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Electrosurgery Turbinate Reduction Revisited: Can Comparable Volumetric Heating be Achieved Without Feedback Control?

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Background and Objectives: Temperature-controlled radiofrequency inferior turbinate ablation (TCRFA) uses a feedback system to control thermal injury and achieve precise volumetric heating to induce specific scar formation. However, it requires costly single-use proprietary consumables. Comparable volumetric tissue heating may be achieved for a fraction of the cost by adjusting the power settings on traditional monopolar electrosurgery devices that use low-cost needle tips. This pre-clinical study aims to determine the optimized power parameters to achieve electrosurgical coagulum volume similar to that of TCRFA.
Study Design/Materials and Methods: An electrosurgery submucosal diathermy (SMD) system (cut mode, 4–32 W, 5–120 seconds) and a temperature-controlled radiofrequency ablation system (standard clinical parameters for treating inferior turbinate hypertrophy) were used to coagulate egg white and chicken breast. Coagulum major and minor axis were measured, and lesion volume was approximated as prolate spheroid.
Results: No significant difference in volume was found between the temperature-controlled system and the electrosurgery system at 8 W for 30 seconds, 8 W for 60 seconds, 16 W for 30 seconds, 32 W for 5 seconds, and 32 W for 15 seconds. The time to achieve equivalent lesion size was significantly less in the SMD system when compared to the temperature-controlled system ($P < 0.05$).
Conclusion: Electrosurgery handpieces may achieve similar lesion volume effects as the temperature feedback-controlled, single-use handpieces when set to the optimized parameters. SMD handpieces are significantly more cost and time effective than proprietary devices, and they are easily used in the office. SMD devices may be a more affordable alternative to temperature-controlled systems with comparable lesion volume effect and may be valuable for office-based therapy. Lasers Surg. Med. © 2020 Wiley Periodicals LLC

Key words: inferior turbinate hypertrophy; electrosurgery; temperature-controlled radiofrequency; egg white; albumin

INTRODUCTION

Inferior turbinate hypertrophy (ITH) is a major cause of chronic nasal airway obstruction that significantly decreases patients' quality of life [1]. Furthermore, ITH presents a significant financial burden, as patients with ITH who have failed medical therapy may require surgical treatment [2]. Inferior turbinate reduction (ITR) treats ITH by decreasing nasal obstruction, thereby increasing nasal airflow and improving patients' subjective sense of patency [3]. Current reduction techniques include turbinectomy (total and partial), turbinoplasty (outfracture, submucous resection, and microdebrider), thermal procedures (electrocautery and radiofrequency ablation), and laser surgery [4].

Initially, ITH was treated through total and partial turbinate resection. However, the importance of nasal mucosa conservation led to the development of submucosal turbinate resection (SMR), and finally, submucosal diathermy (SMD) [5]. SMD principally achieves its effect by coagulating the venous sinusoids within the turbinate. The subsequent submucosal fibrosis prevents distention of the turbinate [6]. After the advent of electrosurgery in 1909 [7]. Beck [8] was the first to describe the use of high-frequency submucosal electrosurgery using a monopolar electrode [8]. In the following years, the technique was popularized by Richardson [9], Shahinian [10], and Simpson and Groves [11]. The success of SMD varies in the literature and depends largely on patient selection for surgery [10,12–15].

Rijul S. Kshirsagar and Ellen M. Hong contributed equally to this work.

Conflict of Interest Disclosures: All authors have completed and submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest and none were reported.

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An established optimal procedure is not yet identified. The ideal surgical treatment for ITH should alleviate symptoms by achieving significant volume reduction while preserving mucosal function, but no clear consensus exists in the literature with respect to methods or device to accomplish this objective [4,5]. In their 35-year review of the otolaryngology literature published in 2001, Clement and White [16] did not identify any randomized controlled studies of inferior turbinate surgery for nasal obstruction. Furthermore, the authors observed that research in the field appears to be driven by technological advancement rather than by the establishment of clear patient benefit.

