A Cross-Sectional Study of Electronic Cigarette Use Among Chinese Adult Populations in Four Cities of China. Part II. Puffing Topography *

by

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SUMMARY

With the rapid popularity and increasing numbers of E-cigarette (EC) users, debates on possible health risks and regulation of EC products have attracted attention in public. As a useful means to help assessing the risks of EC consumers, puffing topography studies have come to be an important tool globally. In this paper, a cross-sectional epidemiological study on puffing topography of 511 EC consumers in four cities of China was conducted in January 2018. Data acquisition was based on a questionnaire and a Clinical Research Support System (CReSS) Pocket device for the smoking behavior recording. The results showed that EC consumers in the four cities were mainly young males, most of whom preferred tank systems with zero or low nicotine concentrations (1–5 mg/mL) in the liquid. The average puff volume, puff duration and inter-puff interval (IPI) were 87.2 mL, 1.97 s and 22.0 s, respectively. The factors that may have affected puffing topography such as product type, nicotine concentration, using time, smoking status and battery power were studied. The results suggest that the EC product type and the concentration of nicotine in EC liquids were the main factors that affected the puffing topography of the users. This study was the first study on the puff topography of Chinese EC consumers with a large number of participants. The results may not only help to more deeply understand smoking behavior and to better assess the potential risks for the EC users, but they may also supply useful information for the development of smoking machine regimes for ECs. [Contrib. Tob. Nicotine Res. 30 (2021) 149–157]

KEY WORDS: Electronic cigarette; puffing

ZUSAMMENFASSUNG

Mit dem rapiden Anstieg der Nutzung von E-Zigaretten (EZ) erhält die Diskussion über die gesundheitlichen Risiken und die Regulierung von EZ-Produkten viel öffentliche Aufmerksamkeit. Als nützliches Instrument zur Bewertung der Risiken für Nutzer von E-Zigaretten gewinnen hierbei Studien zur Zugtopographie zunehmend global an Bedeutung. In diesem Artikel wird eine epidemiologische Querschnittsstudie zur Zugtopographie mit 511 Nutzern von E-Zigaretten beschrieben, die im Januar 2018 in China in vier Städten mithilfe eines Fragebogens und eines CReSS-Handmessgeräts (Clinical Research Support System) zur Aufzeichnung des Rauchverhaltens durchgeführt wurde. Die Ergebnisse zeigen, dass es sich bei den Nutzern in den vier Städten hauptsächlich um junge Männer handelte, von denen die meisten Tanksysteme ohne Nikotin bzw. mit einer geringen Nikotinkonzentration
RESUME

