-Malis bipolar with a Codman generator set at 25 “Malis Units.” Region 2 was cauterized using the TRIOwand with a Valley Lab generator set at 4 watts. Region 3 was electrocoagulated using the Silverglide with a Valley Lab generator set at 4 watts. The Spetzler-Malis generator manual provides a manufacturer generated equivalency from the “Malis units” to the standard Watt output in the Valley lab generator and these settings were tested in the soft tissues of the animal before cortical brain cauterization for macroscopic cauterization equivalency as subjectively estimated by the neurosurgeon. Within each region, seven separate lesions were made, with each lesion requiring active cauterization for 3 s. The lesions were made without the use of irrigation to assess for maximal possible injury for the duration of electrocoagulation. The VITOM HD II Exoscope (Karl Storz, El Segundo, CA) was used for image acquisition and video documentation. All animal procedures were approved by T3 Labs Institutional Animal Care and Use Committee. All experimental studies comply with animal care complied with the Guide for the Care and Use of Laboratory Animals. All bipolar systems tested have received FDA approval for clinical human use.

### Surgical technique

A farm swine greater than 30 kg was utilized in the study, and the surgery was performed in a dedicated surgical animal facility (T3 Labs, Atlanta, GA). The animal was placed in a ventral recumbent position and administered flunixin 2.0 mg/kg IM and atropine 0.05 mg/kg IM for preoperative management. Anesthesia was subsequently induced using ketamine 20 mg/kg with xylazine 2.0 mg/kg IM and maintained using 0.5–5% isoflurane (with nitrous oxide) for the duration of the surgical procedure. A longitudinal midline skin incision was made in the dorsal head. The scalp was retracted and large bilateral craniectomies were completed with a high speed drill, curettes and Kerrison rongeurs. The dura was subsequently opened and three separate cortical regions were identified with lesions performed as described earlier [Figure 2]. The animal’s blood pressure was noninvasively monitored and maintained within normal range and corrected for any drastic changes. The surgery was planned as a nonsurvival surgery, and the animal was euthanized shortly after the completion of the surgical procedure using KCL (1–2 mEq/kg) IV under deep anesthesia. Before the euthanasia, the animal was administered heparin 300 IU/kg for 15 min to avoid coagulation during perfusion.

### Tissue preparation and histological quantification of thermal injury

Transcardiac perfusion with physiological saline solution followed by 10% buffered formalin was performed after euthanasia following which the brain was harvested. *Ex vivo*

fixation was performed in buffered formalin 10% for 2 weeks. The brain tissues were cut into three tissue blocks for each bipolar region tested, processed, and embedded in paraffin. Tissue sections of 5  $\mu\text{m}$  thickness were obtained 20  $\mu\text{m}$  apart using a microtome and stained with Hematoxylin and Eosin (H&E) per manufacturer instructions (Sigma-Aldrich, St. Louis, MO). Briefly, the tissues were deparaffinized and rehydrated using xylene and alcohol. The slides were then stained using H&E stain (Sigma-Aldrich, St. Louis, MO). The light microscope images were taken using Zeiss Axioskop 2 (Oberkochen, Germany) under  $\times 5$  magnification. The maximal depth of thermal injury was defined as the vertical line from cortical surface to the point of deepest injury and measured manually by Image J (National Institute of Health, Bethesda, Maryland). Similarly, area of injury was traced manually and quantified using with Image J (National Institute of Health, Bethesda, Maryland).<sup>[10]</sup> The measurements were performed by two-blinded investigators. The tissues were also evaluated for histologic evidence of cautery effects (such as parenchymal rarefaction) and ischemic damage by an independent pathologist blinded to the experimental groups.

### Statistical analysis

Statistical analysis was performed using SPSS 22.0 (IBM Corporation, North Castle, NY) software. Maximal depth of injury and mean area of injury were compared across groups using one-way ANOVA followed by *post hoc* Tukey test for multiple group comparisons. All results were expressed as mean  $\pm$  SEM. The criterion for statistical significance was set at  $P < 0.05$ .

## RESULTS

### Gross pathological examination

The craniectomy and cortical coagulation were completed without complications. Intraoperative images acquired during and after coagulation represent the extent of gross tissue damage and are displayed in [Figure 2].



**Figure 2:** Cranial exposure of porcine brain. (a and b) Gross anatomical appearance before and after electrocautery with TRIOwand (c and d) Gross anatomical images before and after electrocautery with Spetzler-Malis (e and f) Gross anatomical images before and after electrocautery with Silverglide. (Area of interest is marked in circle).

