

Safety of smoke generated by Japanese moxa upon combustion

(日本で製造されたモグサの燃焼時の煙の安全性について)

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Abstract

Introduction

Moxibustion is an ancient method of traditional medicine (along with acupuncture) using moxa, or processed mugwort leaves. Both the smoke and heat generated by burning moxa are considered to have therapeutic effects. However, recently there have been reports of harmful substances released in smoke from everyday objects such as scented candles or incense. Therefore, it appeared to be important to evaluate the safety of products resulting from the combustion of moxa.

Methods

We used three types of commonly used moxa. Experiments were conducted by lighting moxa which had been classified according to their level of refinement. Gases released were collected after igniting moxa. A gas chromatograph mass spectrometer (GC/MS) was used for both qualitative and quantitative analysis. Standard conditions for Japanese therapeutic environments were employed.

Results

1,3-butadiene was present from the smoke at the highest level of concentrations of substances governed by assorted indoor air quality and environmental standards (1,3-butadiene, benzene, toluene, ethylbenzene, and xylene) and fell below maximum values. Also, simulation in an indoor environment with 1,3-butadiene was safely within indoor environmental standards.

Conclusion

Our simulation results have shown that quantities of harmful substances released upon combustion of moxa during normal clinical therapy of Japan are below maximum levels. Hence are safe for both patient and practitioner. However we detected few amounts of harmful substances released from moxa. These harmful substances are invariably generated upon combustion, although varieties and quantities vary according to substance. So measures to maintain an appropriately safe work environment must be practiced, even though safety was confirmed.

Key words: Moxa, Smoke, Combustion products, Moxibustion, Japanese style, Safety

1. Background

Traditional medicine's acupuncture and moxibustion began in ancient times in China, and were transmitted largely within East Asia, where throughout the ages techniques were passed down in a closely-knit relationship with local traditions and customs. Moxibustion originally was considered to be performed with materials other than moxa or methods to expose affected parts of the body to smoke^{1,2}, but mugwort leaves came to be the final source of heat. Not only is mugwort a common plant and thus easily procured, but dried leaves of the plant burn in a steady and pleasing manner. Smoke released upon burning of the leaves also has a pleasant fragrance, which has been reported to have a variety of effects³. This smoke is believed to have sterilization effect⁴ in China, and basic research of its effect has been published⁵.

Many combustion products are released in smoke when moxa burns, although the same can be said of any substance. Such combustion products may include substances both innocuous and harmful to humans, although even harmful substances may be handled in such a way as to render them innocuous. National standards governing such substances can vary according to country, but there exist environmental and safety standards requiring that any products exported must comply with. Examples are formaldehyde and 1,3-butadiene, well-known carcinogenic combustion products released upon burning of a multitude of everyday goods. M. Derudi⁶ et al. have studied the toxicity of candles containing chemical substances such as fragrances.

In recent years there have been efforts to standardize moxibustion implements and techniques throughout the world, accompanied by a growing recognition of the need to bring modern scientific analysis to bear on the treatments. There have already been studies of the constituent ingredients of the base ingredient mugwort and the processed substance moxa⁷. However, there has been no such analysis of the constituent products of smoke released upon burning moxa^{8,9}. In particular, there have been no reports on the safety of smoke from moxa produced in Japan.

Therefore, in this study we analyzed the substances contained in smoke released from moxa upon combustion, compared these with relevant standards, and performed a simulation on practitioner exposure.

2. Materials and Methods

2.1 Materials

We used three types of moxa, each refined to a different degree: Tenkyu, Kyutoshin, and Onkyu. In Japanese moxibustion practice, these three types of moxa are used with different techniques according to therapeutic goals^{10,11}. Type of moxa used primarily depends upon degree of refinement (Fig.1). Differing degrees of refinement generate different quantities of heat, and different treatments

require different temperatures. A lower degree of refinement moxa means a higher level of foreign substances in the leaves, causing higher temperatures upon combustion.

High-refined moxa is used with Tenkyu treatment methods, which are practiced primarily in Japan. In this treatment, a moxa cone (twisted moxa for combustion), with about half- to full-size of a rice grain, is placed directly on the skin and gives small burn with an incense stick. High-refined moxa is manufactured by first grinding the leaves in a stone mill, then bamboo implements known as Nagatoshi and grain fans combined with sieves to produce the final product. This type of moxa requires a trained and experienced craftsman to produce, and is golden in color. About 100 kg of dried mugwort leaves yields about 3 kg of Tenkyu moxa.

Medium-refined moxa is used in Kyutoshin and Chinetsu-kyu therapy methods. In Kyutoshin, moxa is affixed to the handle of the needle inserted into the patient, then burned to heat the skin through radiant heat. Chinetsu-kyu therapy may use either a moxa tube or a cardboard base to provide an indirect thermal stimulus to the skin. About 100 kg of dried mugwort leaves yields about 15 kg of the medium-refined moxa.

