NEURAL OUTCOMES AFTER PLASMA KNIFE DISSECTION: A PATHOLOGIC STUDY AND CLINICAL CORRELATION

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Abstract: Background. The initial aim was to determine the rate of pathologic tissue damage when dissecting the rat sciatic nerve with either bipolar forceps or low-temperature tripolar plasma knife. The second aim was to determine the safety and effectiveness of the plasma knife during parotid surgery.

Methods. A prospective, randomized, single-blind study was performed on 40 rat sciatic nerves dissected by either bipolar electrocautery with a cold knife or a plasma knife. Dissected nerves were excised and submitted blindly to pathology for analysis of nerve injury. The degree of nerve trauma was graded by the Carlander nerve injury classification. Separately, a review was performed on the facial nerve outcomes of 30 patients who underwent plasma knife parotidectomy.

Results. No thermal or neural injury was noted in the 40 rat sciatic nerves dissected by either bipolar electrocautery or plasma knife ($p = 1.0$). Two plasma knife–dissected nerves (8%) demonstrated significant numbers of mast cells in the perineural soft tissue. In 30 patients undergoing plasma knife-parotidectomy, 10 (33%) had mild weakness of 1 or 2 preserved facial nerve branch postoperatively (House-Brackmann 2) that resolved within 1 month, whereas 2 (7%) had visible weakness in 1 branch (HB 3) that normalized after 3 months of follow-up.

Conclusion. Plasma knife nerve dissection seems to be a safe and effective alternative to conventional methods. This technique may confer some advantages over conventional methods with the ability to simultaneously cut and coagulate tissue with minimal thermal spread and electrical stimulation of adjacent neural structures. © 2010 Wiley Periodicals, Inc. Head Neck 32: 1321–1327, 2010

Keywords: plasma knife; facial nerve; parotidectomy; nerve injury

The modern era of parotid surgery began in the 1950s when experienced surgeons noted that removal of parotid tumors with a portion of surrounding normal gland resulted in a much lower incidence of tumor recurrence than simple tumor enucleation alone.¹ These early proponents of superficial parotidectomy stressed that the key component of safe and effective partial parotidectomy was wide exposure of the facial nerve using anatomic landmarks with meticulous dissection of glandular tissue away from the nerve. Adequate hemostasis during parotidectomy is a necessity for optimal identification and tracking of the facial nerve.

There continues to be interest among surgeons to identify surgical instruments that provide hemostasis with minimal facial nerve...
stimulation during parotidectomy. Monopolar electrosurgical devices provide cutting with rapid hemostasis, but they drive current deep into tissues increasing the potential for adjacent tissue damage. Bipolar electrosurgical devices limit tissue damage by only driving current through tissue between the 2 poles of the instrument; however, a separate instrument is usually required for tissue separation.

The low-temperature, tripolar plasma knife is an electrosurgical device designed to provide cutting and hemostasis within a single instrument. Plasma knife technology has been shown to be safe and effective in a number of gynecologic, urologic, and general surgical procedures. The plasma knife has a unique tripolar tip with a central pole with an outer pole on either side. When current is passed from the central pole to the outer poles, a corona of energy is created which provides a blade-like incision. A second current passes from 1 outer pole to the other creating a broader field of coagulation similar to a standard bipolar instrument. The plasma knife rapidly alternates between these 2 currents to cut and coagulate simultaneously. When set at the default setting of 40% cut with 60% coagulation, a mean lateral thermal margin of 0.48 mm is achieved. The surgeon may adjust the amount of time spent between the cutting and coagulation phases to allow for separation of tissue with a selectable level of hemostasis. The device also has a second pedal that allows for the mode to switch to 100% coagulation if a significant bleeder is encountered.

The thermal effects of a plasma knife on nerves has not been studied to date. This is of the utmost importance in head and neck surgery due to the close proximity of cranial nerves during dissection. The present study is a 2-part investigation into the safety and effectiveness of the plasma knife when used to dissect tissue overlying neural tissue. First, the study tested the null hypothesis that there would be no difference between the plasma knife and traditional bipolar cautery in the rate of nerve damage in an animal model. Second, the study reviewed the facial nerve outcomes of 30 patients who underwent plasma knife parotidectomy.

MATERIALS AND METHODS

Approval for the study was obtained from the Medical University of South Carolina Institutional Animal Care and Use Committee (Part 1) and the MUSC Institutional Review Board (Part 2). The study protocol was conceived and written by the coauthors, and all data acquisition, analysis, and manuscript writing was performed by the coauthors without sponsor input. The sponsor (Gyrus AMCI-ENT, Bartlett, TN) provided financial support for the animal portion of the study (Part 1), which included laboratory animals, laboratory rental, surgical devices, and general supplies. No salary support or other financial incentives were included in the budget.

