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Unintentional RF Energy Transfer During Tonsillectomy: An *In Vitro* Investigation

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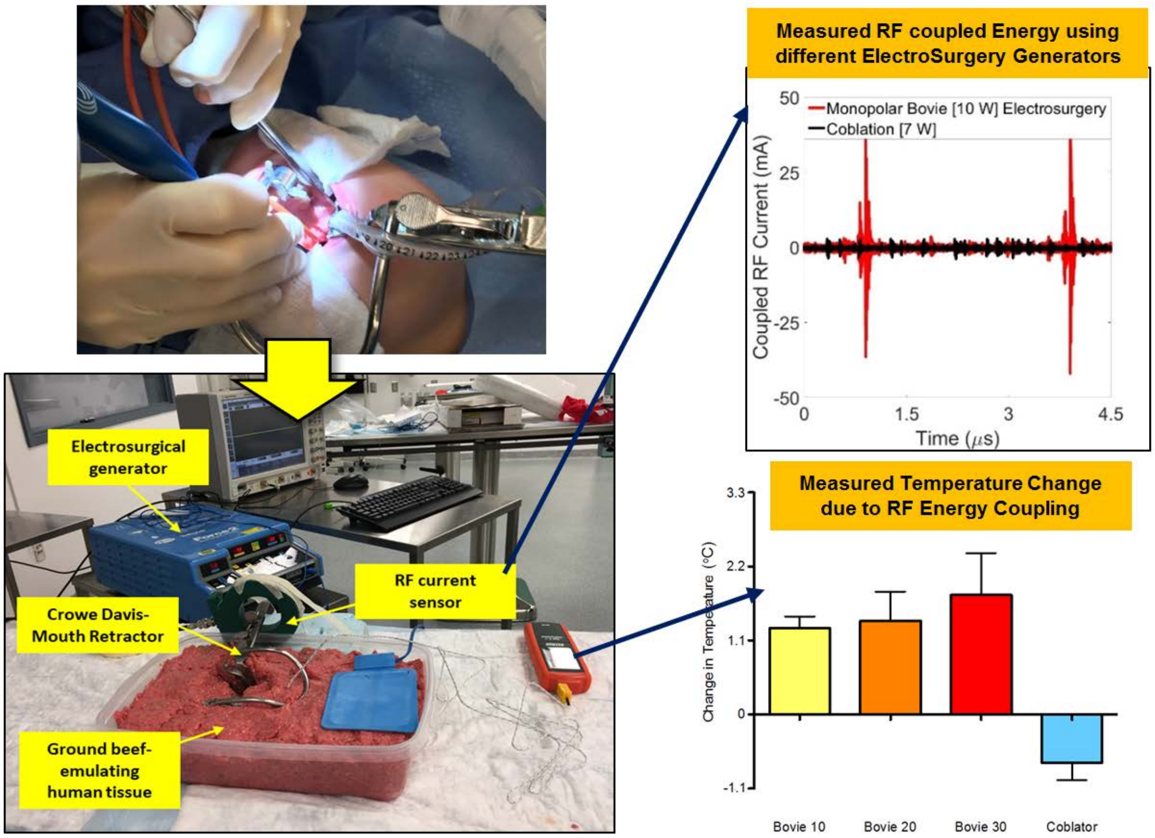


Experimental setup used to explore unintentional RF energy coupling on the mouth retractor during tonsellectomy: measurement results confirm unwanted energy leakage and temperature increase.

Take-Home Messages

- We report the first-ever study that explores unwanted electromagnetic energy coupling to the mouth retractor used during tonsillectomy.
- *In vitro* measurement results demonstrate that unintentional RF energy coupling is indeed a real issue, leading, in turn, to unwanted temperature increase in the surrounding tissues.
- Our ultimate goal is the prevention of related post-operative tonsillectomy complications, including dysgeusia that currently affects one-third of patients.
- This is the first time that RF energy leakage is confirmed during tonsillectomy, and identified as a possible cause of post-operative dysgeusia.
- Both monopolar electrosurgery and coblation tonsillectomy procedures are explored and contrasted at typically used power levels.

