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Electrocautery Devices With Feedback Mode and Teflon-Coated Blades Create Less Surgical Smoke for a Quality Improvement in the Operating Theater

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Abstract: Monopolar electrocautery is a fast and elegant cutting option. However, as it creates surgical smoke containing polycyclic aromatic hydrocarbons (PAHs), it may be hazardous to the health of the surgical team. Although new technologies, such as feedback mode (FM) and Teflon-coated blades (TBs), reduce tissue damage, their impact on surgical smoke creation has not yet been elucidated. Therefore, we analyzed the plume at its source.

The aim of this study was to evaluate if electrocautery FM and TBs create less surgical smoke.

Porcine tissue containing skin was cut in a standardized manner using sharp-edged Teflon-coated blades (SETBs), normal-shaped TBs, or stainless steel blades (SSBs). Experiments were performed using FM and pure-cut mode. Surgical smoke was sucked through filters or adsorption tubes. Subsequently, filters were scanned and analyzed using a spectrophotometer. A high-performance liquid chromatography (HPLC-UV) was performed to detect benzo[a]pyrene (BaP) and phenanthrene as 2 of the most critical PAHs. Temperature changes at the cutting site were measured by an infrared thermometer.

In FM, more surgical smoke was created using SSB compared with TBs ($P < 0.001$). Furthermore, differences between FM and pure-cut mode were found for SSB and TB ($P < 0.001$), but not for SETB ($P = 0.911$). Photometric analysis revealed differences in the peak heights of the PAH spectrum. In HLPC-UV, the amount of BaP and phenanthrene detected was lower for TB compared with SSB. Tissue temperature variations increased when SSB was used in FM and pure-cut mode. Furthermore, different modes revealed higher temperature variations with the use of SETB ($P = 0.004$) and TB ($P = 0.005$) during cutting, but not SSB ($P = 0.789$).

We found that the use of both TBs and FM was associated with reduced amounts of surgical smoke created during cutting. Thus, the surgical team may benefit from the adoption of such new technologies, which could contribute to the primary prevention of smoke-related diseases.

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Abbreviations: BaP = benzo[a]pyrene, FM = feedback mode, HPLC = high-performance liquid chromatography, PAH = polycyclic aromatic hydrocarbons, SETB = sharp-edged Teflon-coated blade, SSB = stainless steel blade, TB = Teflon-coated blade, UV = ultraviolet.

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INTRODUCTION

Electrocautery is a fast and precise cutting option in various fields of surgery.[1,2] It is regularly used in visceral surgery, otorhinolaryngology, dermatology, head and neck surgery, and plastic surgery.[3] Taking into account the reduced intraoperative blood loss as the result of coagulation of small vessels and, in addition, the minimized incidence of injuries to surgeons, monopolar electrocautery is often seen as a safer method to use compared with the traditional scalpel.[4–6]

Nevertheless, electrocautery involves certain risks. First, the smoke plume in the surgical field can irritate the surgeons' eyes and affect vision, interfering with the performance of the procedure. Second, electric shocks may harm a member of the surgical team. Third, in case of moisture, or if return electrode pads are not placed properly, the patients' skin might be injured, resulting in soft tissue burns. In addition, it may inhibit wound healing in comparison with the traditional scalpel.[7] Moreover, because of vaporization surgical smoke contains toxic components[7–11] and may harm the surgical team in an acute as well as a chronic manner. In addition, there is evidence that surgical smoke can contain blood cells and even melanoma cells and fragments of viral DNA.[12,13]

Krones et al[14] detected aldehydes in surgical smoke, such as formaldehyde, as well as acetone, polycyclic aromatic hydrocarbons (PAHs), acrylamide, and volatile organic compounds, such as benzene, toluene, and naphthalene, as well as inorganic gases, such as acid gases, chlorine, carbon monoxide, and carbon dioxide. Particles released in surgical smoke measure <0.1 μm in diameter. In general, particles <2.0 μm settle in the alveoli of the lungs and cannot be exhaled efficiently.[12] Standard surgical masks are able to protect the airways from particles just >5 μm.[15] Therefore, special breathing masks, skin protection, and even safety goggles would be needed to protect the surgical team properly from such particles. However, these measures are expensive and not very practicable. Hence, regulations regarding operation room evacuation do exist. In addition, direct evacuation close to the blade improves plume evacuation, but suction cannot eliminate all of the smoke.

