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## Observational Study

## Analysis of electrocautery smoke released from the tissues frequently cut in orthopedic surgeries

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## Abstract

## BACKGROUND

Electrosurgical smoke could be different by the device of cutting or the type of tissue that is being cut.

## AIM

To analyze the electrocautery smoke released from the tissues that are frequently cut in orthopedic surgeries.

## METHODS

The released smoke from electrocautery of five different tissue types (meniscus, ligament, adipose, muscle, and synovium) of five patients who underwent total knee arthroplasty were collected and analyzed for volatile organic compounds (VOCs) and 27 candidate polycyclic aromatic hydrocarbons ( $n = 25$ ). Surgical smoke was produced with an electrocautery device for 4 min.

## RESULTS

None of the 27 evaluated polycyclic aromatic hydrocarbons compounds were detectable in electrocautery smoke collected from the surgical cutting of the different tissues. The number and identity of detected VOCs were similar between the patients but not between tissue types. The number of detected VOCs was the highest in synovial tissue ( $n = 21$ ) and the lowest in the meniscus and adipose tissue ( $n = 12$ ). The number of toxic and/or carcinogenic VOCs were the most in the muscle and meniscus tissues (Toluene, Ethylbenzene, and Styrene).

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No toxic and/or carcinogenic VOCs were identified in the ligament and adipose tissue.

## CONCLUSION

Meniscus and muscle tissue are associated with the highest number of toxic and/or carcinogenic VOCs. Therefore, we recommend that surgeons avoiding the electrocautery of these tissues.

**Key words:** Electrocautery smoke; Volatile organic compounds; Polycyclic aromatic hydrocarbons; Surgeon caution

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**Core tip:** No toxic and carcinogenic volatile organic compounds was detected in electrocautery smoke released from ligament and adipose tissue, while electrocautery smoke released from meniscus and muscle tissue contains significant toxicity and carcinogenicity. Therefore, we recommend that surgeons to use other electrosurgical techniques for cutting these tissues.

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## INTRODUCTION

Electrosurgery is a necessary technique that is being used in almost every surgical procedure to cut tissues and to control bleeding at the same time. Several electrosurgery techniques, including electrocautery, laser ablation, and ultrasonic scalpel dissection, are widely being used for tissue cutting and to decrease bleeding during surgery through coagulating small blood vessels<sup>[1]</sup>.

The breakdown of cellular membranes and other tissue structures during the electrosurgical cutting produces many biological by-products that are released in the form of smoke in the operating room environment. The presence of chemical pollutants (volatile organic compounds or VOCs) and biological hazards in surgical smoke have been reported in several investigations<sup>[2-5]</sup>. Surgical smoke has also been revealed to contain several carcinogenic components, mainly polycyclic aromatic hydrocarbons (PAH)<sup>[6,7]</sup>. Therefore, full identification of the toxicological effects of surgical smoke is important to prevent an occupational hazard to operating room staff by providing proper protection procedures and devices in surgical rooms.

Recent investigation of Fitzgerald *et al*<sup>[8]</sup> suggests that different electrosurgical tools may produce smokes containing different concentrations of carcinogenic compounds and irritant hydrocarbons. Furthermore, dissections from different tissues have been reported to produce different quantities and types of smoke<sup>[9]</sup>. Based on this evidence, the optimal pair matching of the electrosurgical tool and the tissue type could be a valuable approach to minimize the potential harm of the released smoke.

In this study, we aimed to compare the VOCs as well as PAH in electrocautery smoke released from five different human tissue types mainly cut in orthopedic surgeries. We hypothesized if the number of these hazardous components is more in a specific tissue, other electrosurgical tools could be suggested for surgical cutting of that tissue type. Further exposure preventing strategies could be suggested for that particular tissue as well.

## MATERIALS AND METHODS

This cross-sectional study was approved by the review board of Iran University of Medical Sciences under the code of IR.IUMS.REC.1393.25468. The smoke released during the electrocautery of five different tissue types (meniscus, ligament, adipose, muscle, and synovium) of five patients who underwent total knee arthroplasty were



collected and analyzed. In total, 25 samples were evaluated, consisting of five samples for each tissue.