Unintentional RF Energy Transfer During Tonsillectomy: An *In Vitro* Investigation

Satheesh Bojja Venkatakrishnan, *Student Member, IEEE*, Vigyanshu Mishra, *Student Member, IEEE*, Maria Koenigs, Tendy Chiang, and Asimina Kiourti, *Member, IEEE*

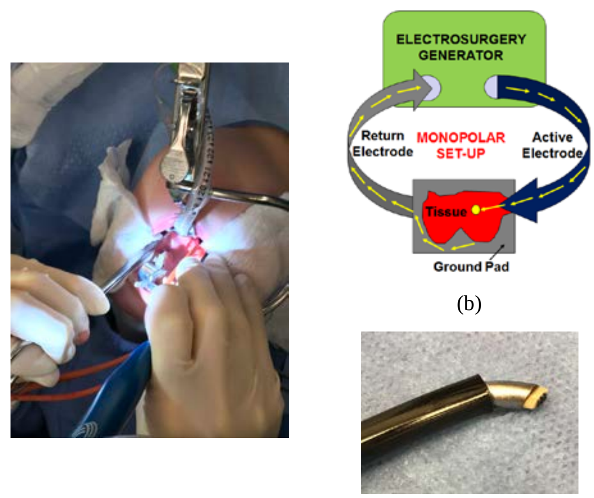
Abstract One-third of tonsillectomy patients experience post-operative taste disturbances (dysgeusia), yet the underlying cause is unknown. We hypothesize that unwanted radio-frequency (RF) energy couples to the metal-based mouth retractor during tonsillectomy and could be a possible cause of dysgeusia. To validate our hypothesis, *in vitro* studies are performed in a ground beef phantom with sensors measuring: a) the unwanted current coupled to the mouth retractor, and b) the unwanted temperature rise in the tissues that surround the retractor. The simulated surgery was performed using two separate surgical techniques: monopolar electrosurgery and coblation. Results indicate that unintentional RF energy transfer is indeed a real issue. During electrosurgery, peak-to-peak unwanted currents vary from 80.53 to 181.48 mA for typical power levels ranging from 10W to 30W. Tissue temperature unintentionally increases by 1.3^{o}C and 1.8^{o}C, respectively. Coblation indicates smaller coupling effects, with peak-to-peak currents on the mouth retractor capped at 12.33 mA for a typical 7 W setting. Concurrently, tissue temperature is reduced by 0.73^{o}C, as attributed to the saline solution inherent to coblation. As the first of its kind, this study illuminates possible causes of post-tonsillectomy dysgeusia and intends to trigger future studies. The ultimate goal is safe and complication-free tonsillectomies.

***Keywords* — Bioelectromagnetics, coblation, dysgeusia, electrosurgery, tonsillectomy, energy coupling.**

I. INTRODUCTION[1]

TONSILLECTOMY involves the partial or total removal of the tonsils as needed to treat recurrent tonsillitis; sleep-disordered breathing; or other less common entities [1]. Tonsillectomy remains one of the most commonly performed surgeries on kids [2]. There is surgeon preference towards operative technique with tonsillectomy, two of the most common ones entailing monopolar electrosurgery [3]-[6] and coblation [6],[7] per Fig. 1.

Both monopolar electrosurgery and coblation involve the use of radio-frequency (RF) energy to remove tonsillar tissue. Associated frequencies are typically in the KHz to MHz range, as needed to avoid the risk of electrocution and alterations in nerve or cardiac activity [4], [5]. Referring to Fig. 1(b), monopolar electrosurgery uses two electrodes to produce a current flow within the tissues [7], [8]. The first electrode is called 'active' and is in direct contact with the tissue to be excised, while the second electrode is called 'return' and serves as a ground reference, typically placed upon the patient's body. While propagating through the tissue resistance, the resulting current flow generates heat. The latter heat is, in turn, serving to cut the tissue that is in direct contact with the active electrode (in this case, the tonsils). Referring to Fig. 1(c), coblation employs an RF signal that is passed through a conductive medium (typically a saline solution, such as isotonic sodium chloride) to generate a plasma field [6], [7]. In turn, the conductive medium breaks down into free ions (sodium and chloride), causing the disintegration of intercellular bonds



(a) (b) (c)

Fig. 1. (a) Typical set-up of tonsillectomy procedure, showing a Crowe-Davis mouth retractor used to keep the patient's mouth open. (b) Monopolar electrosurgery-based tonsillectomy procedure. (c) Coblator used in coblation-based tonsillectomy procedure.