### Maximal depth of injury

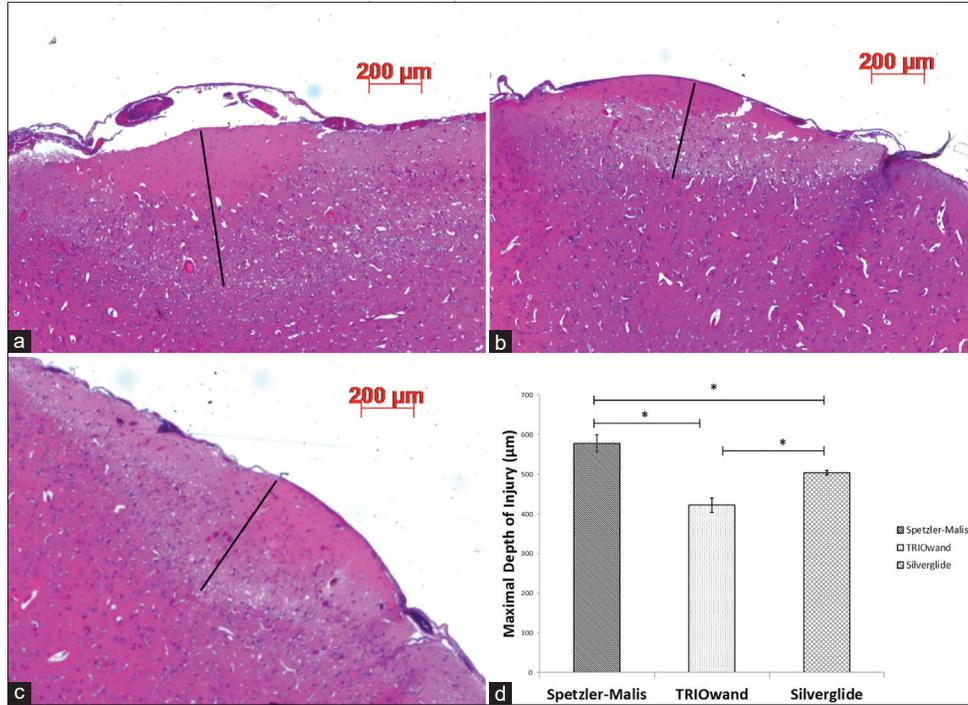
The maximal depth of injury was significantly different among all groups ( $p < 0.001$ ). Multiple group comparison using *post hoc* Tukey test showed that TRIOwand cauterization resulted in significantly less depth of injury when compared to both Spetzler-Malis (TRIOwand:  $421.8 \pm 18.7 \mu\text{m}$  vs. Spetzler-Malis:  $577.3 \pm 21.7 \mu\text{m}$ ;  $P < 0.001$ ) and Silverglide cauterization (TRIOwand:  $421.8 \pm 18.7 \mu\text{m}$  vs. Silverglide:  $483.5 \pm 5.8 \mu\text{m}$ ;  $P = 0.048$ ). Silverglide cauterization caused significantly less injury depth compared to Spetzler-Malis cauterization (Silverglide:  $483.5 \pm 5.8 \mu\text{m}$  vs. Spetzler-Malis:  $577.3 \pm 21.7 \mu\text{m}$ ;  $P < 0.001$ ) and significantly greater depth of injury than the TRIOwand (Silverglide:  $483.5 \pm 5.8 \mu\text{m}$  vs. TRIOwand:  $421.8 \pm 18.7 \mu\text{m}$ ;  $P = 0.048$ ). The results are demonstrated in [Figure 3].