TABLE 1. Blades and Modes Used in This Study

Cutting Test	Blade	Mode/Power
1	Sharp-edged Teflon-coated blades	Feedback mode
2	Normal-shaped Teflon-coated blades	Feedback mode
3	Stainless steel blades	Feedback mode
4	Sharp-edged Teflon-coated blades	60 W
5	Normal-shaped Teflon-coated blades	60 W
6	Stainless steel blades	60 W
Control	No cut	

Cutting was performed 6 times per test. Room air was exchanged between every experimental process.

Beside low-voltage cutting modes (pure-cut or blended mode) and high-voltage coagulation mode, new technologies for monopolar cutting are available to reduce output power automatically in response to impedance because of tissue changes in accordance with Ohm's law (also known as ''closed-loop control loops'').[16] Benefits of these feedback mechanisms with adjusted voltage and current include the minimization of tissue necrosis and less neuromuscular stimulation during dissection.[17]

Thus, smoke creation by different electrocautery systems has to be evaluated with regard to primary prevention using a clear experimental set-up. This study was not designed to identify and quantify the components of surgical smoke, but to range the contamination levels associated with feedback circuit electrosurgery and pure current electrosurgery for the first time. A traditional stainless steel blade (SSB) and 2 different blades coated with Teflon (polytetrafluoroethylene) are used. Filter contamination by surgical smoke was evaluated, as a correlation of coal-derived particles with PAH levels was described.[18] Moreover, levels of phenanthrene and benzo[a]-pyrene (BaP) were analyzed via high-performance liquid chromatography (HPLC-UV).

METHODS

This report complies with the reporting standards established by the Standards for Quality Improvement Reporting Excellence (SQUIRE) guidelines. The study has been notified to the Institutional Ethics Committee at the University of Lübeck and was approved under authorization number 13-064.

Cutting Part

An impermeable plastic bag (Ningbo Dingtai Packing Material, Zhejiang, China), measuring 15 dm^3, was used as a reservoir for the surgical smoke. It was placed in an airtight manner over a standardized piece of porcine tissue containing skin, dermis, fat, fascia, and muscle. The skin surface properties were comparable to human skin. The electrocautery device penetrated the bag tightly in order to hold the developing smoke in place. Skin and subcutaneous fat were cut to a depth of 1 cm and a length of 20 cm. Cutting speed was 4 cm/s. Directly after dissection, the device was switched off.

For dissection, a sharp-edged blade coated with Teflon (ACE Blade®, Megadyne, UT), a normal-shaped blade coated with Teflon (E-Z Clean®, Megadyne, UT), and an SSB (E1551G®, Covidien, MN) were used in combination with a power generator (Megapower®, Megadyne, UT) at fixed 60 W and in feedback mode (FM) (Table 1). Between every cutting process, room air was exchanged. All experiments were performed at room temperature. Experiments and data analysis were carried out in a blinded fashion by different persons.

Suction Part

To filter the fumes, a flexible hose (60 cm in length) was installed on the opposite side of the plastic bag. In a distance of 10 and 20 cm to its penetration hole, 2 paper-based filters (4 cm in diameter) were interposed, while the tube ending was attached to an automatic tube pump (X-act® 5000, Dräger Safety AG & Co KG, Lübeck, Germany). The pump was turned on until the entire smoke was evacuated from the bag. Procedures were repeated 6 times. As a control, the bag filled with room air was sucked through the filters. Afterward, the filters were preserved for further analyses. A similar set-up was used to collect the surgical smoke on activated carbon. For this, the paper-based filters were replaced by XAD-2 adsorption tubes (SKC Inc, Dorset, UK) and suction was performed using a flow of 2 L/min. As a control, suction was performed without cutting.

Filter Analysis

For analyzing the contaminated paper-based filters, central, middle, and outer areas were defined as regions of interest assuming homogenous contamination. These were scanned in a standardized manner using a digital microscope (VHX-1000, Keyence, IL) at a magnification of 100×. Pixel density was measured using ImageJ with automated color threshold[19] and reported as percentage of the scanned area. Mean values were used for comparison. Directly after scanning, the filters were washed twice in 1 mL ethanol (70%) to dissolve the grime components. The solution was then analyzed using a spectrophotometer (Ultrospec 3100 pro™, Amersham Biosciences, NJ). Absorption was measured at spectrum $\Delta\lambda$ 300 to 800 nm.