### ***Surgical smoke collection and VOCs evaluation***

Five tissue samples, including meniscus, ligament, adipose, muscle, and synovium with a size of 2 cm × 2 cm, were taken from five patients during total knee arthroplasty surgery. Surgical smoke was produced with an electrocautery device (MEG2, Kavandish System, Tehran, Iran); the power of cut: (70) for 4 min. Smokes were collected using evacuated canisters. A grab sampling approach was used to fill the canisters to collect the smoke within 5 cm from the electrocautery interaction site. The collected smokes were analyzed in two modes: The gas model and the soluble model. For the evaluation of VOCs in the gas model, after using a pre-concentrator, the concentrated samples were analyzed using a gas chromatography-mass spectrometry (GC/MS) system (GC-MS Agilent Technologies 6890/5973, NY, United States) in accordance with the methodology presented in an earlier investigation<sup>[10]</sup>. The GC oven was programmed into four steps including a primary temperature of 130 °C and hold time of 3 min, continued by a temperature jump of 50 °C/min to 180 °C, followed by another temperature jump of 2 °C/min to 270 °C. Final temperature jump was 20 °C/min to 300°C with as hold time of 5 min. For the evaluation of VOCs in the liquid model, the concentrated gas was dissolved in 1 ml of methanol and then introduced to the GC/MS device (GC-MS Agilent Technologies 6890/5973, NY, United States)<sup>[11]</sup>.

### ***PAH assessment***

The PAH was assessed using the same GC-MS device and according to the previously described protocol. Briefly, the procedure included sonication extraction, solvent exchange, cleanup, nitrogen blowdown, and the final GC/MS analysis<sup>[12]</sup>. The PAHs analyzed in this study included Naphthalene, 2-Methylnaphthalene, Acenaphthylene, Acenaphthene, Fluorene, Phenanthrene, Anthracene, Fluoranthene, Pyrene, Benzo(c)fluorene, Cyclopenta(c,d)pyrene, Benz(a)anthracene, Chrysene, 5-Methylchrysene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Benzo(j)fluoranthene, Benzo(e)pyrene, Benzo(a)pyrene, Perylene, Indeno(1,2,3,-c,d)pyrene, Dibenz(a,h)anthracene, Benzo(g,h,i)perylene, Dibenzo(a,l)pyrene,, Dibenzo(a,e)pyrene, Dibenzo(a,i)pyrene, Dibenzo(a,h)pyrene.

### ***Statistical analysis***

Statistical significance is expressed as <sup>a</sup>*P* < 0.05, <sup>b</sup>*P* < 0.01 (*P* > 0.05 usually does not need to be denoted). If there are other series of *P* values, <sup>c</sup>*P* < 0.05 and <sup>d</sup>*P* < 0.01 are used, and a third series of *P* values is expressed as <sup>e</sup>*P* < 0.05 and <sup>f</sup>*P* < 0.01.

## **RESULTS**

### ***Direct smoke analysis***

The results of VOCs released from electrocautery smoke of different tissue types have been demonstrated in Table 1. In this respect, a complete agreement was seen between VOCs of the same tissues obtained from different cadavers. However, the VOCs of various tissues were considerably different. In this respect, the number of detected VOCs was the highest in the synovium (*n* = 21) and the lowest in the meniscus and adipose tissue (*n* = 12 for both tissues).

### ***Analysis of liquid model***

When the collected gas was dissolved in the methanol, the VOCs number reduced to four compounds, including hexadecanoic acid, methyl ester, 9,12-Octadecadienoic acid (Z, Z), methyl ester, 9-octadecenoic acid, methyl ester, (E), and heptadecanoic acid, 9-methyl, methyl ester. These VOCs were only detectable in adipose tissue and not in other tissue smokes, including meniscus, synovium, ligament, and muscle. The detected VOCs were similar between different cadavers.

### ***PAH analysis***

None of the 27 evaluated PAH compounds were detectable in any electrocautery smoke collected from the surgical cutting of the different tissues, including meniscus, synovium, ligament, muscle, and adipose tissue.