Finally, low-refined moxa is used in Onkyu therapy, a method to warm the affected part with radiant heat using larger moxa cones than those for Tenkyu or moxa sticks, or indirect heat with medical herbs placed between a moxa cone and the skin. Therefore, relatively un-refined moxa is used as it provides a higher temperature upon combustion. About 100 kg of dried mugwort leaves yields about 30 kg of this type of moxa.

In this study we used three types of moxa of different grades produced by a major Japanese producer of moxa for clinical use. Sample 1 (S1) was high-refined moxa (Tenkyu), sample 2 (S2) was medium-refined moxa (Kyutoshin), and sample 3 (S3) was low-refined moxa (Onkyu).

Study measurements were performed by the Chemicals Evaluation and Research Institute, Japan.

3 Methods

We collected smoke for qualitative analysis of the materials released from the smoke. Only substances governed by the environmental standards were subjected to the quantitative analysis and measurement of the density. In addition, we measured the density of carbon monoxide (CO) and carbon dioxide (CO₂) by gas-detecting tube test. These results were subsequently used to perform a simulation of exposure to the substances.

3.1 Test method

3.1.1 Qualitative analysis

S1, S2 and S3 were ignited, placed in a glass combustion chamber, then subjected to a high-purity air stream produced by a mass flow controller (75 mL/min for S1 and 500 mL/min for S2 and S3). Gasses released from the combustion chamber were captured in a Tedlar bag. Gas collected in this manner was then aliquoted with a gas-tight syringe (1 mL, or 5 mL for low-concentration samples) and transferred to a gas chromatograph mass spectrometer (GC/MS) with a liquid argon cold trap at the column entrance. After concentration, the liquid argon container was removed from the thermostatic bath and heated rapidly to perform qualitative analysis.

3.1.2 Quantitative analysis

Next, quantitative analysis was performed on substances identified from the qualitative analysis which are particularly harmful and regulated according to standards or guidelines concerning indoor air quality or environmental pollution (1,3-butadiene, benzene, toluene, ethylbenzene, xylene, CO, and CO₂). Quantities of these substances were evaluated according to the following standards: Japan's Law for Maintenance of Sanitation in Buildings¹², the UK's air quality standards¹³, Japanese Ministry of the Environment's (MOE) environmental regulations¹⁴, and the Japanese Ministry of Health, Labor, and Welfare's (MHLW) indoor concentration guideline values¹⁵. The Japanese indoor concentration values for chemical substances are "Chemical substance concentrations below which even a lifetime of exposure should result in no harmful effects, as based on currently available scientific evidence."

3.1.3 Detector tube test

- Gas sampling pump: GV-100S
- CO rapid detector tube No. 1L (Gastec)
- CO₂ rapid detector tube: No. 2L (Gastec)

3.2 Reagents and equipment

- Air: Purified Air G-3(Japan Fine Products)
- Tedlar bag: 3 L type A (Omi Odor-Air Service)
- Mass flow controller: SEC-40 (Horiba Stech)

3.3 Combustion test

3.3.1 Combustion device

A schematic of the combustion device used is shown in Figure 2.

A preliminary cleaning of the combustion chamber was performed with water and methanol, then it

was further cleaned with a heat gun while passing through 1 L/min air for approximately 20 minutes.

3.4 Samples

Experiments used moxa samples of the same size and shape generally used in clinical situations in Japan in order to best reflect actual use^{10,11}.

Towards this end, for S1 (high-refined moxa for Tenkyu) two cones of about 1 mg each were placed side-by-side (Fig.3), while for S2 (medium-refined moxa for Kyutoshin) and S3 (low-refined moxa for Onkyu) 40 mg cones were used (Fig.4).

3.4.1 Sample 1

One mg of sample was precisely measured out and shaped into a cone; two of these were placed on a stand and ignited with an electrical filament before being placed in the combustion chamber. A mass flow controller was used to blow high-purity air adjusted to 50% RH over the samples for exactly 1 minute at a flow rate of 75 mL/min. This operation was repeated five times, and the gas released trapped in gas collection bags to be used as samples for measurement. This entire process was performed two times for a total of ten data calculations.

Gas was collected according to the same process without igniting the samples as a control. Figure 5 shows the moxa combustion methods.

3.4.2 Sample 2 and Sample 3

Forty mg of sample was precisely measured out, shaped into a cone, then placed on a stand before being ignited with an electrical filament and placed in the combustion chamber. A mass flow controller was used to blow high-purity air over the samples for exactly 3 minutes at a flow rate of 500 mL/min. Gas released was trapped in Tedlar bags to be used as samples for measurement.

Before measuring these samples, the same process was used on S2 without igniting the moxa to obtain control samples. Figure 5 shows the moxa combustion methods.