Part 1: Animal Model. The rat sciatic nerve was selected as an optimal model due to size similarities between it and distal branches of the human facial nerve. Twenty-five adult Sprague-Dawley rats (weight 300–400 grams) were obtained. Five rats were utilized to practice the appropriate technique and to recognize any anatomic differences in the rat model. The surgical procedure was standardized with 1 of 2 surgeons performing all operations. Each rat was premedicated with ketamine (75–100 mg/kg) and xylazine (10 mg/kg). General anesthesia was induced and nitrous oxide was delivered using a close-fitting face mask. The rats were maintained on spontaneous ventilation. The rats were placed in the prone position and the hindquarters of each animal were shaved. The left limb was dissected first. Overlying the proximal end of the femur, an incision was made and blunt dissection with Mayo scissors allowed exposure of the lateral fascial line demarcating the anterior and posterior thigh muscle groups. Atraumatic dissection continued in the fascial plane until the sciatic nerve was exposed. Microvascular retractors allowed exposure of the nerve and care was taken not to directly handle the nerve (Figure 1).

After assignment by a 2:1 experiment to control randomization scheme, tissue was dissected from the sciatic nerve using either plasma knife (experimental) or bipolar electrocautery with cold scalpel (control). The instrument was lowered onto the muscle at an approximate distance of 2 mm from the nerve for 5 seconds. The default setting of the plasma knife was utilized which blends 40% cut with 60% coagulate. The 100% coagulation mode (blue pedal) was applied to the overlying tissue for 5 seconds followed by application of the default cut and coagulation blend mode (yellow pedal) until tissue separation. Bipolar coagulation set at 20 mV was
applied to overlying tissue for 5 seconds followed by division of the tissue with a cold steel blade. These are the same settings recommended by the manufacturers and used in clinical practice. At the conclusion of the operation, the animals were killed with pentobarbiturate.

Nerve specimens were collected and fixed in 10% neutral buffered formalin. After fixation, specimens were cut into multiple segments and the cut edges were inked to allow for subsequent identification of proximal to distal relationships. Inked specimens were dehydrated in a series of graded ethanols and cleared in xylene using an automatic tissue processor. Specimens were infiltrated and embedded in paraplast. Multiple segments of each nerve were grouped in 1 composite block. One 5-micron step section was obtained every 50 microns. Three sections were placed on each slide. This resulted in 3 slides/nerve specimens. The 3 slides contained sections at 1-50-100 ums, 150-200-250 ums, and 300-350-400 ums from the tissue block. This allowed sampling of 9 discrete locations separated by at least 50 um from each nerve specimen. The slides were stained routinely with hematoxylin and eosin.

Stained slides were blindly examined by a pathologist with extensive experience in neuropathology. Neuronal features were described utilizing the Carlander classification system as follows: (1) normal: myelin free from vacuoles and no apparent thickening of the myelin sheath; (2) slight injury: small myelin vacuoles and no apparent thickening of the myelin sheath; (3) moderate injury: obvious vacuolization and swelling with thickening of the myelin sheath, causing encroachment on the axon; (4) severe injury: coagulated fibers with myelin sheath that were markedly thickened, homogenous, and pale. Comparisons between groups were made using the Fisher exact test with significance set at $p < .05$.

**Part 2: Clinical Review.** A retrospective review of 30 patients who underwent plasma knife parotidectomy over a 24-month period was performed. The patients were a consecutive series of parotidectomy patients treated by 3 surgeons (M.B.G., E.J.L., J.D.H.) whose operations were performed in the main operating suite at the Medical University Hospital. Patients who received parotidectomy at other locations were not included because the plasma knife device was only available in the main operating suite. Factors related to these patients were prospectively recorded in an MUSC Department of Otolaryngology–Head & Neck Surgery quality assurance database designed to evaluate the safety of the plasma knife for parotidectomy. Factors recorded included patient demographics, indication for parotidectomy, extent of parotidectomy, estimated operative blood loss, operative time, histopathologic findings, tumor size, and House-Brackmann facial nerve scale scores (preop; immediate postop; 1-month postop; and 3-month postop). No paralytics were used during surgery, and facial nerve monitoring was performed using a nerve integrity monitor (Medtronic ENT, Jacksonville, FL) set at a threshold level of 100 mV. During parotidectomy, the plasma knife was used to divide the tissue superficial to the facial nerve in a manner similar to standard technique. The initial 7 cases used the D-plasma knife device, which is analogous to a standard 15 blade with cutting surface on the inferior convex surface, whereas the final 23 cases utilized the J-plasma knife device which has a hook shape analogous to a standard 12 blade.
with cutting surface on the superior, convex surface (Figure 2). The plasma knife default setting of 40% cut/60% coagulation phase was used on the thicker portion of the gland divided to the pes. The setting was then changed to 60% cut/40% coagulation for the thinner gland overlying the individual distal nerve branches.