### Mean area of injury

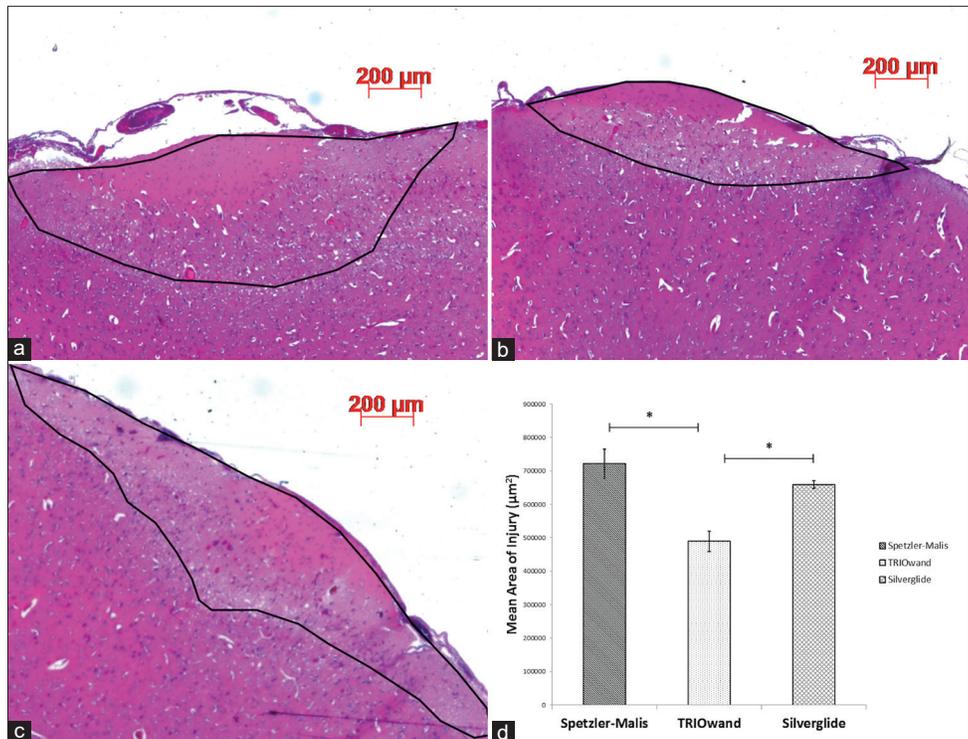
The total area of injury differed significantly among all groups as well ( $p < 0.001$ ). Multiple group comparison using *post hoc* Tukey test showed that the injured area resulting from cauterization with the TRIOwand was significantly less than that of the Spetzler-Malis (TRIOwand:  $489349.8 \pm 31005.3 \mu\text{m}^2$  vs. Malis:  $721129.6 \pm 43269.9 \mu\text{m}^2$ ;  $P < 0.001$ ) and the Silverglide (TRIOwand:  $489349.8 \pm 31005.3 \mu\text{m}^2$  vs. Silverglide:  $719561.4 \pm 10960.0 \mu\text{m}^2$ ;  $P < 0.001$ ). Moreover, the areas of injury caused by the Spetzler-Malis and Silverglide systems were not significantly different than each other (Spetzler-Malis:  $721129.6 \pm 43269.9 \mu\text{m}^2$  vs. Silverglide:  $719561.4 \pm 10960.0 \mu\text{m}^2$ ;  $P = 0.99$ ), the results of histological analysis are represented in [Figure 4].

### Ischemic damage and rarefaction

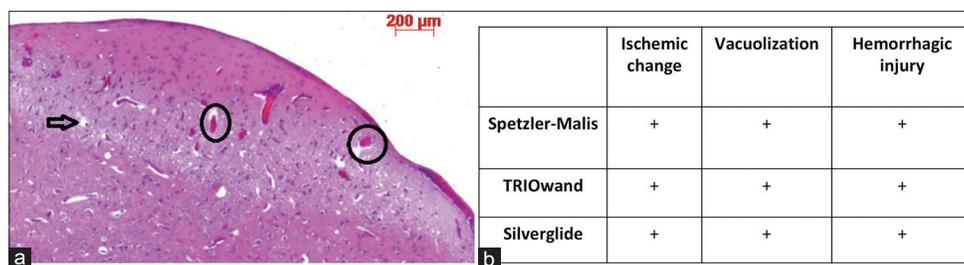
All histological slides were assessed for evidence of rarefaction and ischemic injury. All three groups showed ischemic injury and rarefaction as demonstrated in [Figure 5].



**Figure 3:** Maximal depth of injury. (a) Spetzler-Malis bipolar forceps (b) NICO TRIOwand (c) Silverglide bipolar forceps. (d) TRIOwand cauterization resulted in significantly less depth of injury when compared to both Spetzler-Malis and Silverglide. Silverglide cauterization caused significantly less injury depth compared to Spetzler-Malis cauterization and significantly greater depth of injury than the TRIOwand.



**Figure 4:** Mean area of injury. (a) Spetzler-Malis bipolar forceps (b) NICO TRIOwand (c) Silverglide bipolar forceps. (d) The injured area resulting from cauterization with the TRIOwand was significantly less than that of the Spetzler-Malis and the Silverglide. Moreover, the areas of injury caused by the Spetzler-Malis and Silverglide systems were not significantly different than each other.



**Figure 5:** (a) Representative areas of hemorrhagic injury (ovals) and vacuolization (arrows) (b) Ischemic change, hemorrhagic injury, and vacuolization were seen in all three bipolar systems.