High-Performance Liquid Chromatography

An exemplary analysis of the surgical smoke components was performed using HPLC-UV. The samples were eluted from the XAD-2 adsorbents with 0.5 mL acetonitrile/methanol (3/2) and diluted to 2 mL. HPLC-UV analysis was carried out using the Dionex UltiMate® 3000 (Thermo Fisher Scientific, MA) with automated sample injector and a variable wavelength detector. The following instrument set-up was used: column Nucleosil® 100-10 C_{18} (4 × 250 mm) (Macherey-Nagel GmbH, Düren, Germany); eluent A water with 5% methanol; eluent B methanol; gradient 0 minute 60% B; 20 minutes 80% B, 30 minutes 90% B; 40 minutes 100% B; flow 1 mL/min; injection volume 20 μL. Ultraviolet (UV) absorption was recorded at 260 nm. A PAH-Mix (according to Environmental Protection Agency) containing 16 PAH standards (10 ng/μL each in acetonitrile) was used as reference for the calibration curve. No internal reference was used as only relative levels were relevant.

Temperature Measurement at Cutting Site

To analyze the influence of the different blades and electrocauter systems on heat generation, tissue temperature was measured by an infrared thermometer (Voltcraft, Wollerau, Switzerland). Before, during, and 10 seconds after cutting, temperatures were measured. The procedure was repeated 6 times. Mean temperature changes were used for comparison.

Statistical Analysis

Data were analyzed using SigmaPlot^{TM} statistical software version 12.3 (Systat, San José, CA). Normal distribution was tested using the Shapiro–Wilk test. In case of parametric data, statistical analysis was carried out using ANOVA followed by Tukey test. In case of nonparametric data, ANOVA on ranks was used. Data were expressed as mean ± SD. Differences among means were considered significant when $P < 0.05$.

RESULTS

The collection of the surgical smoke was easy using the impermeable reservoir bag. The second filter, serving as a quality marker, showed no contamination, indicating that nearly all particles of the surgical smoke were reliably caught by the first filter. Suction by the tube pump worked efficiently until no more gas remained in the bag. Harvesting the filters from their cases using a side cutter prevented the fine membranes from damage.

Filter Contamination

The different blades were used at different power settings. Analysis of filter contamination (Figure 1) was performed using a standardized threshold pixel count. In FM, no difference was found between the sharp-edged blade coated with Teflon and the normal blade coated with Teflon (148 ± 32.1 vs 1,473 ± 147.2, $P = 0.988$), but both showed significant differences when compared with the SSB (32,986.1 ± 26,570.0, $P < 0.001$). Using 60 W, the sharp-edged blade covered with Teflon showed significant differences to both the Teflon-covered blade (16,856 ± 1,135.3 vs 18,180.0 ± 46,461.6, $P < 0.001$) and the SSB (55,942.2 ± 45,301.8, $P < 0.001$). Moreover, statistically significant differences between FM and 60 W were found for the SSB ($P < 0.001$) and the Teflon-coated blade (TB) ($P < 0.001$). However, no differences were found when the sharp-edged blade coated with Teflon was used ($P = 0.911$). Affected areas are shown in Figure 2.

Photometry

After removing the grime from the filter using the solvent, the solution was analyzed using a photometer. Spectrum measured was from 300 to 800 nm. Two peaks, localized at about 310 and 580 nm, were evident in all samples except control. Hence, there was a significant difference in absorption from 300 to 450 nm between the groups; in contrast, the absorption peak at 580 nm was stable at about 0.018 A in all groups.

High-Performance Liquid Chromatography

Here the PAH amounts, which were reeluted from the XAD-2 adsorbent, were compared with each other. We found that BaP was elevated after suction of 15 L of gas when the stainless steel device was used at 60 W for a 20 cm cutting length of skin in comparison with the use of a sharp-edged blade coated with Teflon in FM (0.216 μg vs 0.006 μg). Moreover, phenanthrene was significantly lower in the sharp-edged blade coated with Teflon sample in comparison with the stainless steel sample (0.083 μg vs 0.333 μg). Both substances are PAHs and chemical components of coal tar.