Du fait de l’augmentation rapide de l’usage de la cigarette électronique, les échanges concernant le risque pour la santé et la régulation des produits fumés par voie électronique attirent l’attention soutenue du grand public. Outils utiles à l’évaluation des risques auxquels s’exposent les utilisateurs d’e-cigarettes, les études consacrées à la topographie du fumage ont gagné en importance partout dans le monde. Le présent article relate une étude épidémiologique croisée, portant sur la topographie de fumage et menée auprès de 511 utilisateurs de cigarettes électroniques dans quatre villes chinoises. Cette étude remonte au mois de janvier 2018 et s’appuie sur un questionnaire et l’utilisation d’un dispositif de poche CReSS (Clinical Research Support System) servant à l’enregistrement du comportement tabagique. Les résultats mirent en lumière que les utilisateurs d’e-cigarettes dans les quatre villes sondées étaient, pour la plupart, de jeunes hommes et que la majorité d’entre eux marquaient une préférence pour les systèmes équipés d’un réservoir avec des concentrations en nicotine faibles (1–5 mg/mL), voire nulles dans le e-liquide. Le volume moyen par bouffée, la durée des bouffées ainsi que l’intervalle entre les-çi étaient respectivement de 87,2 mL, 1,97 s et 22,00 s. Les facteurs susceptibles d’influer sur la topographie du fumage tels que le type de produit, la concentration en nicotine, le temps d’utilisation, le statut du fumeur et la puissance de la batterie furent étudiés. Les résultats laissent à penser que le type de produit fumé par voie électronique et la concentration de nicotine dans le e-liquide constituent les principaux facteurs influençant la topographie du fumage des utilisateurs. Cette étude fut la première à être consacrée à la topographie du fumage des utilisateurs chinois de cigarettes électroniques et à inclure un grand échantillon d’individus. Les résultats concourent, non seulement potentiellement, à une meilleure compréhension du comportement tabagique de cet échantillon et à une meilleure évaluation des risques potentiels auxquels s’exposent les utilisateurs d’e-cigarettes mais peuvent aussi livrer des informations utiles à la mise au point des paramètres de fumage sur machine pour les cigarettes électroniques. [Contrib. Tob. Nicotine Res. 30 (2021) 149–157]
duration was similar with both types of ECs (2.0 s and 2.2 s), but mean puff volumes (52.2 mL and 83.0 mL) and IPI (23.2 s and 29.3 s) differed significantly. Other researchers including ROBINSON et al. (23), LEE et al. (19), GONIENWICZ et al. (20), and SPINDLE et al. (26, 27) have also studied the puffing topography of EC users under different conditions. CORESTA (32) also published a recommended method for machine-smoking of ECs in 2015. Their recommended machine-puffing parameters are 55 mL, 3 s, and 30 s for puff volume, puff duration, and IPI, respectively. There were significant differences between the various studies, for example, the average puff volume ranged from 51 to 148 mL and the average puff duration ranged from 1.8 to 5.29 s. These large differences might be ascribed to different EC types, nicotine concentrations in liquids, testing instruments and experimental designs, as well as the participants' numbers (from 11 to 60 participants) and different populations in the various studies. To better understand the puffing topography of EC users, much research covering more participants, different EC products and different populations are urgently required. Although ECs were first invented in China and Chinese users also increased greatly recently no puffing topography studies have been reported yet. In our study, a cross-sectional epidemiological investigation on puffing topography of 511 EC consumers in four cities of China (Beijing, Shanghai, Guangzhou and Shenzhen) was conducted in January 2018. The relationship between topography and nicotine concentration in EC liquid, as well as product type and smoking status were also studied. The results may help to better understand the puffing topography of EC users, and also may help to provide useful data for the development of smoking machine parameters of EC.

2. METHODS

2.1 Participants

Through the EC users’ geographical distribution and the city ranking of the Baidu Search Index (39), four cities including Beijing, Shanghai, Guangzhou and Shenzhen were chosen as the typical EC users areas in China. The study was reviewed by and received ethics clearance from the Public Health Institute of Zhengzhou University. Voluntary informed consent, confidentiality, rigorousness and authenticity were followed throughout the investigation. In this study, 18,970 EC users were invited through both online advertisements and local EC stores. Finally, 511 users agreed to participate in this study and the final groups consisted of 82, 123, 149, and 157 volunteers from Beijing, Shanghai, Guangzhou and Shenzhen, respectively. Eligible subjects were healthy adult EC consumers aged 18–55 who had used ECs at least on 3 days per week for more than 3 months. Exclusion criteria were: a) illicit drug abuse; b) severe depression or other psychiatric disorders; c) severe cardiovascular diseases, chronic obstructive pulmonary disease, lung cancer and other cancers. Women were excluded if they were breastfeeding or pregnant. Participants were asked to sign informed consent before being included in the study.

2.2 Method for recording the smoking behavior

The CReSS Pocket device (Version 1.0.1.2001, Borgwaldt KC Inc., Richmond, VA, USA) was used to record vaping topography. CReSS was originally designed for measuring puffing topography when smoking cigarettes. Due to the various tank and cartomizer systems, ECs may not always be compatible to the CReSS Pocket. Thus a connector made of a silicone tube was developed to fit the different ECs. The calibration method and accuracy validation was developed in our previous work (33). Participants attended the clinical study at the designed time to complete the computerized questionnaires, and then made at least 15 puffs with their own EC that had been connected to the CReSS Pocket. The process was video-recorded in order to verify compliance and ensure that the data had been correctly recorded. About 10% of the participants were randomly selected to verify the number of puffs recording. To mimic real-world EC use, the staff chatted with the participants before and during the topography recording process to make them relax and use ECs as usual.