Two commonly practiced turbinate reduction techniques are temperature-controlled radiofrequency ablation (TCRFA) and SMD. TCRFA uses a feedback system to achieve volume reduction, but requires expensive (~$400), single-use consumables. TCRFA avoids tissue desiccation and char, thereby ensuring that current flow and thermal lesion formation is unimpeded [17]. SMD can be performed with an electrosurgery system, such as the inexpensive monopolar SMD, with a needle tip inserted into the turbinate to achieve volume reduction [18]. However, there is still a gap in scientific rigor, as this technique has been performed and reported in the literature without standardized device settings, leaving much to the discretion of the surgeon [6,10,12]. This presents a need for controlled studies to assess and compare current ITR procedures, and controlled studies need a firm foundation in lab bench work focused on characterizing biophysical processes.

Here, we use egg white and raw chicken breast, tissue phantoms widely used in biophotonics research to study laser-tissue interactions, as media to gauge the extent of thermal injury with two RF devices [19–21]. We compared a traditional monopolar SMD device with a TCRFA device to see if similarity of tissue effect could be achieved with the former.

MATERIALS AND METHODS

Egg White Phantom

Experimental set-up and protocol. To establish the control, a TCRFA generator (G3 RF Workstation; Gyrus ACMI, Southborough, MA) was used to create a coagulum in egg white. Fresh egg white (650 ml) was placed within plastic housing and allowed to equilibrate to 37°C using a temperature-controlled phosphate-buffered saline (PBS) bath until use for electrode insertion. A three-dimensional micro-positioning stage was used to position either electrode within the vat of egg white. The grounding electrode was immersed at the base of the reservoir. A digital camera was mounted in front of the reservoir to acquire images. To enhance photography, diffuse lighting is used from both the front and side directions. A turbinate handpiece (Model 1120 Somnoplasty; Gyrus ACMI) was connected to the generator and submerged to a depth of 1.5 cm. The device was set to the clinical parameters for treating ITH with a target temperature of 85°C and a target energy output of 350 J, per the manufacturer's specifications [22]. After each trial, the coagulated egg white was gently removed from the reservoir and the procedure was repeated. Five independent lesions were created with the specified clinical parameters and the time to lesion formation was recorded. Reservoir volume was kept constant by refilling with fresh egg white.

To test the SMD parameters, an electrosurgical generator (Valleylab Force 2; Valleylab, Boulder, CO) with a needle electrode (Covidien Edge Insulated Needle Electrode 7.2 cm E1465; Covidien, Mansfield, MA) was used to generate the coagulum. Fresh egg white (650 ml) was placed within the plastic housing depicted. The insulation material was removed from the end of the needle tip electrode, leaving an exposed electrode length of 11 mm (Fig. 1). Though lesion size is dependent on the current density surrounding the electrode and duration of energy delivery, stripping the needle provided sufficient surface area to allow adequate lesion volume creation [17]. The electrode was secured in the testing apparatus frame and submerged in the egg white to a depth of 1.5 cm in the egg white. On the "cut" setting, the electrosurgical system was used to create the coagulum in the egg white. Based upon preliminary investigations, the following power and application times were evaluated: 4 W for 120 seconds, 8 W for 15 seconds, 8 W for 30 seconds, 8 W for 60 seconds, 16 W for 15 seconds, 16 W for 30 seconds, 32 W for 5 seconds, and 32 W for 15 seconds. Therefore, 480, 120, 240, 480, 240, 480, 160, and 480 J were applied, respectively. These settings encompass the power and times used in previous SMD studies, but they do not exactly replicate them [23,24]. After each trial, the coagulated egg white was gently removed from the reservoir and the procedure was repeated. Five independent lesions were created for each specified clinical parameter. Reservoir volume was kept constant.

Measurement of lesion volume. After each individual trial with either monopolar electrosurgery or TCRFA devices, digital photographs (Canon EOS Rebel T2i; Canon, Tokyo, Japan) of the coagulated volume surrounding the electrode tip were acquired with the electrode still within the egg white reservoir. The major and minor axes of the lesion were measured for each photograph using IMAGE-J software (National Institute of Health, Rockville, MD) with the known, cross-sectional diameter of the electrode needle as reference. Lesions assume the geometry of a prolate spheroid, the volume of which can be calculated:

$$V = \frac{4}{3}\pi a^2 b$$

where "a" is the minor radius and "b" is the major radius [25].