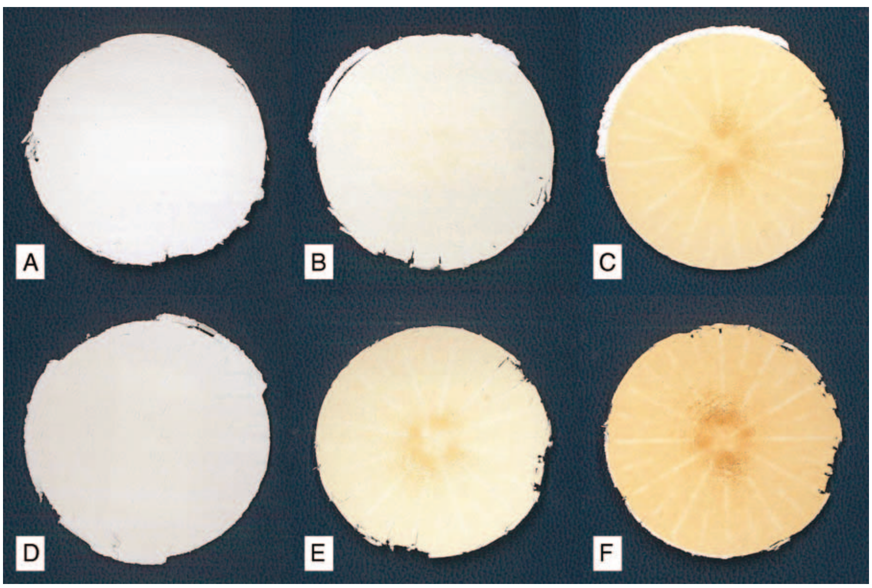

FIGURE 1. Filter contamination. SETBs show a very low filter contamination in FM (A) and at 60 W (B). Filters used for cutting with normal-shaped TBs are much more contaminated at 60 W (E) than in FM (D), while filters used for SSBs exhibit a high contamination in FM (C) and even more at 60 W (F). FM = feedback mode, SETBs = sharp-edged Teflon-coated blades, SSBs = stainless steel blades, TBs = Teflon-coated blades.

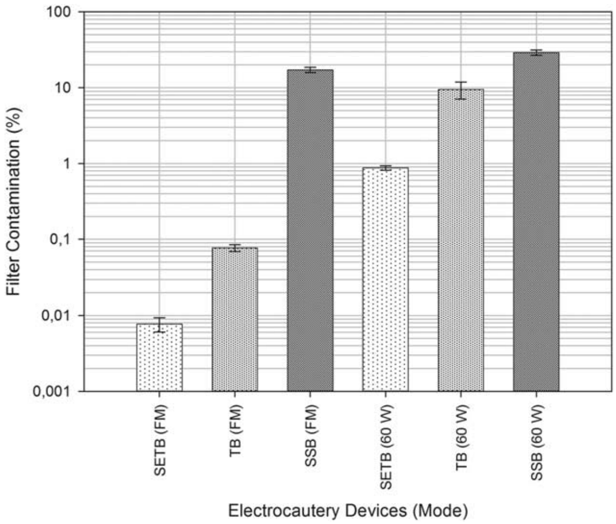

FIGURE 2. Proportion of filter contamination after monopolar cutting (log). Significant differences are evident between SSBs and SETBs or normal-shaped TBs in FM ($P < 0.001$). Moreover, filter contamination, when 60 W, was used to show significant differences between the groups ($P < 0.001$). Further, statistically significant differences are found between FM and 60 W in all 3 groups ($P < 0.001$) except SETB ($P = 0.911$). FM = feedback mode, SETBs = sharp-edged Teflon-coated blades, SSBs = stainless stainless steel blades, TBs = Teflon-coated blades.

Temperature

Tissue temperature alterations were measured with an infrared thermometer. Temperature changes in °C were significantly higher in the group of SSBs compared with the group of sharp-edged blades coated with Teflon (12.5 ± 2.7 vs 2.0 ± 0.6, $P < 0.001$) and TBs (3.0 ± 0.7, $P < 0.001$) during cutting in FM. Ten seconds after cutting, significant differences were still found between SSB and sharp-edged blade coated with Teflon (4.3 ± 1.0 vs 1.3 ± 0.6, $P = 0.003$) and TB (0.9 ± 0.3, $P < 0.001$). In 60 W mode, temperature changes were significant during cutting between stainless steel and sharp-edged blades coated with Teflon (13.3 ± 6.6 vs 4.2 ± 1.6, $P < 0.001$), but not for TB (7.9 ± 3.3, $P = 0.079$). Ten seconds after cutting, use of SSBs showed significant differences between sharp-edged blades coated with Teflon (4.3 ± 1.0 vs 1.3 ± 0.6, $P < 0.001$) and TBs (0.9 ± 0.3, $P = 0.001$).