3.5 Measurement conditions

3.5.1 Gas chromatography/gas chromatograph mass spectrometer (GC/MS) measurement conditions

- Device: 5973MSD (Agilent Technologies)
- Column: Equity-1 (SUPELCO), diameter 0.32 mm, length 60 m, membrane thickness 5.0 μm
- Column temperature: 40°C for 7.0 minutes (5°C/min.), then 20°C (20°C/min.), then 250°C (for 2.5 min.)

- Sample insertion point: 250°C
- Sample injection volume: 1.0 mL
- Sample insertion method: Splitless injection with cold trap at temperature of liquid argon. Analysis initiated 2 minutes after column head pressure returned to room temperature value (120 kPA) (about 5 minutes).
- Carrier gas: Helium (1.2 mL constant flow mode)

3.5.2 Gas chromatography / flame ionization detector (GC/FID) measurement conditions

- Device: 6890N (Agilent Technologies),
- Column: Equity-1 (SUPELCO) diameter 0.32 mm, length 60 m, membrane thickness 5.0 µm
- Column temperature: 40°C for 7.0 minutes (5°C/min.), then 20°C (20°C/min.), then 250°C (for 2.5 min.)
- Sample insertion point: 250°C
- Sample injection volume: 5 mL
- Sample insertion method: Splitless injection with cold trap at temperature of liquid argon. Analysis initiated 2 minutes after column head pressure returned to room temperature value (120 kPA) (about 5 minutes).
- Carrier gas: Helium (1.2 mL constant flow mode)

3.6 Simulation of indoor air concentration during therapy

Based upon the results obtained above, simulations of indoor air concentration during moxibustion therapy were performed for 1,3-butadiene, which was the highest-concentration substance detected (among 1,3-butadiene, benzene, toluene, ethylbenzene, and xylene). Exposure levels were calculated according to measurements obtained from S2, as this sample resulted in the highest levels.

3.6.1 Exposure scenario

The scenario assumes moxibustion therapy in a room with a volume of 20 m³, with no transdermal exposure, only inhalation of smoke and its constituent combustion products. If moxa less than medium-refined is burned directly on the skin, complete combustion can cause scarring because about 40 mg of moxa is used. Therefore, recently in Japan the moxa is removed from the skin and extinguished as soon as it reaches therapeutic temperatures.

Therefore, we assumed a combustion ratio of 63% for each piece of moxa in our simulation of the combustion product 1,3-butadiene. Eighteen pieces of 40-mg moxa were used in one treatment. Each piece burns for 30 seconds, so the entire combustion time is 9 minutes. We assume that therapy rooms will either have a ventilation system or windows, resulting in 0.5 air changes per hour in the

simulated therapy room with volume of 20 m³.

3.6.2 Algorithm

Figure 6 shows concentration of 1,3-butadiene in indoor air during a therapy session: repeated combustion causes elevated concentrations which taper off as the treatment ends, followed by a decrease due to ventilation. The formula for calculating Ca_{ti} (average air concentration of exposure duration) is shown in Figure 7. Concentration during use, Ca_i must incorporate factors such as elevation of concentration during combustion and decrease due to ventilation, which is shown as an algorithm in Figure 8. Finally, Figure 9 shows the algorithm Ca_{tii} (average air concentration during post-use stay).

4. Results

4.1. Qualitative results

Qualitative analysis of volatile organic compounds present in moxa combustion smoke after burning 40 mg of each sample showed 66 compounds in S1, 99 in S2, and 102 in S3. Table 1 shows a list of compounds detected in S3.

5. Quantitative results

1) Results of detector tubes measurement

Table 2 shows detector tube measurements for CO₂ and CO. These levels assume a 20 m³ therapy room volume with no ventilation. S1 values were converted to those representing about 40 mg in order to enable comparison with S2 and S3.

Figures for S2 and S3 in Table 1 were measured twice each. These concentrations were evaluated according to Japan's Law for Maintenance of Sanitation in Buildings, the statutes which govern these substances. The law stipulates 1000 ppm or below for CO₂ and 10 ppm or below for CO. As Table 2 shows, S1, S2, and S3 yielded concentrations below the regulated maximum (average of two measurements).

2) Results of volatile organic compounds analysis

Table 3 shows concentrations of substances regulated by various standards and policies governing indoor air and environmental pollution (1,3-butadiene, benzene, toluene, ethylbenzene, and xylene), as well as converted concentrations of these assuming a non-ventilated treatment area of 20 m³. S1 values were converted to those representing about 40 mg in order to enable comparison with S2 and S3 (average of two measurements used).

Table 2 shows substance concentrations according to various standards, which differ according to entity. As shown in Table 3, all samples resulted in concentrations within standard limits (average of

two measurements).