Chicken Breast Phantom

Experimental set-up and protocol. Five chicken breast samples were placed in a temperature-controlled PBS solution and allowed to equilibrate to 37°C for

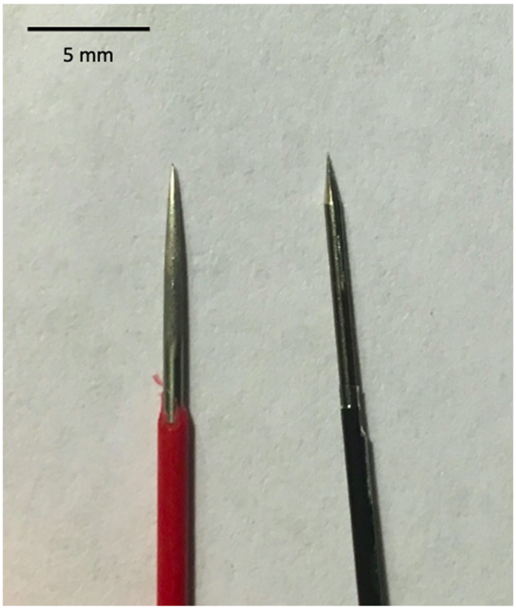

Fig. 1. A comparison of the needle electrodes of the modified submucosal diathermy (L) and temperature-controlled radiofrequency inferior turbinate ablation (R) devices. There are 11 mm of exposed needle in each.

2 hours. Samples were then placed on a dispersive electrode (grounding pad) within the experimental apparatus. To establish the control, a TCRFA device was used to create lesions in the chicken breast samples. The device was connected to the turbinate handpiece and the needle tip was placed within the sample by securing the handle to a rigidly fixed clamp and burying the needle to entirely encapsulate it with tissue. The device was set to the clinical parameters for treating ITH with a target temperature of 85°C and a target energy output of 350 J. Five independent lesions were created in the same chicken breast with the specified clinical parameters and the time to lesion formation was recorded.

To test the SMD parameters, the electrosurgery system was used to generate lesions in the tissue. A needle-tip electrode with modified insulation as described above was fully inserted into the sample in the same manner as the TCRFA device. On the “cut” setting, the electrosurgical system was used to create the coagulum in the chicken. The same parameters described for the egg white were tested in the chicken breasts as well. Five independent lesions were created for each specified clinical parameter in the same chicken breast. The size of the chicken breast samples allowed for the generation of 10 lesions per sample.

Measurement of lesion volume. After each run with either the electrosurgery or TCRFA devices, chicken breast samples were sectioned along the major axis of the lesion as in Figure 2. Digital micrometers were used to measure the length and width of the lesion. Denatured tissue presents as white and provides an obvious visible demarcation from surrounding native tissue. The geometry of the lesions was again approximated as a prolate spheroid, and the volume was determined using the previously stated formula [25].

Data Analysis

Coagulated volume was calculated. One-way analysis of variance was performed to compare the mean coagulated volume between groups using MATLAB (MATLAB R2015a; Mathworks, Natick, MA). Tukey's post hoc analysis was performed to compare mean coagulated volume using SPSS (version 21; IBM, Armonk, New York). Two-samples t test was used to compare the average time to lesion formation between the RFA group and the entire electrosurgery group. Statistical significance was defined as $P < 0.05$.