**Table 1 Volatile organic compounds detected in electrocautery smoke released from different tissue types (gas model)**

Synovium	Muscle tissue	Ligament tissue	Adipose tissue	Meniscus tissue
Toluene	2-Nonynoic acid	(replib)1,2,3,4-butanetetrol	Nonanal	Pyrrole
1,3,5-cycloheptatriene	Toluene	(mainlib) Propanal, 2,3-dihydroxy	Propane	Toluene
1-Octene	1,3,5-Cycloheptatriene	(replib)2(R),3(S)-1,2,3,4-butanetetrol)	Acetaldehyde	1H-Pyrrole , 2-methyl
1,6-heptadiene	Ethylbenzene	2S,3S)-(-)-3-Propyloxiranemethanol	1-hexanol,5-methyl	Ethylbenzene
L-Homoserine	DL-3-Aminoisobutyric acid	Glycerin	Histamine	Phenylethyne
2-Decene,(z)	Styrene	N-(tert-Butoxycarbonyl) glycine	Maleic acid	Styrene
2,5,7 -Cyclooctatetraene	1,3,5,7-cyclooctatetraene	7-methylguanosine	5-Methyl-1-heptanol	Bicyclo[4.2.0] octa-1,3,5 - triene
1, Bicyclo[4.2.0]octa- 1,3,5-triene	1-Hexanol, 4-methyl	Vinyl Ether	2-Octenal	Tetrahydro 1H-pyrrolo[1,2-c]imidazole-1,3(2H)-dione,
Cyclohexene	Butanal	Caprolactam	l-prolinamide	l-proline
Phenylacetic acid	Acetamide	2,3,dihydrofuran	Methylphosphonic acid	l-prolinamide
1-Hexene,3,5-dimethyl	2,5-Pyrrolidinedione	2-Butenal	Pyrrolo[1,2-a]pyrazine-1,4-dione, hexahydro	Pyrolo(1,2-a) pyrazine-1,4-dione,hexahydro
Propane	Maleic acid	Pyrrolo[1,2-a]pyrazine-1,4-dione, hexahydro		
Nonanal	2-Pyrrolidinemethanamine, N-methyl	l-prolinamide		
2,5-Pyrrolidinedione	Isoxazole			
5-dodecene	5-Methyl-2-pyrrolidinone			
1H-Pyrrolo[1,2-c]imidazole-1,3(2H)-dione, tetrahydro	Pyrrolo[1,2-a]pyrazine-1,4-dione, hexahydro			
L-proline, 1-acetyl-, methyl ester	(mainlib) Sydnone, 3-methyl			
L-Glutamic acid				
2-acetyl-cyclohexanone				
Pyrrolo[1,2-a]pyrazine- 1,4-dione, hexahydro				
1,2,3-Trimethyl-5-(2-thia-n-hexyl)piperid-4-one				

## DISCUSSION

Operating room staff are exposed to surgical smoke as the by-product of surgical cutting using the different electrosurgical tools. This surgical smoke is a mixture of biological and chemical pollutants that could be infectious, toxigenic, and carcinogenic<sup>[13]</sup>. Therefore, the development of protection strategies to facilitate less exposure of operating room personnel to surgical smoke is of critical value. One effective strategy could be the identification of the tissues and devices with the most hazardous smokes.

In this study, we aimed to identify the VOAs and PAH released from electrocautery cutting of five different tissues taken from five different cadavers. The tissue selection was based on the most frequently cut in orthopedic workouts. Based on the results of the present study, several hazardous VOCs were detected in the electrocautery smoke of different tissues. The highest number of VOCs were detected in the synovium ( $n = 21$ ), and the lowest number of VOCs were detected in adipose and meniscus tissues ( $n = 12$ ). While the number of detected VOCs was different between the tissues, a complete agreement was seen between the numbers of VOCs in the same tissues of different cadavers. In the solubilized model, only four VOCs were detectable in adipose tissue, while no VOCs were detected in the solubilized model of the other tissues. None of the 27 PAH compounds were detected in any of the evaluated tissue smokes.