6. Results of simulation of indoor air concentration during therapy

The formulae described above were used to calculate concentrations over time.

$$Ca_{ti} = 6.76 \mu\text{g}/\text{m}^3 \text{ (average air concentration of exposure duration)}$$

$$Ca_i = 13.3 \mu\text{g}/\text{m}^3 \text{ (concentration at time of use)}$$

$$Ca_{tii} = 9.89 \mu\text{g}/\text{m}^3 \text{ (average air concentration during post-use stay)}$$

The final formula used for calculating average air concentrations over time from beginning to end of therapy is as follows:

$$(Ca_i \times t_i + Ca_{tii} \times t_{ii}) / (t_i + t_{ii}) = 0.0103 \text{ mg}/\text{m}^3 \text{ (10.3 } \mu\text{g}/\text{m}^3)$$

The threshold limit value – time-weighted average (TLV-TWA) for 1,3-butadiene according to the American Conference of Governmental Industrial Hygienists is $4.4 \text{ mg}/\text{m}^3$ (2 ppm). Therefore, levels detected in our study are not considered problematic.

7. Discussion

This study evaluated the composition of smoke produced by three grades of Japanese moxa with difference in refinement degree and used in regular clinical moxibustion in Japan. We examined the ingredient of the smoke at the time of the combustion.

In order to enable comparisons, we performed the examination under the worst environment, with no ventilation in calculating simple estimates of harmful combustion products in each sample. However, to develop the exposure scenario for simulation, we assumed and calculated under the actual clinical environment which could ventilate by a ventilation fan or windows. That complies with the structure and facility standards¹⁶ regulating acupuncture and moxibustion therapy rooms which dictate that “at least one-seventh of the therapy room’s area be open to outside air, or use an equivalent ventilation system.”

Our experiments used 1 mg of S1 and 40 mg each of S2 and S3, reflecting actual clinical quantities. In preliminary experiments we used 40 mg of S1 as well, resulting in higher concentrations of 1,3-butadiene and benzene released than either S2 or S3, although still below the maximum standards assuming an unventilated 20 m^3 therapy room. These values were higher for S1 because its higher level of purification resulted in finer, denser plant fibers. Therefore, it may be assumed that when a 40 mg cone of moxa is burned in the same manner as our preliminary experiments, air does not reach the core of the cone, causing incomplete combustion. Therefore, S1 was prepared to have 1/20 of quantity and an increased ratio of surface area by dividing in half. This quantity of 1 mg for S1 conforms to that used in medical practice. In addition, we changed flow volume and the ventilation time with S2 and S3 at the time of the examination. Nevertheless, the ventilation volume

per 1 mg of sample was maintained at 37.5 ml/g under the same condition.

Levels of CO₂ and CO released upon moxa combustion were below Japanese environmental standards, and were not problematic. Meanwhile, volatile organic compounds were evaluated according to UK environmental standards, as Japan lacks such standards for 1,3-butadiene. Measurement results showed acceptable levels of 1,3-butadiene, benzene, toluene, ethylbenzene, and xylene. The aldehydes formaldehyde, acetaldehyde, and acrolein were detected, but quantitative analysis of all three samples demonstrated that levels generated fell below WHO guidelines¹⁷ as well as MHLW's indoor concentration guideline values¹⁵.

Harmful substances may be released upon either complete or incomplete combustion. Recent years have seen increasing study of indoor air pollution arising from a multitude of familiar, everyday sources, from wood stoves^{18, 19} to incense^{20, 21} and candles^{6, 22}. Even wood untreated with any chemical additives generates harmful substances when burned, and the same is true for moxa produced from natural mugwort leaves alone. In this study we detected harmful substances released, albeit in very small amounts, from moxa used clinically in Japan. These harmful substances are invariably generated upon combustion, although varieties and quantities vary according to substance. This becomes problematic when such quantities exceed standards. According to Mo.F et al.⁸ . combustion of Chinese moxa sticks releases “toluene, xylene, formaldehyde, and benzene.” Simulations assuming Chinese clinical use resulted in high concentrations for some substances.

For this reason, we determined it necessary to study the question of exposure in Japanese clinical practitioners of moxibustion exposed to the smoke for long periods of time. In particular, our analysis focused on 1,3-butadiene, the substance released in greatest quantities, in usage simulations modeled on the size of Japanese therapy rooms as well as moxa size, shape, and quantity. Our calculation assumed a moxa combustion rate of 63%, as recently in Japan 40-mg moxa cones are often removed from the skin once the patient feels heat in order to avoid scarring. The 63% figure was obtained by precisely measuring out about 40 mg of S2 moxa, igniting it on the back of the hand, then extinguishing it with nitrogen gas just prior to the heat becoming painful. The combusted portion was then removed, the non-combusted portion weighed, and the two weights used to calculate the percentage of moxa burned. This process was repeated three times to obtain the 63% combustion rate for S2 moxa.