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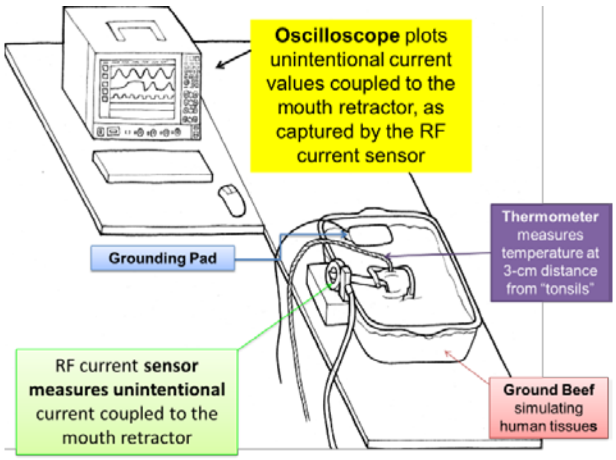


Fig. 2. *In vitro* measurement set-up used to explore unintentional RF energy coupling during tonsillectomy.

and ultimately resulting in tissue dissociation. Compared to electrosurgery, coblation is performed at lower temperatures (60^{o}C to 70^{o}C vs. 400^{o}C to 700^{o}C used in electrosurgery), and has been reported to involve less post-operative pain and accelerated healing [6], [7].

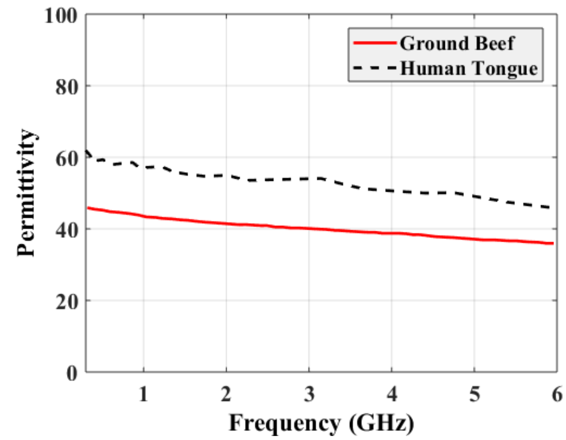
Though tonsillectomy procedures are widely practiced, a number of post-operative complications still exist and are rather not well understood. This paper focuses on dysgeusia (i.e., distortion of the sense of taste), a post-tonsillectomy complication reported by as many as one third of patients [9]-[11]. Unfortunately, the underlying cause of this adverse effect remains unknown. Literature addressing post-tonsillectomy dysgeusia is extremely sparse [12], [13], and mainly suggests damage or thermal injury to the glossopharyngeal nerve. However, these suggestions have yet to be proven. Current practice for addressing dysgeusia is symptom-based, and typically relies on self-healing or a neural healing process that is often slow and rarely complete [14]. As expected, lack of a known cause restricts treatment options, negatively impacts quality of life [9]-[11], and, eventually, prohibits a complete solution to the problem.

In this paper, we hypothesize that unwanted RF energy couples to the metal-based mouth retractor that is used to keep the patient's mouth open during the procedure, Fig. 1(a). This inadvertent current flowing through the mouth retractor could be a possible cause of dysgeusia. Our previous work has already demonstrated unwanted coupling on metal-reinforced breathing tubes employed during endoscopic surgery [15]. However, studies for unintentional RF coupling during tonsillectomy have yet to be performed. Building on our previous expertise, here we present the first study of its kind, leveraging an *in vitro* testing set-up to validate our hypothesis.