Statistical Analysis. All analyses were performed with Sigma Stat 3.5, SPSS 15.0, and Sample Power 2.0 (SPSS, Chicago, IL). Categoric variables are presented as percentages and continuous variables are presented as mean (range) in text and tables. All continuous variables were normal distributed as determined by Kolmogorov-Smirnov test. Comparisons of pathologic findings were performed using the chi-square or Fisher exact test (categoric variables). A multiple linear regression model with predictor variables (eg, age, sex, pathology, surgery tumor size, operative time) was used to determine its effects on the outcome variable of postoperative facial paresis. Power calculation could not be done, considering this study was a consecutive case series without a comparison group. The rate of permanent facial nerve injury is only about 1%; therefore, with 30 patients, we only had a 0.33% chance of observing a permanent facial nerve injury if the technique is as good as the traditional technique. A \( p \) value of less than .05 was considered indicative of a statistically significant difference for all tests.

RESULTS

Part 1: Animal Model. Twenty rats underwent bilateral dissection and resection of the sciatic nerve. After randomization, there were 26 limbs (65%) that were dissected using the plasma knife and 14 (35%) with bipolar electrocautery. Muscle twitches were noted with the plasma knife decreasing its precision compared to the bipolar device. There was no observed gross thermal trauma on any of the 40 sciatic nerves. There was no pathologic evidence of thermal damage or nerve injury in either group of nerves, therefore, the null hypothesis of no difference in the rate of nerve injury with the plasma knife versus bipolar was not rejected (Table 1). The only pathologic finding of note was increased mast cells observed in the perineural soft tissue in 2 nerve specimens dissected by plasma knife.

Part 2: Clinical Review. Thirteen women and 17 men with a mean age of 62 years (range, 24–88 years) underwent plasma knife parotidectomy over a 24-month period. Fourteen patients undergoing parotidectomy for intraglandular malignancies with a mean size of 3.3 cm (range, 0.9–6.0 cm) included 9 with metastatic squamous cell carcinomas of skin origin, 3 with low-grade mucoepidermoid carcinomas, 1 with poorly differentiated adenocarcinoma, and 1 with metastatic melanoma. The majority of

<table>
<thead>
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<th>Pathologic findings</th>
<th>Bipolar electrocautery</th>
<th>Plasma knife</th>
<th>( p ) value</th>
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<tr>
<td>Carlander nerve damage class</td>
<td>14/14 Normal</td>
<td>26/26 Normal</td>
<td>1.0</td>
</tr>
<tr>
<td>Increased mast cells in perineural tissue</td>
<td>0/14</td>
<td>2/26</td>
<td>.53</td>
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eleven (60%) 28 (93%) 30 (100%)
HB II 0 10 (33%) 2 (7%) 0
HB III 0 2 (7%) 0 0

<table>
<thead>
<tr>
<th>Preserved VII nerve branches</th>
<th>Preop</th>
<th>Postop day 1</th>
<th>1-mo follow-up</th>
<th>3-mo follow-up</th>
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<tbody>
<tr>
<td>HB I</td>
<td>30 (100%)</td>
<td>18 (60%)</td>
<td>28 (93%)</td>
<td>30 (100%)</td>
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<tr>
<td>HB II</td>
<td>0</td>
<td>10 (33%)</td>
<td>2 (7%)</td>
<td>0</td>
</tr>
<tr>
<td>HB III</td>
<td>0</td>
<td>2 (7%)</td>
<td>0 0</td>
<td>0</td>
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Table 2. House-Brackmann (HB) scale scores in preserved facial nerves dissected by plasma knife.

patients (n = 13) received superficial parotidectomy and neck dissection, whereas 1 underwent total parotidectomy with neck dissection. Thirteen patients underwent superficial parotidectomy for benign tumors with a mean size of 2.8 cm (range, 0.8–4 cm), including 7 pleomorphic adenomas (2 recurrent), 3 Warthin tumors, and 1 each of basal cell adenoma, oncocytoma, and benign eccrine hydadenoma. Two patients with chronic sialadenitis underwent superficial parotidectomy, whereas 1 with chronic sialadenitis required total parotidectomy with neck dissection for flap reconstruction.