2.3 Subjective questionnaires

Content of the questionnaire mainly includes three sections. The first one is on demographics and personal information, including age, gender, education, etc. The second one shows the consuming behavior of the users, including product type, nicotine content in the EC liquid, battery power, etc. The third one states their current smoking status, which was mainly used for investigating whether participants also smoked cigarettes at the same time.

2.4 Data analysis

The data was analyzed by SPSS 22.0 Demo software (SSPS Inc., Chicago, IL, USA). Tukey’s test method was used to eliminate outlier values in the sample. Mean value, standard deviation (SD) and 95%-CIs of puff topography parameters were calculated. Comparison of the parameters was performed by using One Way ANOVA. The level of significance was set at p < 0.05. When the variance was homogeneous, the Least Significant Difference (LSD) method was used for the multiple comparisons between groups. In case of heterogeneity, the Dunnett’s T3 was used for the multiple comparisons between groups.

3. RESULTS

3.1 Participant’s characteristics

In total, 511 experienced EC users were recruited in the four cities. Information on the participants is shown in Table 1. Most participants were male (90.6%) with only minor difference between the four cities. The age of the participants ranged from 18 to 62 years. 48% of them were between 19 and 29 years old, the average age was 31 years. In the city of Shenzhen, the average age was only 26 years.
3.2 Vaping status

The questionnaire results (Table 2) show that some participants had been using ECs for more than 5 years, while the shortest interval was 3 months. The majority of participants (65.3%) had used ECs for approximately 6 months to 2 years.

In our study, EC products can be classified into three types: a) tank ECs that are designed to be refilled with liquid by the user; b) disposable ECs; c) cartomizer ECs that are operated with prefilled cartridges which need to be replaced once emptied. The results show that most of the users (96.1%) chose the new generation of ECs that are tank systems.

The concentrations of nicotine in EC liquids were divided into 5 levels according to the product survey. These were nicotine-free (0 mg/mL), low-level (1–5 mg/mL), mid-level (6–11 mg/mL), high-level (12–20 mg/mL) and ultra high-level (> 20 mg/mL). The results in the study showed that consumers preferred ECs with low nicotine concentrations (N = 298, 58.3%), and then ECs with no nicotine (N = 88, 17.2%) and mid-nicotine (N = 78, 15.3%). Products with high nicotine levels were rarely used (N = 14, 2.7%). The average and median values of battery power of the ECs used by the consumers were 97.5 W and 80.0 W, respectively. Most consumers preferred a battery power lower than 100 W.

3.3 Smoking status

To find out whether the consumers also smoked cigarettes, the participants’ smoking status was investigated. Exclusive EC users were defined as those who used only ECs within one month before the begin of this study. Dual users are those who used ECs and cigarettes at the same time. The findings (Table 3) show that EC users were mainly dual users, accounting for about 73.2%, and exclusive EC users were only about 26.8%. Among the exclusive EC users, 80.3% were ex-smokers, 54.6% of them ex-smokers who had quit smoking conventional cigarettes within six months past. Among the dual users, 88.2% had smoked cigarettes before using ECs, the others had never smoked before using ECs.

3.4 Puffing topography

The results of the puffing topography measurements obtained from the CReSS are shown in Table 4. In the machine-smoking protocols, parameters of puff volume, duration and IPI are mainly focused on. As opposed to cigarettes, there is no smoldering process with ECs, and the influence of smoking intervals on the aerosol delivery is slightly lower, thus puff volume and duration were our main focuses in the study.

In general, the average and median puff volumes of EC users were 87.2 and 75.4 mL, respectively. The distribution of participants’ puff volumes is shown in Figure 1.
The percentages of puff volume of < 30, 30 ≤ V < 60, 60 ≤ V < 90, 90 ≤ V < 120, and ≥ 120 mL were 6.5%, 27.4%, 28.0%, 18.0% and 20.1%, respectively. Overall, puff volume of 73.4% participants was in the range of 30–120 mL. The average puff duration was 1.97 s (0.20–4.56 s), and the median was 1.9 s. The distribution of the puff duration for the ranges of 0.2–1.0, 1.01–2.0, 2.01–3.0, 3.01–4.0 and > 4.01 s was about 7.8%, 48.2%, 34.2%, 8.8% and 1.0%, respectively. Overall, puff duration time of most participants was in the range of 2.0–4.0 s (82.4%). Means +/- SD for IPI, average flow rate, peak flow rate and peak time were 22.0 ± 79.1 s, 47.3 ± 19.2 mL/s, 68.7 ± 27.6 mL/s and 0.87 ± 0.43 s (mean ± SD), respectively. Data analysis showed that the two parameters (puff volume and puff duration) were significantly different when comparing Beijing to either Guangzhou or Shenzhen. For the puff volume the significance was p = 0.001 for Beijing/Guangzhou and p = 0.000 for Beijing/Shenzhen; for the puff duration the significance was p = 0.031 and p = 0.001, respectively.