II. Methods and Procedures

A. Scientific Hypothesis

Mouth retractors are common practice in tonsillectomy, as needed to keep the patient's mouth open, depress the



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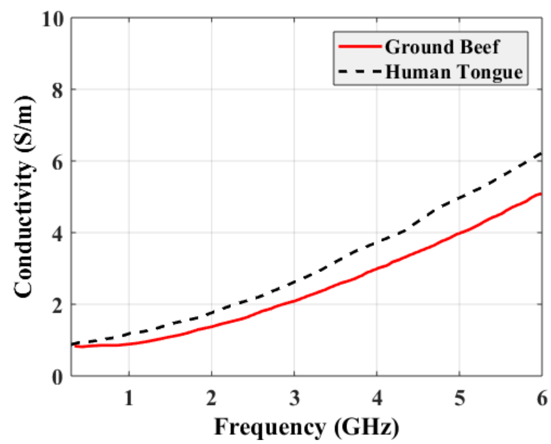

(b)

Fig. 3. Dielectric properties of ground beef phantom as compared to the human tongue: (a) permittivity, and (b) conductivity.

tongue, and maintain the airway. Mouth retractors used to date, such as the widely used Crowe-Davis shown in Fig. 1(a), are metal-based. This implies that metal frames and blades are in direct contact with biological tissues, including the patient's tongue. Although grounding devices should disperse RF energy during tonsillectomy [8], conductive materials in contact with adjacent tissues may lead to unintended electrical current paths.

With these in mind, we hypothesize that unwanted RF energy couples to the metal-based mouth retractor used to keep the patient's mouth open during tonsillectomy. In turn, this unwanted current could cause peri-operative low-grade injury (e.g., tissue and nerve damage or stimulation) that may, eventually, explain dysgeusia.

B. In Vitro Experimental Set-Up

To validate our hypothesis, we consider the *in vitro* experimental set-up depicted in Fig. 2. Specifically, a ground beef phantom (20% fat, 80% lean) is used to emulate the dielectric properties of human tongue. As shown in Fig. 3, the employed ground beef phantom provides a very close representation of the dielectric

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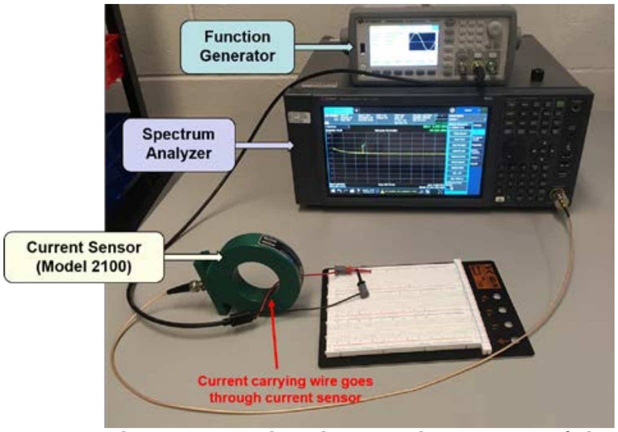

Fig. 4. Benchtop set-up used to determine the sensitivity of the employed current sensor (Pearson Electronics model 2100 [17]).

properties of the human tongue as a function of frequency. Specifically, Fig. 3 shows the frequency-dependent permittivity and conductivity of: a) the ground beef phantom (measured using Keysight's 85070E high-temperature probe [16]), and b) the average human tongue [17]. As seen, very good agreement is achieved between the two. It is noted that measurements down to 200 MHz are shown in Fig. 3, as limited by the employed measurement equipment. Nevertheless, the measured frequency-dependent pattern and the fact that ground beef is by itself a biological tissue make it safe to assume the validity of this surrogate model at other frequencies as well.

To emulate a realistic tonsillectomy set-up, the mouth cavity and tonsils are manually formed within the phantom. In particular, the average dimensions corresponding to a 7-year-old child are used in this experiment, i.e., a 4.5 cm mouth opening with tonsils measuring 5 cm [18], [19]. A standard metal-based Crowe-Davis mouth retractor (per Fig. 1(a)) is properly positioned within the emulated mouth, and two types of tonsillectomy procedures are performed, viz. monopolar electrosurgery and coblation. In the first case, an electrosurgical generator is used to control the firing mechanisms of a monopolar Bovie. Three firings are explored at 10 W, 20 W, and 30 W, respectively, as commonly used in tonsillectomy. In the latter case, a coblator is used at a typical 7 W power level.

C. *Current and Temperature Sensors*

To monitor and record the hypothesized unwanted RF current coupled to the Crowe-Davis mouth retractor, an RF current sensor is employed. As shown in Fig. 2, the current sensor is loop-shaped and serves to capture the magnetic field around the current carrying wire passing through it. In selecting the current sensor, the requirements are to: (1) operate in the kHz to MHz frequency range, as suitable for the tonsillectomy studies under investigation, and (2) exhibit high sensitivity, capable of measuring low levels of unintentionally coupled currents.