All patients had intact facial nerve function preoperatively, except for 2 patients with malignant tumors involving single branches of the facial nerve (1 marginal and 1 frontal). During dissection of distal nerve branches, the plasma knife caused intermittent audible signal on the facial nerve monitor in 26 patients (87%), and visible facial muscle twitch in 23 patients (77%). The facial nerve outcomes of preserved branches of the facial nerve are presented in Table 2. Of the 12 patients (40%) with immediate postoperative paresis of a preserved facial nerve branch, 11 (92%) had weakness in a single branch, whereas 1 (8%) had weakness in 2 branches. Of the 13 nerves with immediate postoperative paresis, the marginal mandibular was involved in 6 cases (46%), followed by the buccal branch in 4 (31%), the frontal in 2 (15%), and the zygomatic in 1 case (8%). A regression analysis found that immediate postoperative facial nerve weakness could not be predicted by various evaluated independent variables (Table 3).

The single (3%) nonfacial nerve-related complication was a postoperative seroma in a patient who underwent superficial parotidectomy for recurrent pleomorphic adenoma. In the 14 patients undergoing superficial parotidectomy alone, mean operative time was 140 minutes (range, 90–239 minutes), mean operative blood loss 107 mL (range, 50–300 mL), and mean closed suction drain output 88 mL (range, 25–300 mL).

**DISCUSSION**

Head and neck surgery requires a balance that allows sufficient resection of diseased tissue while maintaining vital structures critical for function and cosmesis. This delicate balance is especially true for parotidectomy. Despite acceptance of standard techniques for safe parotidectomy, between 5% and 65% of patients will experience temporary paresis of 1 or more branches of the facial nerve after parotidectomy. Recovery of temporary facial paresis occurs within 6 months in the majority of patients. A higher incidence of both temporary and permanent facial paralysis has been associated with malignant parotid tumors, chronic sialadenitis, total parotidectomy, revision parotidectomy for recurrent tumors, and performance of a neck dissection in conjunction with parotidectomy.

Neural preservation during head and neck surgery requires a trade-off between sufficient hemostasis for visualization and the need to prevent unwanted electrical and mechanical stimulation of the nerve. Various surgical techniques that allow for hemostasis with minimal nerve stimulation have been described. Cold knife with ligation is effective but potentially time consuming. Bipolar cautery followed by cold knife division is faster but requires the surgeon to switch instruments multiple times during the procedure. Harmonic scalp (Ethicon, Somerville, NJ) was observed to significantly

<table>
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<tr>
<th>Independent variable</th>
<th>Coefficient</th>
<th>Standard error</th>
<th>p value</th>
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<tbody>
<tr>
<td>Age (y)</td>
<td>0.005</td>
<td>0.007</td>
<td>.484</td>
</tr>
<tr>
<td>Sex</td>
<td>−0.262</td>
<td>0.229</td>
<td>.266</td>
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<tr>
<td>Pathology (benign or malignant)</td>
<td>0.292</td>
<td>0.437</td>
<td>.512</td>
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<tr>
<td>Surgery (SP or P plus)</td>
<td>−0.254</td>
<td>0.407</td>
<td>.540</td>
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<tr>
<td>Tumor size (cm)</td>
<td>0.065</td>
<td>0.204</td>
<td>.753</td>
</tr>
<tr>
<td>Operative time (min)</td>
<td>−0.002</td>
<td>0.001</td>
<td>.106</td>
</tr>
<tr>
<td>NIMS stimulation</td>
<td>0.273</td>
<td>0.299</td>
<td>.372</td>
</tr>
<tr>
<td>Visible intraoperative muscle twitch</td>
<td>−0.241</td>
<td>0.287</td>
<td>.411</td>
</tr>
<tr>
<td>Plasma knife type</td>
<td>−0.285</td>
<td>0.299</td>
<td>.352</td>
</tr>
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| Abbreviations: SP, superficial parotidectomy; P plus, parotidectomy plus neck dissection. |
reduce intraoperative blood loss and facial nerve paresis in a retrospective review comparing 44 patients undergoing Harmonic parotidectomy to 41 patients undergoing conventional parotidectomy.8 Harmonic dissection, however, has not been widely applied to parotidectomy perhaps due to the bulk of the handpiece along with concerns about the slow cooling of the tip which may increase the risk of adjacent thermal damage. In a retrospective series of 50 patients, the Hemostatix (Shaw) scalpel (Hemostatix Medical Technologies, Bartlett, TN) demonstrated significantly shorter operative time and intraoperative blood loss compared with conventional parotidectomy.9 Another study by Ramadan et al10 of 77 patients with parotidectomy asserted that the Hemostatix scalpel was an independent risk factor for facial nerve paralysis; however, the larger Hemostatix number 10 blade was used in this series instead of the more widely accepted number 15 blade.