Karjalainen *et al*<sup>[9]</sup> estimated the composition of particulate matter from surgical smoke of different tissue types obtained from Finnish landrace porcine, including lung, skeletal muscle, renal pelvis, liver, subcutaneous fat, renal cortex, bronchus,

cerebral gray and white matter, and skin. They found a significant difference in the identity and concentration of the surgical smoke particles depending on the electrocauterized tissue. In this respect, the liver tissue produced the highest number of particles. They suggested that the tissues can be divided into three distinct categories including (1) high-PM tissue such as liver; (2) medium-PM tissues such as skeletal muscle; and (3) low-PM tissues such as skin. Similar to the study of Karjalainen *et al*<sup>[9]</sup>, the results of the present study revealed the different surgical smoke particles in different tissue types.

Sisler *et al*<sup>[14]</sup> aimed to determine the airborne particle number concentration and distribution in electrocautery smoke of human breast tissue. All targeted VOCs ( $n = 17$ ) were detected in most of the sampling sessions. Furthermore, electrocautery smoke generated from human breast tissue induced cytotoxicity in cell culture. Fewer VOCs were detected by headspace analysis (solubilized gas model) compared to direct gas analysis due to different solubility and volatility of the VOCs. Similar to the study of Sisler *et al*<sup>[14]</sup>, fewer VOCs were detected in the dissolved gas model of the present study.

The VOCs content of electrocautery smoke released from different human tissues has also been evaluated in many other investigations, and their hazardous characteristics have been revealed<sup>[6,15]</sup>. To the best of our knowledge, analysis of electrocautery smoke released from synovium has not been performed in earlier surveys. Since the highest number of VOCs was detected in the synovial tissue in present comparative study, more preventive strategies should be implemented in surgeries that involve synovium cutting, such as total arthroplasty, to protect the safety of operating room personnel.

Tseng *et al*<sup>[12]</sup> aimed to investigate the potential hazards and cancer risk of electrocautery smoke in ten mastectomies. The particle concentration and gaseous/particle PAHs were measured using a particle counter and filter/adsorbent samplers. High PAH concentrations were detected in electrocautery smoke during regular surgical mastectomies. Most particles were in the size range potentially penetrable through the medical masks. The average concentration of particle/gaseous at the surgeon's breathing height was 20 to 30 times higher than those in regular outdoor environments. The estimated cancer risk was  $117 \times 10^{-6}$  for the surgeons and  $270 \times 10^{-6}$  for the anesthetic technologists. They strongly suggested using an effective smoke evacuator or smoke removal apparatus to diminish the hazards of electrocautery smoke to surgical staff<sup>[12]</sup>. By contrast to the study of Tseng *et al*<sup>[12]</sup>, we did not detect any PAH compounds in any tissues of our series. This could simply be attributed to the different tissue properties or other technical differences such as the power level of electrocautery device, ventilation rate of the operation room, utilizing the LEV system, *etc.* In many cases, future investigations are needed to resolve this inconsistency.

Although the number of VOCs could be considered as an indirect representation of the potential hazard of electrosurgical smoke, targeted identification of toxic and carcinogenic substances could be a more strong approach to estimate the biohazards of the electrosurgical smoke. Kocher *et al*<sup>[16]</sup> identified nine main toxic and/or carcinogenic substances from the smoke released from the electrocautery of the fresh porcine tissue, including acetylene, hydrogen cyanide, 1,3-butadiene, benzene, toluene, furfural, styrene, ethylbenzene, and 1-decene. While the highest number of VOCs was detected in the synovium tissue of the present study, the highest percentage of toxic and/or carcinogenic substances was detected in the meniscus tissue with the lowest number of VOCs. In this regard, three out of 11 VOCs (27.3%) detected in meniscus were toxic and/or carcinogenic (Toluene, Ethylbenzene, and Styrene). The same toxic and/or carcinogenic VOCs were also detected in the muscle tissue (3/17: 17.6%). Toluene was the only toxic and/or carcinogenic substance detected in the synovium (1/21: 4.8%). No toxic and/or carcinogenic substance was detected in the electrocautery smoke released from ligament and adipose tissue. These results reveal that the potential hazard of electrocautery smoke could be more in tissues with less released VOCs, as more toxic and/or carcinogenic substances could be detected in one tissue type regardless of the number of VOCs.