Our measurement and simulation results have shown that quantities of harmful substances released upon combustion of moxa during normal clinical therapy of Japan are below maximum levels, and hence are safe for both patient and practitioner. However, benzene and other harmful substances are

present in moxa smoke, so measures to maintain an appropriately safe work environment must be practiced. Such measures may include installing ventilation equipment or manually ventilating the room sufficiently after each therapy session to reduce indoor air concentrations present at the beginning of each session.

In Chinese practice⁹, extremely large quantities of medium-refined moxa sticks are regularly used for therapy, resulting in different levels of harmful combustion products compared to Japan. A report cites five doctors using 24,000 moxa sticks over the course of a single year. Further, moxa sticks are wrapped in paper, which also burns during therapy. Moxa sticks are also compressed, leading to more incomplete combustion due to lack of available oxygen inside the stick. These differences should be studied in more detail going forward. In addition, since incense is used in Japanese Tenkyu therapy to ignite the moxa, incense smoke should be subjected to the same analysis as the moxa itself.

Finally, though the exposure evaluation was found feasible only by simulation in this study, it would be necessary to examine the density of harmful combustion products in the actual clinical environment in the future.

8. Conclusions

We studied the safety of combustion products in smoke produced by burning moxa used in Japanese moxibustion therapy according to qualitative and quantitative analysis of three common types of moxa, each with a differing level of refinement. Harmful substances were detected, although in extremely small quantities that fell below national safety standards according to both detector tube measurement and volatile organic compound analysis. A simulation was performed on indoor air concentrations of 1,3-butadiene, and levels were found safely within applicable indoor environment standards.

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Figure captions

Figure 1: Moxa sizes in Japan depending on treatment methods

Different levels of purity and sizes are used in Japan depending on treatment method. This figure shows three types of moxa.

Figure 2: Schematic of combustion testing apparatus

This schematic shows the process from moxa combustion to gas collection.

Figure 3: Sample 1 moxa shaped into two 1-mg cones each placed side by side

This figure shows 1-mg samples on the combustion chamber platform.

Figure 4: Samples 2 and 3 shaped into 40-mg cones

This figure shows 40-mg samples on the combustion chamber platform.

Figure 5: Combustion methods for moxa cones using the combustion chamber

This figure shows details of the process used in the combustion chamber.

Figure 6: 1,3-Transition of butadiene concentration by moxibustion in the therapy room

This figure shows simulated substance levels in therapy rooms.

Figure 7: Algorithm for average air concentration of exposure duration

This is the formula for calculating average air concentration of exposure duration in therapy room simulation.

Figure 8: Algorithm for concentration during use

This is the formula for calculating concentration during use in therapy room simulation.

Figure 9: Algorithm for calculating average air concentration during post-use stay

This is the formula for calculating average air concentration during post-use stay in therapy room simulation.

Table legends:

Table 1: Sample 3 qualitative results (102 compounds)

This table lists all compounds detected in sample 3, which exhibited the largest number of combustion products in the experiment.

Table 2: Results of detector tubes measurement

CO and CO₂ were detected in the qualitative analysis. These are regulated substances, so they were measured quantitatively as well.

Table 3: Results of volatile organic compounds analysis

This table shows concentrations of regulated substances (1,3-butadiene, benzene, toluene, ethylbenzene, and xylene) as well as estimated concentrations in an unventilated 20 m³ room.