To cater to the aforementioned requirements, Pearson Electronics' model 2100 current sensor [20] is employed in this study. The sensor exhibits a wide operating frequency range of 125 Hz to 20 MHz, and captures magnetic fields that are, in turn, converted into equivalent voltages via a 1 V/A voltage to current sensitivity. The captured voltages (or, equivalently, currents) may then be monitored via a high-resolution oscilloscope or spectrum analyzer.

To determine the sensitivity of our current sensor prior to carrying out the intended *in vitro* tonsillectomy studies, the benchtop set-up depicted in Fig. 4 is employed. As seen, a function generator is connected to a 47 Ω resistor via conducting wires, one of which passes directly through the current sensor. The sensor is then connected to a spectrum analyzer and the lowest detectable current is noted down. Notably, measurements indicate that the sensor can monitor currents as low as 400 nA across the entire 200 Hz to 16 MHz range. A slight improvement in sensitivity is noticed with increasing frequency, so that currents as low as 100 nA can be detected at 10 kHz or above.

Temperature of the tissues immediately surrounding the mouth retractor is measured using a type-k thermocouple connected to ExTech's TM100 thermometer [21]. As shown in Fig. 2, the temperature sensor is placed approximately 3 cm away from where the electrode is firing. After 3 minutes of electrosurgery/coblation (per the approximate firing duration used during actual tonsillectomy procedures), the temperature recorded by the sensor is noted. Subsequent measurements are only taken after the tissue has returned to room temperature.

D. *Experimental Procedure*

Summarizing the above, our experimental set-up involves passing a known RF energy signal using either a monopolar bovie or a coblator to the phantom. Different power settings are used, as described above. To confirm repeatability, each of these scenarios is measured three times. As the RF energy is fired directly onto the phantom, the Crowe Davis mouth retractor, placed in close proximity to the firing area, starts picking up RF energy. The coupled RF energy is captured via an oscilloscope with the help of a current sensor. Since the RF current sensor has been calibrated before the start of the experiment, the coupled RF signal can directly be quantified. Temperature differentials in close proximity to the tissues are concurrently captured via the temperature sensor described above.

III. Results

A. *Unwanted Current Coupling on the Mouth Retractor*

Our measurement results indicate that current coupling to the mouth retractor is indeed a real issue. Example time-domain waveforms of such unwanted currents recorded during monopolar electrosurgery and coblation are shown in Fig. 5. Here, the different number of peaks shown in each plot is attributed to the different frequency associated with each of the monopolar and coblation procedures. As expected, the waveform patterns and frequency match those that are theoretically associated with monopolar electrosurgery and coblation. This further validates the fact

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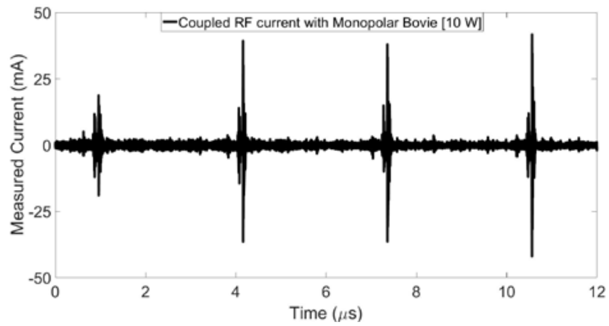

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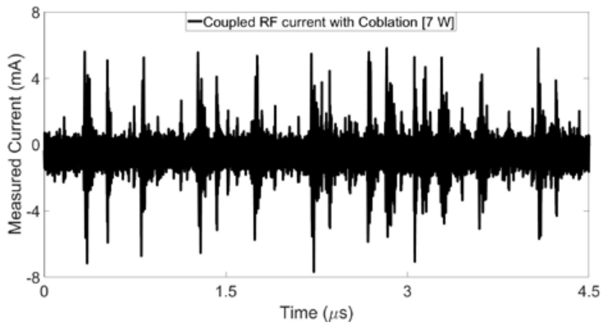


(b)

Fig. 5. Example waveforms of unwanted RF current coupled to the mouth retractor during: (a) monopolar electrosurgery (at 10 W power), and (b) coblation (at 7 W power) tonsillectomy procedures.