### Table 4. Average puffing topography parameters of the participants.

| Puffing topography (average, SD) | Total | Beijing | Shanghai | Guangzhou | Shenzhen |
|----------------------------------|-------|---------|----------|-----------|---------|
| Volume (mL)                      | 87.2 (50.1) | 67.5 (38.2) | 78.5 (41.2) | 91.4 (53.9) | 100.4 (54.0) |
| Average flow (mL/s)              | 47.3 (19.2) | 43.9 (17.8) | 44.2 (19.2) | 48.6 (19.6) | 50.5 (18.8) |
| Peak flow (mL/s)                 | 68.7 (27.6) | 66.9 (26.6) | 63.8 (27.9) | 69.7 (28.5) | 72.8 (26.3) |
| Duration (s)                     | 1.97 (0.73) | 1.77 (0.78) | 1.92 (0.62) | 1.99 (0.75) | 2.09 (0.75) |
| IPI (s)                          | 22.0 (79.1) | 21.3 (11.7) | 11.8 (6.7)  | 21.9 (32.8) | 30.5 (11.0) |
| Time of peak flow (s)            | 0.87 (0.43) | 0.7 (0.45)  | 0.8 (0.34)  | 0.9 (0.46)  | 1.0 (0.42)  |

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### Figure 1. Distribution of puff volume of participants.

4. DISCUSSION

4.1 Consumption behavior of Chinese EC users

Though the EC was invented in China in 2003 (40), EC using became popular not before 2008. Our findings showed that EC consumers in the four cities were mainly young males with a bachelor’s degree. The reason may be that younger consumers with higher education levels pay more attention to health, which is consistent with the low-risk claims of ECs. In terms of EC product types, most consumers preferred tank systems, which was consistent with the results of ETTER’s study (34). The reason may be attributed to the fact that along with the power of the battery, the flavor of the EC liquid can be conveniently adjusted according to satisfy their individual tastes and their desire to blow smoke rings. The variety of the appearance may be another reason for the consumption for fashionable reasons. The most popular concentration of nicotine in refill liquid was found to be low among the participating EC users (1–5 mg/mL), very different from that of European and American EC consumers (7–16 mg/mL) (35). During the survey, it was found that many users initially turned to ECs due to the intention of quitting smoking and decreasing the risk of cigarette smoking. In their perception, low nico-
nicotine concentrations in the EC’s liquid meant low health risk as well as low risk of addiction. This perception may be a reason that they preferred the low nicotine concentrations in the liquid.

The evaluation of the questionnaires showed that 73.2% of the participating users in the study were dual-users. It is speculated that ECs might not fully satisfy the consumer, which may be resulting from their nicotine dependence, but this would need to be proved. Among the exclusive and dual EC users, about 80.3% and 88.2%, respectively, were ex-smokers, showing that most EC users were former cigarette users, and that some consumers were able to quit smoking via the use of EC. Based on the data that showed that 19.7% consumers did not smoke cigarettes prior to start using ECs, it should be noted that ECs could also attract nonsmokers. The result showed that 11.8% of dual users had not smoked cigarettes before using ECs. This finding requires verification in future studies. In particular, the question should be addressed how many adolescent nonsmokers start using ECs and then become dual users.

4.2 Puffing topography of EC consumers

In previous literature reports (17–27), the average puff volume, puff duration and IPI ranged from 51–148 mL, 1.8–5.29 s and 10–118 s, respectively. Contrarily, in our study the average puff volume, puff duration and IPI were found to be 87.2 mL, 1.97 s and 22.0 s, respectively. Overall, our observed values were within the reported levels. These dissimilarities may have been caused by differences in populations, experimental conditions, EC types, nicotine concentrations in the liquid, and EC battery power. As the participants were using products of their own preference, the individual differences observed in our study were relatively large.

