SCIENTIFIC ARTICLE

The Effect of Electronic Cigarettes on Hand Microcirculation

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Purpose Smoking conventional cigarettes reduces peripheral microcirculation leading to worse outcomes after hand surgery. Patients are increasingly using electronic cigarettes (eCigarettes); however, there is no published research investigating the effects of eCigarettes on hand microcirculation.

Methods Fifteen healthy subjects with a median age of 26 years were recruited: 7 smokers and 8 nonsmokers. A noninvasive O_2C laser Doppler probe measured a baseline control reading at deep (7-mm) and superficial (3-mm) levels. Participants commenced a 5-minute smoking protocol of nonnicotine (0-mg) eCigarettes with continuous microcirculation measurements during smoking and for 20 minutes afterward. This was repeated with nicotine (24-mg) eCigarettes. Readings were averaged over 5-minute periods and standardized as a percentage of baseline. A linear mixed-effects model with an unstructured covariance structure was used to analyze the data.

Results Smokers had a statistically significant reduction in hand microcirculation during and up to 20 minutes after smoking a 24-mg eCigarette. There was a maximum reduction of 77% in superficial flow and 29% in deep flow. After smoking a 0-mg eCigarette, smokers demonstrated an increase in superficial flow of up to 70% with no change in deep flow. Nonsmokers had no statistically significant change in superficial or deep flow after smoking either eCigarette.

Conclusions A 24-mg eCigarette significantly reduced smokers' hand microcirculation during and after smoking. Microcirculation increased in smokers after inhalation of a 0-mg eCigarette.

Clinical relevance We advise smokers undergoing hand surgery to avoid high-dose eCigarettes and, if necessary, to use 0-mg eCigarettes as an alternative. *(J Hand Surg Am. 2017;■(■):■–■.*

Key words eCigarette, smoking, microcirculation, laser Doppler, vaping.

Inhalation of nicotine and carbon monoxide from tobacco cigarettes is well known to be associated with worse outcomes after hand surgery, and quitting smoking has been associated with a 41% reduction in postoperative complications.[1] All smokers are advised to avoid tobacco cigarettes for at least 4 weeks before elective hand surgery or after a hand injury.[2] A recent literature review into pathophysiology studies has shown that nicotine replacement therapy (NRT) can impair the inflammatory stages of wound healing but highlights that there is currently no evidence to determine whether this has any effect on clinical outcome.[3] However, despite their increasing use, there is currently no evidence surrounding the effects of electronic cigarettes (eCigarettes) on hand surgery outcomes and whether hand surgeons should be advising patients to abstain from eCigarettes as with their tobacco counterparts.

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Nicotine from both tobacco and NRT greatly increases circulating catecholamines,[4] leading to impaired microcirculation in the hand.[5] Tobacco cigarettes also significantly increase levels of vasopressin[6] and fibrinogen,[7] causing tachycardia, hypertension,[8] and a hypercoagulative state,[7] whereas NRT does not have these effects.[5] Carbon monoxide is formed during the burning of tobacco and, when inhaled, has a very high affinity for hemoglobin. This increases carboxyhemoglobin[8] and subsequently reduces tissue oxygenation.[9] A combination of impaired microcirculation, a hypercoagulative state, and reduced tissue oxygenation is responsible for the adverse effects seen in tobacco smokers following hand surgery.

Van Adrichem et al[10] showed there was a mean decrease in blood flow of 29% when smokers inhaled from 3 cigarettes. Netscher et al[5] confirmed a similar reduction in blood flow of 31% after smoking tobacco cigarettes and a smaller reduction of 20% after application of a transdermal nicotine patch. The duration of the reduced blood flow appeared to be quite short and had returned half way to normal at 10 minutes.[10]

Patients are increasingly using both nicotine and nicotine-free eCigarettes as a method of quitting smoking.[11] The eCigarettes consist of replaceable nicotine or flavored cartridges, a heating element, and a battery source. They can deliver vaporized nicotine in the absence of other ingredients found in normal cigarettes, such as tar and carbon monoxide. The nicotine delivery and pharmacokinetics of the eCigarette are comparable with nicotine inhalers both delivering approximately 15 μg nicotine/100 mL puff and resulting in serum levels of nicotine of 1.3 to 2.1 ng/mL compared with 13.4 ng/mL after smoking a tobacco cigarette.[12]

The eCigarettes remain a controversial topic among health care professionals owing to the lack of research surrounding them. A recently published literature review identified only 3 *in vivo* human studies into the effects of smoking eCigarettes.[12] All these studies showed an adverse effect on pulmonary function, but to date, there is no published research investigating the effects of eCigarettes on the microcirculation of the hand.

The primary aim of this study was to determine whether smoking nicotine eCigarettes has any effect on blood flow in the hand. We also investigated whether this effect is present in nicotine-free eCigarettes and whether being a smoker has any influence on the change in microcirculation.

MATERIALS AND METHODS

Patient recruitment

Smokers and nonsmokers were recruited through word of mouth and advertisement posters displayed to staff members of the 2 involved investigative sites within staff-only areas. Inclusion criteria were volunteers between 18 and 65 years old with no comorbidities. Exclusion criteria included people lacking mental capacity according to the Mental Capacity Act 2005.[13] Exsmokers and people taking any form of NRT were also excluded. Smokers were asked to refrain from using any form of nicotine within 4 hours of beginning the study.

Intervention

Participants had a noninvasive laser Doppler probe (O_2C; Medizintecknik, Germany) attached to their nondominant hand to measure microcirculation. This apparatus measures the movement of blood at superficial (3-mm) and deep (7-mm) levels. The units are arbitrary (AU) and can be equated to milliliters per minute with calculations specific to the tissue being investigated. It has been used in the assessment of burns[14] and foot ulcers[15] and has been validated as a reliable, noninvasive method of monitoring microcirculation.[16,17] The sensor was embedded in a custom-molded foam-padded orthosis (Fig. 1) and placed over the pulp of the middle finger. It was then covered with an occlusive, nonadhesive dressing to prevent contamination from ambient light. The forearm was rested on a surface placed at the level of the participant's chest.

After manipulation of the sensor placement to obtain the optimum trace (ie, avoiding superficial vessels and bony prominences), an initial baseline reading of microcirculation was taken over 5 minutes. A 5-minute smoking protocol of a nonnicotine (0-mg) eCigarette was then commenced with the participant inhaling from the eCigarette at a rate of 1 inhalation every 30 seconds, a total of 10 inhalations. This protocol was based on the method described by Monfrecola et al[18] who used inhalations every 10 seconds. This was not tolerated by our participants who, on attempting this protocol, developed severe nausea, and therefore, the frequency of inhalations was reduced. It was subjectively agreed among both the investigators and the participants that our protocol mimicked a natural smoking rate.

Measurements of microcirculation were taken continuously at a rate of 1 per second during smoking and for 20 minutes thereafter. In all participants, microcirculation readings had returned to baseline at the end of the 20-minute monitoring period. This was then repeated with the nicotine (24-mg) eCigarette. Farsalinos et al[19] have demonstrated that eCigarettes are less efficient at distributing nicotine than traditional cigarettes, and therefore, we chose the highest