This study had some limitations that should be pointed out. As the main limitation of this study, we did not evaluate the size and concentration of particles, which are determining factors when assessing the potential hazards of chemical pollutants. Therefore, further studies are recommended with a focus on the size and concentration of VOCs and PAHs in tissues that were assessed in this study.

In conclusion, although no PAH component was detected in any of the evaluated tissues, the electrocautery smoke of the tissues that are frequently cut in orthopedic surgeries was different in terms of hazardous particle content. In this respect, synovial tissue was associated with the highest number of VOCs, and meniscus tissue was associated with the lowest number of VOCs. The number of toxic and/or carcinogenic



substances was the most in the meniscus and muscle tissue.

Therefore, further preventive strategies are required to be provided for the safety of operating room personnel who are exposed to electrocautery smoke released from these tissues. In this regard, we recommend using a knife for cutting meniscus and muscle tissue instead of electrocautery.

## ARTICLE HIGHLIGHTS

### Research background

Electrosurgical methods, including electrocautery, laser ablation, and ultrasonic scalpel dissection, are widely being used in routine surgeries to cut tissues and to control bleeding at the same time. The smoke released from electrosurgical cutting may contain biological by-products which are toxic and carcinogenic. No study has been performed to compare the hazardous compounds released from the electrocautery of tissues frequently cut in orthopedics, which is the main purpose of this study.

### Research motivation

The operating room staff is frequently exposed to the electrocautery smoke released from different tissue types. Analysis of the toxicity and carcinogenicity of this smoke is necessary to avoid this health-endangering condition. For tissues releasing a high number of toxic and carcinogenic compounds, other electrosurgical devices could be suggested.

### Research objectives

In this study, we compared the toxic and carcinogenic compounds released in the electrocautery smoke of five different tissues frequently cut in orthopedics, including meniscus, ligament, adipose, muscle, and synovium, to find which tissues produce the most hazardous smoke.

### Research methods

The smoke released during the electrocautery of five different tissue types (meniscus, ligament, adipose, muscle, and synovium) of five patients who underwent total knee arthroplasty were collected and analyzed for volatile organic compounds (VOCs) and 27 candidate polycyclic aromatic hydrocarbons using gas chromatography-mass spectrometry.

### Research results

None of the 27 evaluated polycyclic aromatic hydrocarbons compounds were detectable in electrocautery smoke collected from the surgical cutting of the different tissues. The number and identity of detected VOCs were similar between the patients but not between tissue types. The number of detected VOCs was the highest in synovial tissue ( $n = 21$ ) and the lowest in the meniscus and adipose tissue ( $n = 12$ ). However, the highest percentage of toxic and/or carcinogenic substances was detected in the meniscus tissue with the lowest number of VOCs. In this regard, three out of 11 VOCs (27.3%) detected in meniscus were toxic and/or carcinogenic (Toluene, Ethylbenzene, and Styrene). The same toxic and/or carcinogenic VOCs were also detected in the muscle tissue (3/17: 17.6%). Toluene was the only toxic and/or carcinogenic substance detected in the synovium (1/21: 4.8%). No toxic and/or carcinogenic substance was detected in the electrocautery smoke released from ligament and adipose tissue.

### Research conclusions

The quality of released compounds in the electrocautery smoke is more important than the quantity of them so that the potential hazard of electrocautery smoke could be more in tissues with less released VOCs. In the present study, the highest number of toxic and/or carcinogenic substances was detected in meniscus and muscle tissue with the lowest number of VOCs.

### Research perspectives

Further preventive strategies are required to be provided for the safety of operating room personnel who are exposed to electrocautery smoke released from these tissues. In this regard, we recommend using a knife for cutting meniscus and muscle tissue instead of electrocautery.

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