Comparing each blade in the different modes, significant differences during cutting were found for sharp-edged blades coated with Teflon ($P = 0.004$), TBs ($P = 0.005$), but not for SSBs ($P = 0.789$) (Figure 3).

DISCUSSION

In our study, we showed that the creation and composition of surgical smoke in electrocautery depends on various factors. First, the use of blades coated with Teflon led to reduced plume emission. Second, the architecture of the blade influenced the vaporization process during tissue dissection. Moreover, variation of output power had an impact on the smoke production. Less power led to reduced filter contamination and a lower amount of examined PAHs. Therefore, a generator was used that had the ability to reduce power and voltage in response to changes of tissue impedance. Feedback circuit electrosurgical generators are available from Bovie Medical (Fast Digital Feedback System, BovieFDFS™), Conmed (Dynamic Response technology), Covidien (Instant Response™ Technology), ERBE Elektromedizin (Automatic Power Dosing), Megadyne (ACE™ Mode), Utah Medical Products (Controlled Output Circuitry), and others.

Regular output power used by surgeons for tissue dissection ranges from 25 to 50 W. In this study, we used a FM and a pure-cut mode at 60 W because of the short dissection length. As the periods of time surgeons and other members of the surgical team work with electrocautery vary widely, exposure to the fumes can be significantly higher than in this study. In a porcine tissue model, a power of 30 to 120 W was chosen for dissection. The authors also cut the skin.[14] On the contrary, Hill et al[20] performed their cutting in porcine muscle tissue. However, muscle dissection might not be a realistic scenario because electrosurgical cutting is mainly used in skin, subcutaneous fat, and fascia dissection. It is known that transection time, tissue properties, vascularity, and blade temperature influence the degree of thermal damage to the tissue.[21] Therefore, we used standardized flaps containing skin, fascia, and fat without any visible fat seams. Moreover, dissection took place in a standardized manner. The described method represents an easy, fast, and viable option for comparison of surgical smoke produced by electrocautery devices.

In our experiments, higher tissue temperature changes during and after monopolar cutting were found when SSBs were used, indicating a correlation to the creation of surgical smoke. Significantly, more surgical smoke was produced during tissue cutting when SSBs were used in comparison with blades coated with Teflon. In addition, the sharp-edged blade coated with Teflon produced even less smoke than the normal-shaped Teflon blade, possibly because of a special current flow. After testing the blades at 60 W, they were used in FM, in which the electrosurgical generator reduces current and power in response to the tissue impedance.[16] Interestingly, surgical smoke produced by the SSBs was even higher in FM compared with the TBs at 60 W. The least surgical smoke creation was found when sharp-edged blades coated with Teflon were used in FM.

For analyzing the plume of smoke, the filter content was measured with a photometer. In photometry, PAHs can be recognized in the UV spectrum, which is localized between 280 and 380 nm wavelength.[22] In our study, the absorption at the spectrum between 300 and 400 nm was significantly increased in the solution containing the grime removed from the filters, indicating contamination of the filters by PAHs. In addition, the spectrum at about 400 to 680 nm is visible for the human eye. At 580 nm, the orange to brown color is localized. This may be the reason why a second peak was evident at this wavelength in all groups, except the control group, because of the browning of the filters.

As it is known that organic compounds like PAHs have a negative impact on human health, we analyzed the surgical smoke with an HPLC-UV method in an exemplary fashion. The exposure to pyrolysis products is known to increase laryngeal papillomatosis caused by human papilloma virus.[23] Calero et al[24] published the first case of the recognition as an occupational disease in an operating room nurse in Germany in 2003. In our study, attention was paid to 2 of the most critical PAHs: phenanthrene and BaP. Phenanthrene has irritating and photosensitizing effects on the skin, whereas BaP is known to be mutagenic and highly carcinogenic, for example for lung cancer. These were found in every sample, regardless which device was used. However, quantity was lower for Teflon-