TABLE I
UNWANTED CURRENT COUPLED ON THE MOUTH RETRACTOR AS MEASURED BY THE CURRENT SENSOR *IN VITRO*

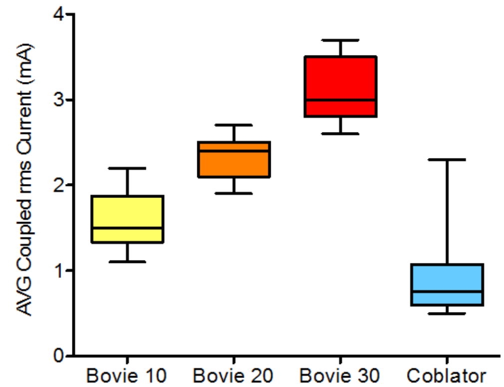
	Root-Mean-Square Current, I_{rms}*	**Peak-to-Peak Current, I_{pp}***
Noise Floor	0.28 mA	4.55 mA
Monopolar Bovie [10 W]	1.54 mA	80.53 mA
Monopolar Bovie [20 W]	2.30 mA	107.11 mA
Monopolar Bovie [30 W]	3.11 mA	181.48 mA
Coblator [7W]	0.65 mA	12.33 mA

** Averaged over three independent measurements.*

TABLE II
UNWANTED TISSUE TEMPERATURE INCREASE AS MEASURED BY THE TEMPERATURE SENSOR *IN VITRO*

	Tissue Temperature Increase at 3cm Distance from where Firing Takes Place*
Monopolar Bovie [10 W]	1.3ºC
Monopolar Bovie [20 W]	1.4ºC
Monopolar Bovie [30 W]	1.8ºC
Coblator [7W]	-0.73ºC (temperature decreases)

** Averaged over three independent measurements.*



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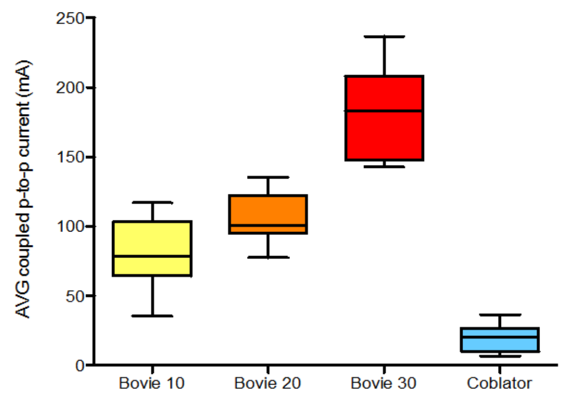

(b)

Fig. 6. Comparison of measured unwanted currents coupled upon the mouth retractor by surgical technique: (a) root-mean square current (number of repetitions, n=3), and (b) peak-to-peak current (n=3). Box and whisker plots are shown with median, interquartile range, and true maximum and minimum values.

that the currents recorded on the mouth retractor are indeed attributed to the related tonsillectomy procedures.

As discussed in Section II.B, four scenarios are considered, namely monopolar electrosurgery at 10 W, 20 W, and 30 W, and coblation at 7 W. For repeatability, three independent measurements are performed per scenario. The average root-mean-square and peak-to-peak values of the unwanted currents coupled to the mouth retractor are summarized in Table I. As seen, peak-to-peak values of unwanted currents vary from 80.53 to 181.48 mA for power levels ranging from 10W to 30W. Coblation indicates smaller unintentional coupling, with peak-to-peak currents on the mouth retractor capped at 12.33 mA. For comparison, noise floor measurements are also included in Table I, i.e., currents measured on the mouth retractor when both monopolar electrosurgery and coblation generators are turned off. This recorded current typically corresponds to the thermal noise from the generator.