Fig. 1: Moxa sizes depending on treatment methods in Japan

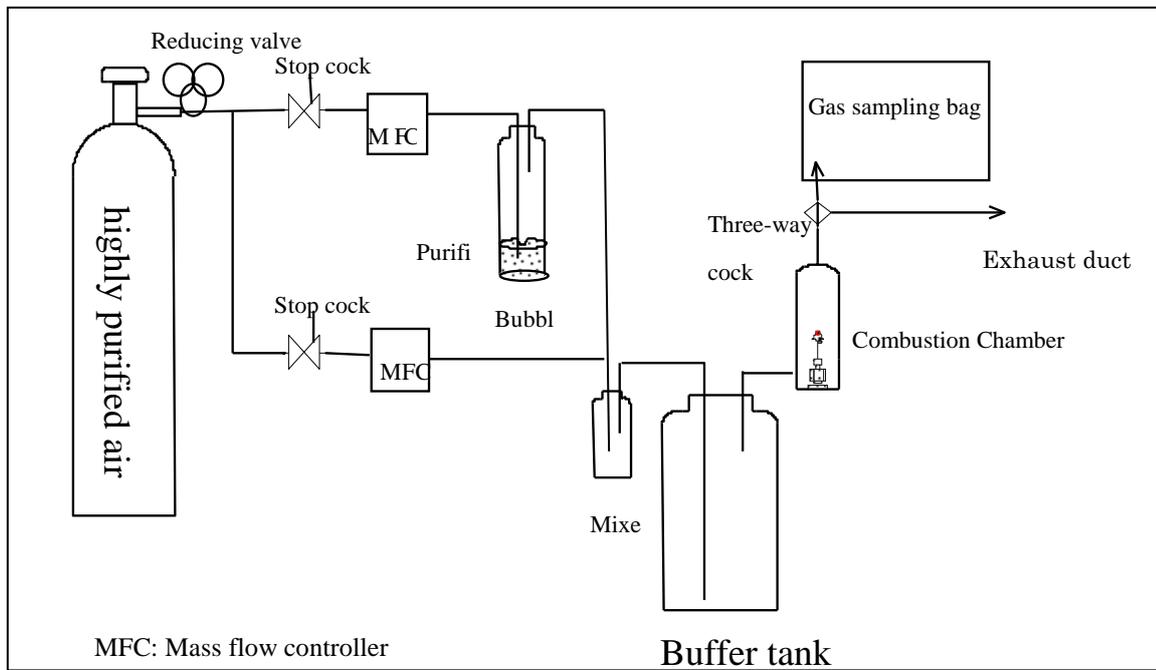


Fig. 2: Schematic of combustion testing apparatus



Fig.3: Sample 1 moxa shaped into two 1-mg cones each placed side by side

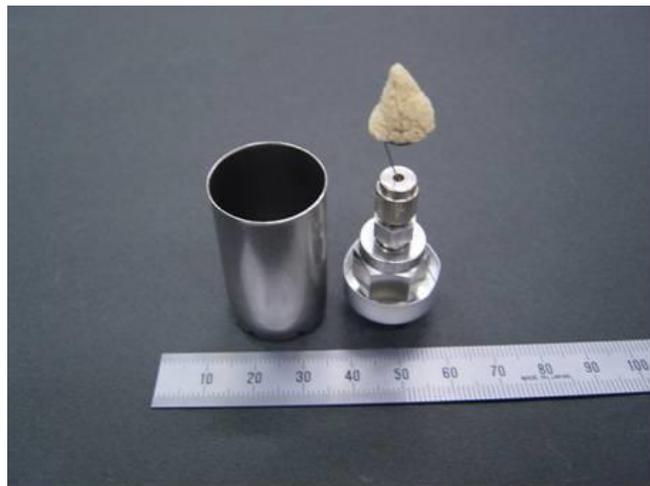


Fig. 4: Sample 2 and sample 3 shaped into 40-mg cones

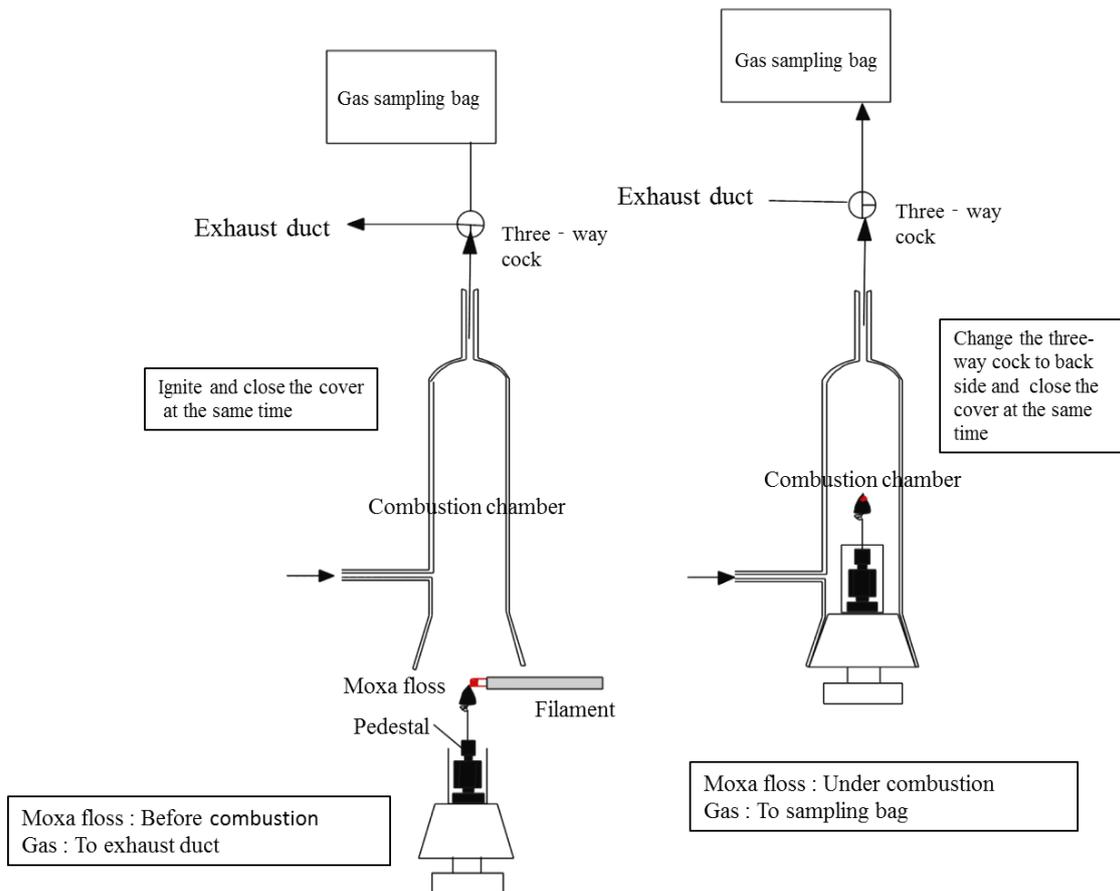


Fig. 5: Combustion methods for moxa cones using the combustion chamber

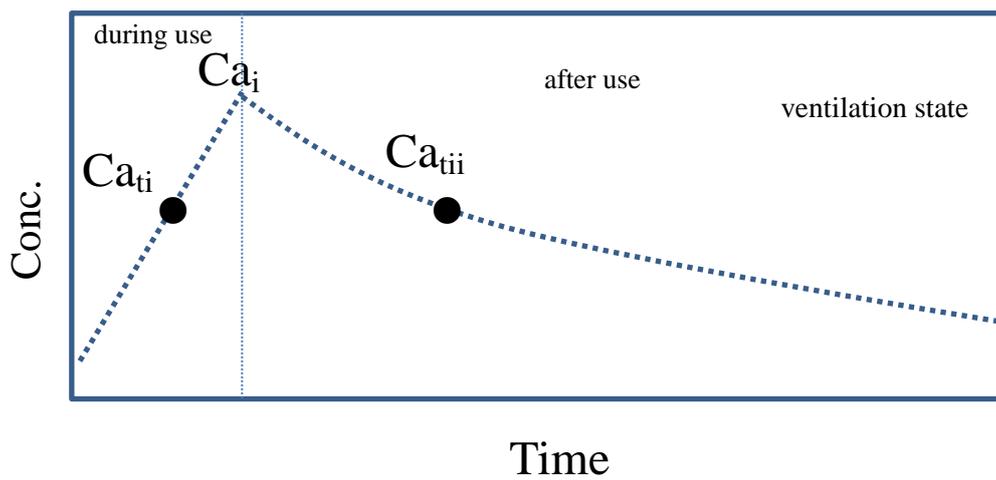


Fig.6: Transition of 1,3-butadiene concentration by moxibustion in the therapy room

$$Ca_{ti} = \frac{\frac{Ap \times Wr}{N \times V} / t_i \times \left\{ t_i - \frac{1}{N} \times [1 - \exp(-N \times t_i)] \right\}}{t_i}$$

Fig. 7: Algorithm for average air concentration of exposure duration

$$Ca_i = \frac{G}{N \times V} \times [1 - \exp(-N \times t_i)]$$

Fig. 8: Algorithm for concentration during use

$$Ca_{tii} = \frac{\frac{Ca_1}{N} \times [1 - \exp(-N \times t_{ii})]}{t_{ii}}$$

Fig. 9: Algorithm for average air concentration during post-use stay

Table 1: Sample 3 qualitative results (102 compounds)

Peak No	Name of compound (libraly serch results)	retention time(min)
#1	Carbon dioxide	2.692
#2	Ethane	2.824
#3	1-Propene	3.346