The present study on the plasma knife was performed due to ongoing interest among parotid surgeons to identify surgical instruments that provide hemostasis without excessive facial nerve stimulation during parotidectomy. The plasma knife is a tripolar electrocautery device with intrinsic properties that seem potentially suitable for head and neck surgery. An outer bipole on the tip rapidly alternates between a cutting and coagulation setting to produce a hemostatic cut. A return pole is located in the center of the instrument which prevents current from being driven deeply into tissue, theoretically limiting damage to surrounding structures. On its default settings of 30 W (40% cut and 60% coagulate), the mean lateral thermal margin is 0.48 mm at the relatively low temperature of 80°C.

The study found no evidence of pathologic nerve damage in rat sciatic nerves dissected with either plasma knife or bipolar electrocautery. The rat sciatic nerve is a similar size to the human facial nerve and has been used extensively as the optimal model for measuring the effects of energy-based devices on the human facial nerve.11,12 Histologic changes included increased number of mast cells in the perineural soft tissue of 2 nerves dissected by plasma knife. Although the clinical significance of this is unknown, further study will be needed to determine whether stimulation from the plasma knife produces a surrounding inflammatory response.

The present clinical review of plasma knife parotidectomy seems to support the conclusion of the animal study that the plasma knife can safely be used for nerve dissection. The 40% rate of temporary paresis in predominantly single branches of the facial nerve was within rates reported in the literature5–7 and was considered acceptable given that 57% required parotidectomy for either malignancy or sialadenitis, 47% required neck dissection, 10% were revision cases, and 7% required total parotidectomy. There were no cases of permanent paralysis in nerve branches that were intentionally preserved. The surgeons did note that the plasma knife resulted in Nerve Integrity Monitoring System (NIMS) stimulation and visible muscle twitch in 100% of plasma knife parotidectomies. This stimulation was especially evident when dissecting the thinner layers of tissue over distal nerve branches, possibly from leakage of current from the central pole of the plasma knife into the tissue. The surgeons found that this undesirable stimulation could be reduced by narrowing the plasma field at the device tip by increasing the cut time to 70% while reducing the coagulation time to 30% from the default 60% coagulation and 40% cut setting.

The mean operative time of 140 minutes for patients undergoing superficial parotidectomy alone compares favorably to a mean of 192 minutes in a recent study of 937 patients undergoing parotidectomy.13 However, it is noted that operations ranged from 30 to 550 minutes in that study with many variables including type of operation, tumor pathology, skill level of surgeon, and whether or not it was a teaching operation.

Three of 4 fellowship-trained head and neck surgeons at our program who have tried plasma knife parotidectomy now prefer the plasma knife for the procedure due to a subjective perception of improved hemostasis and reduced operative times. The current plasma knife tip of choice is the J-plasma knife because it has a shape and cutting surface similar to a number 12 blade used in conventional parotidectomy. The fourth surgeon did not care for the 2 foot pedal design (blend cut mode [yellow]; 100% coagulation mode [blue]) that sometimes requires the surgeon to look away from the field to the floor to step on the correct pedal.

Limitations of the study are the lack of a concurrent control group undergoing parotidectomy using the standard technique to which to
compare facial nerve outcomes. The study was of a limited sample size, and, therefore, the estimated rates of facial nerve weakness may be imprecise. Further evaluation by a randomized controlled study is needed to confirm our initial observations. Finally, additional observations are needed to confirm that the rate of permanent paralysis is as low as the traditional technique.

CONCLUSION

Plasma knife seems to be both safe and effective for parotidectomy. Plasma knife resulted in no pathologic nerve damage in an animal model and demonstrated rates of facial nerve paresis consistent with the published literature in a series of parotidectomy patients. This technique may confer some advantages over conventional methods with the ability to simultaneously cut and coagulate tissue with a single instrument. Muscle twitches and facial nerve stimulation, however, were noted with its use, indicating spread of the electrical field beyond the instrument tip. Further study is needed to determine if the subjective impression of improved hemostasis and operative times can be objectively confirmed.

REFERENCES