RESULTS

Egg White Phantom

The average coagulated volume of egg white is plotted for the TCRFA and each setting of the SMD system in Figure 3. Figure 4 depicts a photographic comparison of

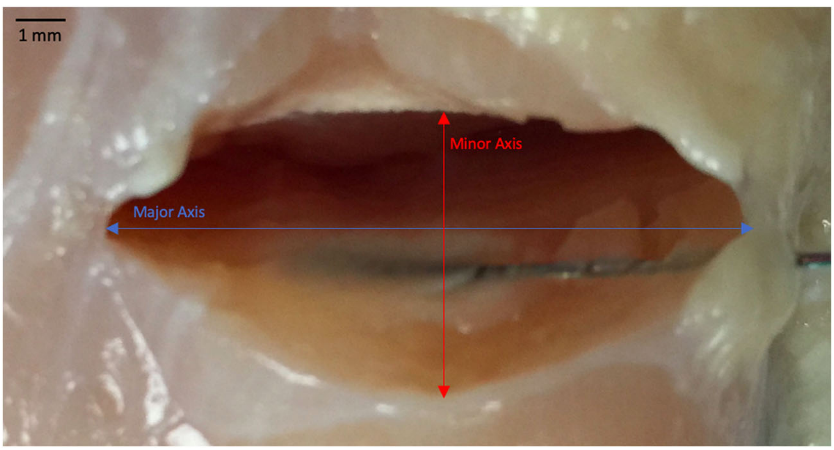

Fig. 2. Section of chicken breast depicting major and minor axes of the lesion with needle still inserted.

lesions formed by the electrosurgical generator at selected energy settings and the TCRFA device.

The difference in the average volume among the SMD parameters had a $P = 0.004$. As the $P < 0.05$, this difference is statistically significant. Tukey's post hoc analysis revealed a significant difference between the average volume obtained by the TCRFA group and that of the SMD parameter of 4 W for 120 seconds ($P = 0.017$), but differences between other SMD parameters and TCRFA were not statistically significant.

The average time to the completion of lesion creation in the egg white phantom was significantly longer using the TCRFA device (78.6 ± 32.1 seconds) compared with that of the SMD device (36.3 ± 35.8 seconds, $P < 0.05$).

Chicken Breast Phantom

The average volume for each trial is plotted in Figure 5. The difference in average volume among the SMD parameters had a $P = 0.006$, indicating the difference was statistically significant. Tukey's post hoc analysis revealed a significant difference between the average volume obtained by the TCRFA group and that of the SMD parameter of 8 W for 15 seconds ($P = 0.005$) and 16 W for 15 seconds ($P = 0.01$). Differences between other SMD parameters and TCRFA were not statistically significant.

The average time to the completion of lesion creation in the chicken breast phantom was significantly longer using the TCRFA device (190.2 ± 16.4 seconds) compared with that of the SMD device (36.3 ± 35.8 seconds, $P < 0.001$).

DISCUSSION

Clinical studies demonstrate that the efficacy of TCRFA over SMD is controversial [26–28]. Furthermore, it is difficult to appropriately compare the two methods, as studies use different parameters for SMD devices [6,10,12]. In a rabbit model, Kaplama et al. [29] used 25 W at 30 seconds. In a sheep model, Kakarala et al. [23] applied 20 W at 10 seconds to the turbinates. Gouveris et al. [24] only states that a “constant power” was applied for 15 seconds in a sheep model. Clinically, Kilavuz et al. [30] examined patients treated at 40 W for 5 seconds. Uluyol et al. [27] applied 20 W until coagulation was visible from tissue whitening. In this study, a range of power and time settings was identified for the conventional monopolar SMD system that created a similar volumetric coagulum as the TCRFA device. Additionally, the time to lesion formation was significantly shorter using the monopolar SMD system. This study is the first step in establishing a standardized protocol by which to compare the SMD as a low-cost alternative to TCRFA in ITH treatment.

A range of SMD power and time combinations yielded a coagulum similar to those of TCRFA. In the egg white phantom, only the parameter of 4 W for 120 seconds in the SMD yielded a coagulum volume with a statistically significant difference. In the chicken breast, out of eight SMD parameters, 8 W for 15 seconds and 16w for 15 seconds were the only parameters that yielded statistically significant differences in coagulum volume. It is noted that there is little relation between different times or different powers in the resulting coagulum volume, and this can be attributed to the nature of electrosurgery.