#4	Propane	3.402
#5	Water	3.746
#6	Methane, chloro-	3.948
#7	Acetaldehyde	4.262
#8	1-Propene, 2-methyl-	4.762
#9	1,3-Butadiene	4.877
#10	Butane	5.028
#11	1-Butene	5.289
#12	Methane, bromo-	5.583
#13	1-Butene	5.704
#14	1-Propanamine	6.186
#15	Acetonitrile	6.778
#16	Acrolein	7.184
#17	Acetone	7.537
#18	1-Pentene	8.348
#19	Furan	8.449
#20	2-Propenenitrile	8.679
#21	Pentane	8.928
#22	1,3-Butadiene, 2-methyl-	9.186
#23	2-Butene, 2-methyl-	9.657
#24	2-Butene, 2-methyl-	9.946
#25	1,3-Pentadiene,	10.092
#26	1,3-Cyclopentadiene	10.767
#27	Cyclopentylethyne	10.93
#28	Propanal, 2-methyl-	11.154
#29	Propanenitrile	11.289
#30	2-Butenal	11.741
#31	Cyclopentene	11.889
#32	2-Butanone, 3-methyl-	12.503
#33	Acetic acid	13.095
#34	1-Hexene	13.841
#35	Furan, 2-methyl-	14.127
#36	Hexane	14.48
#37	Furan, 2-methyl-	14.713
#38	Pentane, 3-methylene-	14.836
#39	Cyclopentene, 1-methyl-	15.133
#40	2,4-Hexadiene	15.615
#41	2-Butenal	15.876
#42	2-Propanone, 1-hydroxy-	16.26
#43	1,3,5-Hexatriene	16.507
#44	Butanal, 2-methyl-	17.084
#45	Cyclopentene, 3-methyl-	17.334
#46	Benzene	17.519
#47	Propanoic acid	18.027
#48	1,3-Cyclohexadiene	18.15
#49	2,3-Pentanedione	18.355
#50	Cyclopentanol	18.708
#51	Cyclohexene	18.882
#52	1-Heptene	19.314