To find out what factors may have played a role in the puffing topography of ECs, the possible influence of parameters such as product type, nicotine concentration in the EC liquid and the power of the battery for the tank ECs were analyzed. The puffing parameters for the different EC product types are given in Table 5.

For the different EC product systems, the results showed that participants using disposable and cartomizer systems took puff volumes of $57.4 \pm 19.9$ mL and $57.5 \pm 22.9$ mL, respectively, whereas participants using tank systems took larger puffs of $88.6 \pm 50.5$ mL. The results were very similar to those of CUNNINGHAM et al. (21) with puff volumes of $52.2$ mL among cartomizer users and $83.0$ mL among tank users. The puff durations were in the range of 1.91–1.97 s, and there were no significant differences between the three types. The average IPI of the participants with disposable and cartomizer system types were 10.5 s and 10.4 s, while for users with tank system types it was 22.5 s. The difference among the parameters needs to be re-addressed in a future study which should feature a higher number of users of disposable and cartomizer system types. One unambiguous finding in previous investigations was that there is a substantial difference in topography patterns between experienced and naïve EC users (11, 14). In this study with experienced EC users, the influence of using time on the puffing topography was also studied (Figure 2). The average puff volumes were $85.0, 90.2, 89.9, 88.9, 62.7$ and $69.9$ mL for consumers using ECs for the time span of 3–6 months, 6–12 months, 1–2 years, 2–3 years, 3–5 years and above 5 years, respectively.

Table 5. The influence of EC type on the puff parameters.

| Puffing topography | Mean value | Tank | Cartomizer | Disposable |
|--------------------|------------|------|------------|------------|
| Volume (mL)        | Average    | 88.6 | 57.5       | 57.4       |
|                    | SD         | 50.5 | 22.9       | 19.9       |
| Average flow (mL/s)| Average    | 48.0 | 29.5       | 32.2       |
|                    | SD         | 19.2 | 10.1       | 18.8       |
| Peak flow (mL/s)   | Average    | 69.7 | 39.8       | 46.3       |
|                    | SD         | 27.6 | 16.1       | 30.2       |
| Duration (s)       | Average    | 1.97 | 1.91       | 1.97       |
|                    | SD         | 0.74 | 0.57       | 0.75       |
| IPI (s)            | Average    | 22.5 | 10.4       | 10.5       |
|                    | SD         | 80.6 | 6.2        | 7.5        |
| Time of peak flow (s)| Average  | 0.87 | 0.84       | 1.04       |
|                    | SD         | 0.43 | 0.43       | 0.63       |

Figure 2. The effect of using time on the puff volume of EC consumers.
Overall, with the increase of the time span the participants used ECs, the puff volume first increased slowly, then remained stable and finally decreased notably. The results showed that there were significant differences between the puff volumes of longtime consumers of ECs of e.g., 3–5 years and those who used ECs for shorter periods of time as e.g., 6–12 months 1–2 years, 2–3 years (p = 0.01, 0.01 and 0.03, respectively). The reason of this finding is still unclear. Puff duration did not vary with duration of use, with the average values of 2.02, 1.98, 1.96, 1.94, 1.85, 1.88 s, respectively, for users with 3–6 months, 6–12 months, 1–2 years, 2–3 years, 3–5 years and above 5 years use time.

In previous studies (36, 37), participants who switched from cigarettes with high “tar” levels to cigarettes with low “tar” levels were found to always increase their puff intensity to get the amount of nicotine they crave. In this study, the influence of nicotine concentration in EC liquid on the puffing topography was studied. Since the number of participants of ultra-high nicotine levels was too small, the participants in this group were not included in the evaluation. The results showed that participants who chose nicotine-free liquid had the highest puff volumes of 93.9 ± 59.6 mL, while the puff volumes of participants with low, medium and high nicotine levels were 90.3 ± 49.8, 76.4 ± 43.4, 65.6 ± 28.9 mL, respectively (Table 6). Data analysis results showed significant differences between the participants in the nicotine-free group and those in the medium or high nicotine groups (p = 0.025 or 0.049, respectively). The higher the concentration of nicotine in EC liquid, the smaller the users’ puff volume, which was consistent with the results of LOPEZ et al. (25). The puff duration and IPI were not affected by the concentration of nicotine in the liquid.