A statistical analysis of our collected *in vitro* measurements is illustrated in Fig. 6. It is noted that all statistical analyses were performed using IBM's Statistical Package for the Social Sciences (SPSS) v24. As seen, there was an associated significant dose dependent increase in

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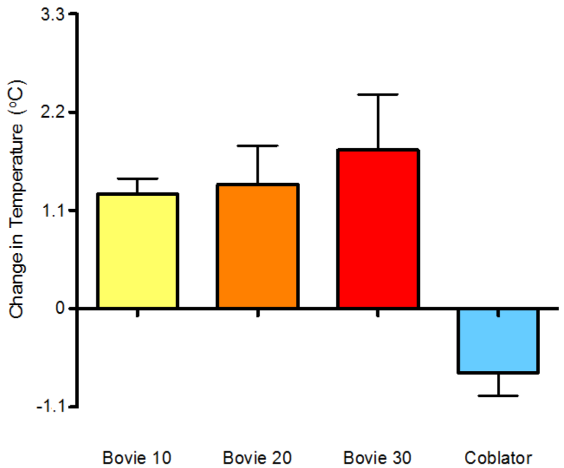

Fig. 7. Temperature changes in simulated surgery. Bar graph represents mean temperature with error bars representing standard error of mean.

unwanted current detected based on increased monopolar cautery settings (Kruskal Wallis; root-mean square current, $p < 0.001$; peak to peak current, $p < 0.001$). There was less detectable current flow through the retractor with Coblation compared with monopolar cautery (Kruskal Wallis; root-mean square current, $p < 0.001$; peak to peak current, $p < 0.001$).

B. Unwanted Temperature Increase in the Tissues Surrounding the Mouth Retractor

Temperature changes recorded 3 cm away from the tonsils (per Fig. 2) are summarized in Table II and Fig. 7. Again, four scenarios are considered in this study (monopolar electrosurgery at 10 W, 20 W and 30 W, and coblation at 7 W), and three independent measurements are collected per scenario. Averaged results are provided in Table II, and a statistical analysis is illustrated in Fig. 7.

During monopolar electrosurgery, tissue temperature unintentionally increases by 1.29°C, 1.41°C, and 1.79°C at 10 W, 20 W and 30 W, respectively. By contrast, coblation indicates a reduction of 0.72°C in tissue temperature. This is likely due to the saline solution that is concurrently poured during firing. Coblation, being a non-heat driven process, employs a constant irrigation of normal saline (and for increased efficiency, cold saline).

Statistically, we found that temperature increases after simulated tonsillectomy with monopolar electrocautery (see Fig. 7), although not significant between the four surgical techniques used (Kruskal-Wallis, $p = 0.09$). Monopolar cautery had increased temperature dispersion when compared directly to the coblator (Mann-Whitney U, $p < 0.001$).

IV. Conclusion

We presented the first-ever study that intends to assess and quantify unintentional RF energy transfer to the metal-based mouth retractor during tonsillectomy procedures. An *in vitro* measurement set-up was employed and both monopolar electrosurgery and coblation procedures were explored at typically used power levels. Our results indicated peak-to-peak values of unwanted currents as high as 80.53 to 181.48 mA for monopolar electrosurgery power levels varying from 10W to 30W. Tissue temperature 3 cm away from the firing location was shown to unintentionally increase by up to 1.8°C. Coblation indicated smaller unintentional coupling, with peak-to-peak currents on the mouth retractor capped at 12.33 mA for a typical 7 W setting. In this case, tissue temperature was reduced by 0.73°C, as attributed to the saline solution used during coblation.

This work lays the foundation for testing these unintentional current pathways during tonsillectomy, which may be linked to common adverse effects, associated with the procedure, including dysgeusia. For example, computational methods may be employed in future that take into account the human body thermoregulation mechanism. The ultimate goal is safe and complication-free tonsillectomy via suitable selection of procedures, power levels, materials used for the mouth retractor (e.g., other than metal), and so on.

Acknowledgment

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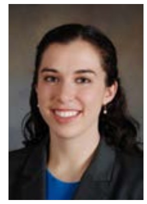

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Dr. Kiourti has received several awards and scholarships, including the URSI Young Scientist Award for 2018, the IEEE Engineering in Medicine and Biology Society (EMB-S) Young Investigator Award for 2014, the IEEE Microwave Theory and Techniques Society (MTT-S) Graduate Fellowship for Medical Applications for 2012, and the IEEE Antennas and Propagation Society (AP-S) Doctoral Research Award for 2011. She is currently serving as an Associate Editor for the IEEE Transactions on Antennas and Propagation.