Peak No	Name of compound (library search results)	retention time(min)
#53	2-Propyn-1-ol	19.555
#54	Furan, 2,5-dimethyl-	19.734
#55	Heptane	19.903
#56	2-Cyclopenten-1-one, 3-methyl-	20.102
#57	Pyrimidine	20.405
#58	Phenol	20.564
#59	Furan, 2,3-dihydro-3-methyl-	20.671
#60	Acetamide	20.887
#61	1H-Pyrrole, 1-methyl-	20.959
#62	Pyridine	21.263
#63	Pyrrole	21.389
#64	Disulfide, dimethyl	21.549
#65	3-Butene-1,2-diol	21.725
#66	Propanoic acid, 2-oxo-, methyl-	22.028
#67	Toluene	22.933
#68	1,4-Cyclohexadiene, 1-methyl-	23.124
#69	Hexanal Aldehyde	23.713
#70	3-Furaldehyde	23.833
#71	1-Octene	24.083
#72	Pyridine, 2-methyl-	24.512
#73	2-Furancarboxaldehyde	24.652
#74	2-Propanone, 1-(acetyloxy)-	25.238
#75	2-Furanmethanol	25.339
#76	Ethylbenzene	26.155
#77	p-Xylene	26.352
#78	Quinone	26.657
#79	Styrene	26.795
#80	o-Xylene	26.921
#81	2-Cyclopenten-1-one, 3-methyl-	27.863
#82	Phenol	27.986
#83	Corylone	28.883
#84	Benzene, 1-methyl-4-(1-methyl-2-propenyl)-	29.144
#85	2-Methylphenol	29.2
#86	Limonene	29.318
#87	Phenol, 4-methyl-	29.419
#88	3-Pyridinol	29.483
#89	N-Methyl-2-benzyloxyethylamine	29.64
#90	Pentanamide, 4-methyl-	29.752
#91	Phenol, 2-methoxy-	29.823
#92	Benzoic acid	30.425
#93	Phenol, 2-ethyl-	30.624
#94	1,2-Benzenediol	30.851
#95	Benzofuran, 2,3-dihydro-	31.152
#96	1,2-Benzenediol, diacetate	31.471
#97	1,3-Benzenediol	31.611
#98	CinnamicAldehyde	31.676
#99	Indole	32.534
#100	3-methoxy acetophenone	32.78
#101	Phenol, 2-(1-methylethoxy)-	33.081
#102	1,3-Benzenediol, 4-ethyl-	33.423

Table 2: Results of detector tubes measurement

Name of samples	Number of tests	Converted score of indoor area of 20m ²	
		Non-ventilated	
		CO ₂	CO
		ppm	ppm
Sample1	First time	0.45	0.08
	Second time	0.38	0.09
	Average	0.42	0.09
Sample2	First time	0.56	0.11
	Second time	0.56	0.11
	Average	0.56	0.11
Sample3	First time	0.75	0.11
	Second time	0.75	0.10
	Average	0.75	0.11

Notes: CO₂: Management standards of Japan's Law for Maintenance of Sanitation of Building are less than 1,000ppm
CO: Management standards of Japan's Law for Maintenance of Sanitation of Building are less than 10ppm

Table 3: Results of volatile organic compounds analysis

		Name of substances				
		1,3-butadiene	Benzene	Toluene	Ethylbenzene	Xylene
Sample1	First time	0.22	0.12	0.05	0.01	0.01
	Second time	0.30	0.14	0.06	0.01	0.02
	Average	0.26	0.13	0.06	0.01	0.02
Sample2	First time	0.35	0.27	0.24	0.05	0.19
	Second time	0.33	0.26	0.25	0.04	0.17
	Average	0.34	0.27	0.25	0.05	0.18
Sample3	First time	0.13	0.12	0.22	0.04	0.10
	Second time	0.16	0.17	0.28	0.06	0.15
	Average	0.15	0.15	0.25	0.05	0.13
Standards and policies		1 ppb (UK's air quality standards)	0.94 ppb (MOE environmental regulations)	70 ppb (MHLW guideline values)	880ppb (MHLW guideline values)	200ppb (MHLW guideline values)

「ppb」
Converted concentrations of non-ventilated indoor area of 20m²

European Journal of Integrative Medicine. vol 8, No4

平成 28 年 3 月 5 日 公表済