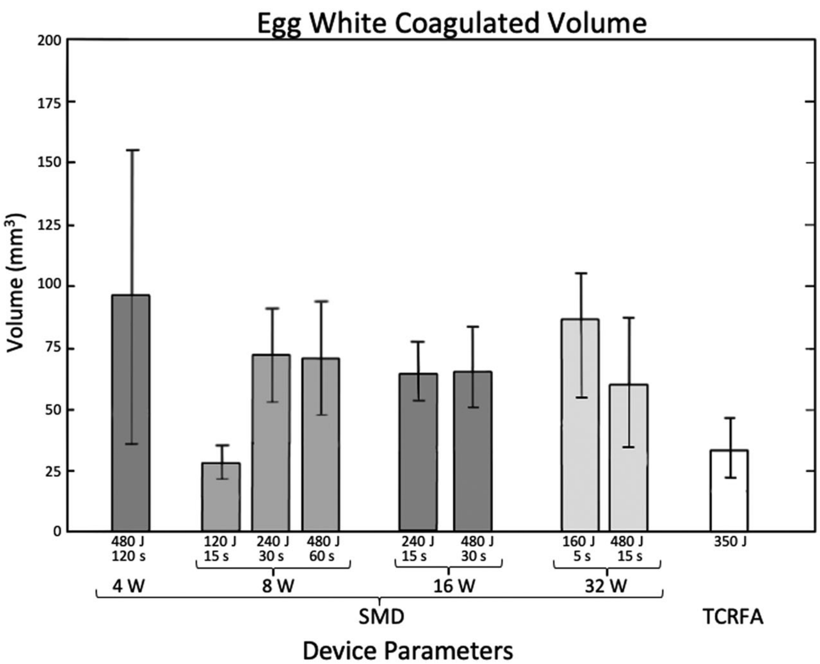

Fig. 3. Egg white coagulated volumes. SMD, submucosal diathermy; TCRFA, temperature-controlled radiofrequency inferior turbinate ablation.

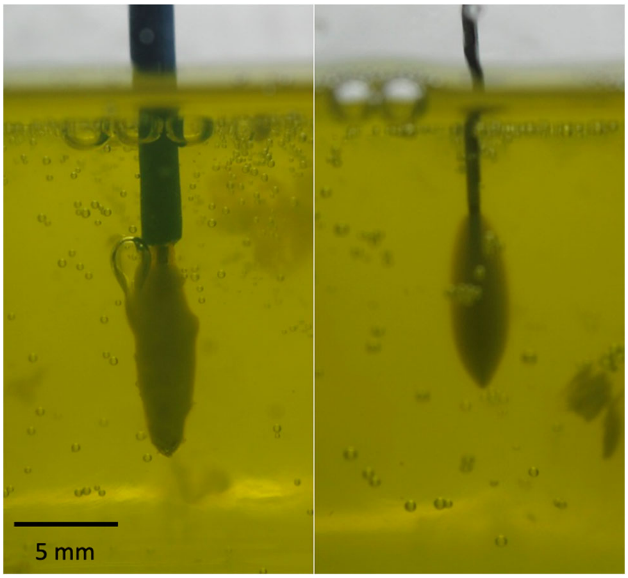

Fig. 4. Comparison between coagulated egg white at (L) 16 W for 30 seconds using the SMD system and (R) the TCRFA device. SMD, submucosal diathermy; TCRFA, temperature-controlled radiofrequency inferior turbinate ablation.

Electrosurgery depends on current density within the surrounding medium to increase the temperature, and the probe itself would only heat through conduction with the heated medium. Therefore, when the tissue most proximal to the probe desiccates, the resistance of the medium increases, causing the current to decrease or stop altogether. This limits the maximum depth of coagulation. However, with a lower power, desiccation may be delayed, allowing for a larger coagulum but at a slower rate [31]. This aspect of SMD highlights the importance of finding a standardized power and time setting to use for further clinical studies.