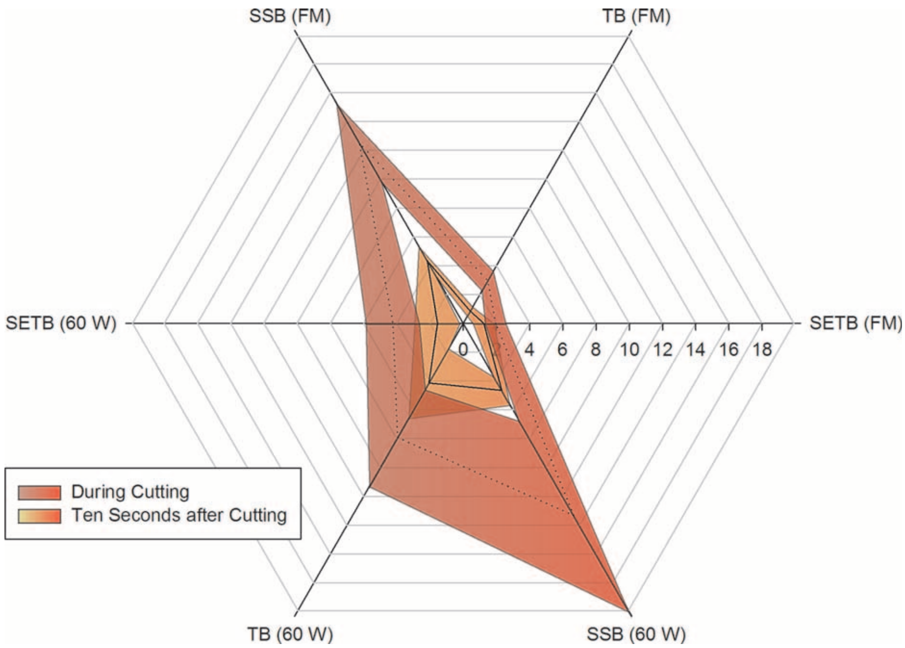

FIGURE 3. Tissue temperature alteration (°C) at cutting site. During cutting in FM temperature measured was significantly higher in the SSBs group than in the group of TBs ($P < 0.001$). Ten seconds later it was still increased ($P = 0.003$). At 60 W SETBs showed a significant lower temperature at cutting site than SSB ($P < 0.001$). Mode variation reveals no statistically significant temperature differences for SSB ($P = 0.789$), but for SETB ($P = 0.004$) and TB ($P = 0.005$). FM = feedback mode, SETBs = sharp-edged Teflon-coated blades, SSBs = stain-stainless steel blades, TBs = Teflon-coated blades.

coated devices and when FM was used. BaP is usually created in combination with other pyrolysis products. Collection is possible with a paper filter; however, sensitivity is higher in spun glass filters and activated carbon. Limits for BaP exposure as such are not defined in the United States. All parts of fume that are soluble in benzene or cyclohexane are interpreted as PAH for fast but unspecific testing. In Europe, different countries have different limits, ranging from 0.15 to 10 μm/m^3.[25] With regard to our findings, these limits can be reached very quickly in small operating rooms, when electrocautery is regularly used. Therefore, room smoke evacuation is strongly recommended. Moreover, several smoke evacuators are available on the market. These are useful to suck out most of the plume at its source. But evacuation of the entire smoke is impossible, even with this technique. Consequently, smoke production should be the primary target, even before smoke evacuation. Innovations, such as the reduction of eschar build-up by using Teflon coating, are required. Lower power settings have to be used during dissection to reduce thermal necrosis of the surrounding tissue. Moreover, feedback circuit electrosurgical generators lower the power output in response to tissue impedance. We showed that these factors, in addition to a special architecture of the blade, can decrease smoke creation.

Considering these facts, one could arrive at the conclusion that FM should be used for all types of electrosurgical dissections. In our experience, this mode works very well for the dissection of skin and fascia, but dissection of collagenous septa in the subcutaneous tissue is not very effective because of the high resistance. In addition, coagulation of small vessels is reduced with this technology. Therefore, we recommend the use of FM especially for skin cutting and fascia dissection, whereas pure cutting with higher power is useful for subcutaneous dissection. The technology is useful for flap rising or skin tumor excision. TBs might be advantageous for both types of dissection.

Limitations of this Study

This study was performed to analyze the smoke produced directly by the electrocautery device. Direct suction near the cutting electrode is used in many departments today and seems to be an effective option to reduce surgical smoke exposure. However, the smoke that is not sucked out by these direct systems should be measured in further studies. Moreover, feedback circuit electrosurgical systems are offered from numerous manufacturers. Differences between these devices could not be evaluated within the scope of this study. In addition, recent device technologies like Argon Beamer systems were not included in our work and may be compared in future studies.

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