## DISCUSSION

The current study provides histological assessment of thermal injury in a porcine brain after bipolar electrocoagulation. The results demonstrate a greater depth and area of injury with Spetzler-Malis bipolar forceps as compared to Silverglide and TRIOwand forceps.

Several advances in bipolar cauterization technologies have been developed since its first introduction in 1940 by Greenwood. Significant improvements were made to bipolar technology by Dr. Leonard Malis with the introduction of the CMC I, II, and III systems.<sup>[8]</sup> The use of irrigation either with an assistant or through the bipolar itself has long been known to minimize tissue adherence and improve bipolar functionality.<sup>[8]</sup> The TRIOwand device was developed with an automated drip irrigation system and variable suction, in addition to its main function of providing coagulation. Heat dissipation has also been found to be a key factor in bipolar functionality as seen with IsoCool bipolar forceps (Codman Neuro, Raynham, Massachusetts) which employs Active Heat Transfer using fluid filled heat pipes to dissipate heat.<sup>[2-4]</sup> Several studies have confirmed the decreased heat spread with IsoCool bipolar forceps.<sup>[1-4]</sup> Chen *et al.* found that IsoCool and Silverglide bipolar forceps to have reduced thermal spread as compared to regular stainless steel and titanium bipolar forceps in a porcine model.<sup>[1]</sup> In a sheep model of spinal cord surgery, Elliott-Lewis *et al.* found the severity of thermal injury was decreased in segments coagulated with bipolar forceps that incorporated heat pipe technology.<sup>[3]</sup>

The use of different materials to minimize sticking and charring has also received attention. Hsiao *et al.* reported that two major issues in electro-surgery are thermal injury and tissue adherence and they found that the total area of injury of rat brain tissue treated with titanium dioxide layer-coated stainless steel type electrodes was significantly lower than that of untreated electrodes.<sup>[6]</sup> Mikami *et al.* compared gold, titanium, and stainless steel forceps and found significantly lower adherence to gold plated bipolar forceps.<sup>[9]</sup>

Although much focus has been placed on bipolar electrode material and heat dissipation, an equally important principle

of bipolar technology is the overall ergonomics. Current bipolars are designed keeping conventional open surgical approaches in mind. The bayoneted design is especially suited to neurosurgical dissection which involves working down deep, and narrow, surgical corridors while maintaining good visibility. This point is especially important as the advancement of robotic surgery into neurosurgery is demanding automation and multifunctional instrumentation from a single instrument, rather than the inefficiency of continuous instrument exchange. At our center, we have recently adopted port based technologies for parafascicular access to subcortical lesions.<sup>[7]</sup> While the traditional bipolar design can work for these approaches, the TRIOwand is designed specifically as a fluid management system with up-toed graspers which do not open and close, but instead are positioned specifically for port based access to maximize visualization of a bleeding vessel located deep from the brain surface and inside a minimal access port [Figure 1]. We were interested to see if this change in bipolar design would impact thermal spread. Our results here suggest that thermal damage is not increased by this change in design.

It should be noted that the absence of irrigation could certainly have impacted our results but we wanted to measure maximal damage and minimize differences across groups. It is also reasonable to hypothesize in a real world situation that the Spetzler-Malis bipolar forceps may simply be able to deal with troublesome bleeding faster and may be used for a shorter duration of time. Our study is not designed to answer this question and future studies will be needed to further address this issue. It is also unclear what these objective differences translate to from a clinical standpoint.

We selected swine as the animal model for this study given the size of its brain and spinal cord. Our goal was to assess thermal damage in anatomical structures that to an extent would mimic real life conditions in the operating room. In addition, pigs are an excellent large animal model in biomedical research since real-time measurement of physiological parameters including blood flow, temperature, tissue oxygenation, perfusion, and diffusion is possible. This can be quite difficult or sometimes impossible to monitor in genetically modified rodent models.

## CONCLUSION

The TRIOwand forceps designed for port based access to deep subcortical and intraventricular pathology were not associated with significantly increased thermal injury when compared to the Spetzler-Malis and Silverglide systems in a swine model under nonhemorrhagic conditions using comparable and clinically relevant power settings. Further testing is required to validate these findings under hemorrhagic conditions in humans.

### Declaration of patient consent

Patient's consent not required as there are no patients in this study.

### Financial support and sponsorship

This study was supported by NICO Corporation (NICO Corporation, Indianapolis, Indiana).

### Conflicts of interest

There are no conflicts of interest.

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