The proposed range of parameters for the SMD device not only created similar coagulum volumes to the TCRFA, but it also was quicker to achieve such volumes. As time is a variable that is established in this study's parameters for the SMD device, the average time to complete the treatment was the same in both egg white and chicken breast: 36.3 ± 35.8 seconds. The TCRFA device, however, was not placed under any time limitations and finished once the established energy output was dispensed. It took an average of 78.6 ± 32.1 seconds to complete the lesion in egg white and an average of 190.2 ± 16.4 seconds to complete the lesion in chicken breast. Both of these times are significantly longer than the average of the time settings used in the SMD parameters. Therefore, SMD is able to create coagulum volumes similar to those of TCRFA in a shorter amount of time.

Findings of the current study should be interpreted with an appreciation of its limitations. Egg white and chicken breast are both phantoms commonly used in benchtop coagulative necrosis experiments as tissue-mimicking materials. Egg white denatures and forms a coagulum at temperatures similar to those of blood [20]. Egg white also has a thermal conductivity and diffusivity similar to those of soft tissues, indicating it would be a good model for lesion formation [32]. Chicken breast has a visible coagulation zone and uniform tissue, resulting in more predictable behavior that would aid in accurate

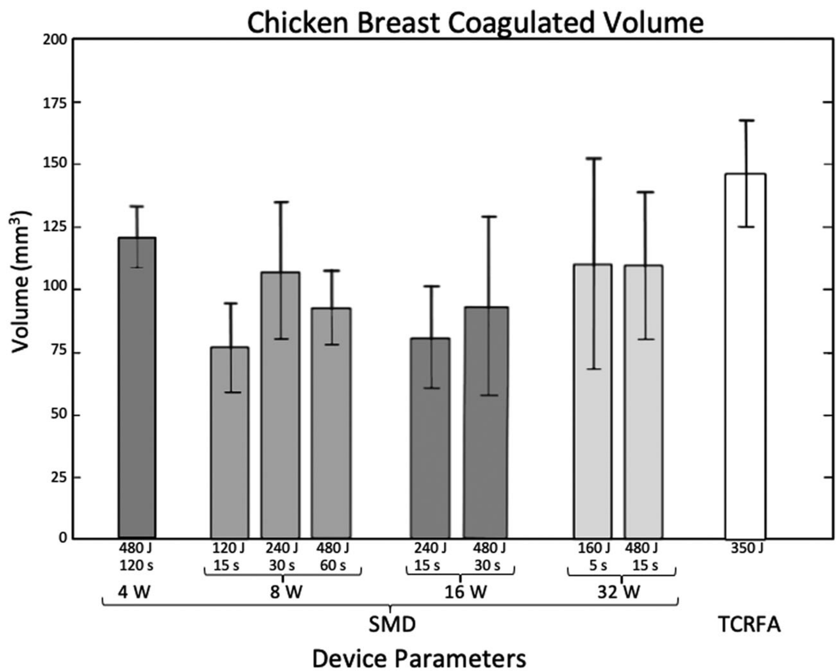

Fig. 5. Chicken coagulated volumes. SMD, submucosal diathermy; TCRFA, temperature-controlled radiofrequency inferior turbinate ablation.

measurements of coagulum [19]. Though both egg white and chicken breast phantoms are well-established, there are obvious differences between the models used in this study and the inferior turbinate [33–35]. One such difference is that the lesions created in the well vascularized nasal inferior turbinate are influenced by the flow of blood, which removes heat from the tissue surrounding the electrode [17]. Additionally, the histological effect of monopolar SMD was not studied in our work. Lastly, while the settings proposed in this study encompass the times and power applied in previous studies, it is recognized that there is an infinite amount of power and time combinations that could be studied. Further work in mucosal tissues should be performed in order to validate the clinical parameters determined for SMD.

CONCLUSION

In this study, the volume of lesions created by a monopolar SMD electrosurgery system was compared to those created by a TCRFA device using egg white and chicken phantoms. No significant difference in lesion volume between the TCRFA system and the monopolar SMD system were found at seven out of eight of the power and application times in egg white and at six out of eight of the power and application times in chicken breast. The time to completion of lesion creation was also significantly lower when using the monopolar SMD system. Considering that costs of SMD handpieces are an order of magnitude less than proprietary devices and can be performed in the office, SMD may be a more affordable alternative to temperature-controlled systems. Further study is necessary to validate the defined parameters for clinical use.

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