In our study, most participants were dual, i.e., EC and cigarette, users. To investigate whether smoking would affect their vaping behavior with ECs, the puffing topographies of the exclusive and dual EC users were compared. The results showed that exclusive EC users took average puff volumes of 84.7 ± 53.3 mL, similar to that of dual-users 88.1 ± 49.0 mL (p = 0.172). Puff duration and IPI for the exclusive EC users were 1.96 s and 17.5 s, respectively. The values for the dual users were 1.9 s and 23.7 s, respectively. These differences between the two groups were statistically not significant (p = 0.824 and p = 0.353, respectively). Based on the participant’s self-reporting on the power of their used batteries, the relationship between the power of the tank-type ECs and the puffing topography parameters was also studied. The results are shown in Figure 3.

Table 6. The influence of nicotine concentrations on the puff parameters.

| Nicotine-free | Low 1–5 mg/mL | Medium 6–11 mg/mL | High 12–20 mg/mL |
|---------------|---------------|-------------------|-----------------|
| Volume (mL)   | 93.9          | 90.3              | 76.4            | 65.6            |
| Average flow (mL/s) | 47.5          | 49.6              | 42.4            | 34.6            |
| Peak flow (mL/s) | 67.5          | 72.8              | 61.2            | 46.7            |
| Duration (s)  | 2.02          | 1.97              | 1.83            | 2.08            |
| IPI (s)       | 22.5          | 25.2              | 14.4            | 16.3            |
| Time of peak flow (s) | 0.82          | 0.87              | 0.87            | 1.11            |

Figure 3. The effect of battery power on the puff volume of EC consumers.

No influence of the battery power on the vaping topography was observed. FARSALINOS et al. found that changing the power settings of an EC device would change the puffing topography of the consumers (38). In our study, the information on the battery power of the ECs were obtained via the questionnaire, whether battery power is comparable among different products needs to be investigated in future research.

In summary, we found that EC product type and nicotine concentration in EC liquids were the main factors that affected the puffing topography. Users’ prior experience with ECs might also have played a role in the puffing topography. Thus in the future, when adjusting the smoking regime of the machine, puff volumes should be classified by EC types.

5. CONCLUSIONS

A puffing topography study of 511 EC consumers in four cities of China has been carried out. Behavior data were assessed by making use of a questionnaire and a CreSS smoking behavior recorder. The results show that most EC users were young males with a high education level who preferred tank-type ECs with zero or low nicotine concentrations in the liquid. Most of the EC users smoked cigarettes at the same time (dual users). As to puffing topography, the average puff volume, puff duration and IPI were 87.2 mL, 1.97 s and 22.0 s, respectively. Some factors, such as nicotine concentration of liquid and EC type significantly influenced puffing topography. Puff volumes were inversely related to nicotine concentration in the liquid. Consumers of tank-system ECs took larger puff volumes than users of disposable and cartomizer ECs. These results suggest that the EC type and the concentration of nicotine in the liquid needs to be focused on when setting the smoking regime of the machine.

53x778 Table 6. The influence of nicotine concentrations on the puff parameters.

| Nicotine-concentration | Volume (mL) | Average flow (mL/s) | Peak flow (mL/s) | Duration (s) | IPI (s) | Time of peak flow (s) |
|------------------------|------------|---------------------|-----------------|-------------|--------|----------------------|
| Nicotine-free          | 93.9       | 47.5                | 67.5            | 2.02        | 22.5   | 0.82                 |
| Low 1–5 mg/mL          | 90.3       | 49.6                | 72.8            | 1.97        | 25.2   | 0.87                 |
| Medium 6–11 mg/mL      | 76.4       | 42.4                | 61.2            | 1.83        | 14.4   | 0.87                 |
| High 12–20 mg/mL       | 65.6       | 34.6                | 46.7            | 2.08        | 16.3   | 1.11                 |
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