Available online at www.sciencedirect.com
ScienceDirect
Journal of Pharmaceutical and Biomedical Analysis 44 (2007) 1–7
JOURNAL OF PHARMACEUTICAL AND BIOMEDICAL ANALYSIS
www.elsevier.com/locate/jpba

Miniaturized sample preparation needle: A versatile design for the rapid analysis of smoking-related compounds in hair and air samples

Yoshihiro Saito [a], Ikuo Ueta [a], Mitsuhiro Ogawa [a], Makiko Hayashida [b], Kiyokatsu Jinno [a,*]

[a] *School of Materials Science, Toyohashi University of Technology, Toyohashi 441-8580, Japan*
[b] *Department of Legal Medicine, Nippon Medical School, Tokyo 113-8602, Japan*

Received 26 December 2006; received in revised form 8 February 2007; accepted 11 February 2007
Available online 14 February 2007

Abstract

Miniaturized needle extraction device has been developed as a versatile sample preparation device designed for the rapid and simple analysis of smoking-related compounds in smokers' hair samples and environmental tobacco smoke. Packed with polymeric particle, the resulting particle-packed needle was employed as a miniaturized sample preparation device for the analysis of typical volatile organic compounds in tobacco smoke. Introducing a bundle of polymer-coated filaments as the extraction medium, the needle was further applied as a novel sample preparation device containing simultaneous derivatization/extraction process of volatile aldehydes. Formaldehyde (FA) and acetaldehyde (AA) in smoker's breath during the smoking were successfully derivatized with two derivatization reagents in the polymer-coated fiber-packed needle device followed by the separation and determination in gas chromatography (GC). Smokers' hair samples were also packed into the needle, allowing the direct extraction of nicotine from the hair sample in a conventional GC injector. Optimizing the main experimental parameters for each technique, successful determination of several smoking-related compounds with these needle extraction methods has been demonstrated.

Keywords: Sample preparation; Smoking; Hair analysis; Air analysis; Derivatization; Gas chromatography

1. Introduction

Sample preparation is an important analytical step especially for the determination of trace analytes in complex sample matrix commonly encountered in environmental and biological analysis [1–5]. Miniaturization of the sample preparation process is also increasingly focused to improve the performance and to meet the recent requirements such as high-throughput and environmentally friendly features, and a large number of publications could be found specially dealing with the miniaturized sample preparation and the effective hyphenation to microscale separation methods [3–9]. Introducing a fiber-packed capillary as the extraction medium, a novel miniaturized sample preparation technique has been developed along with a wide range of applications for the separation of complex mixtures [10–13]. Fiber-packed capillary was also employed as the separation medium in various chromatographic methods such as liquid chromatography (LC) [14–16], capillary electrochromatography (CEC) [17] and gas chromatography (GC) [18–22]. The selectivity of the fibrous stationary phase could be tuned by the fiber surface modification with a polymeric coating or a derivatization reaction [18–21].

Recent studies showed that the needle-type sample preparation [23–28] could realize the most of the advantageous features of conventional sample preparation techniques, but without the typical disadvantage, for the preconcentration of volatile organic compounds prior to the GC separation process. A wide variety of the extraction media could be used and easy to operate in the extraction and desorption processes, which will be attractive features for the automation and the hyphenation to typical GC instruments, although a continuous flow of the gas sample through the extraction needle should be maintained during the sampling process.

In this work, novel in-needle sample preparation devices (Fig. 1) [27,28] were introduced for the GC analysis of several smoking-related compounds in air and hair samples. For the sample preparation of the air samples, a copolymer of methacrylic acid (MAA) and ethylene glycol dimethacrylate

* Corresponding author. Tel.: +81 532 44 6805; fax: +81 532 48 5833.
E-mail address: jinno@chrom.tutms.tut.ac.jp (K. Jinno).

0731-7085/$ – see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.jpba.2007.02.011

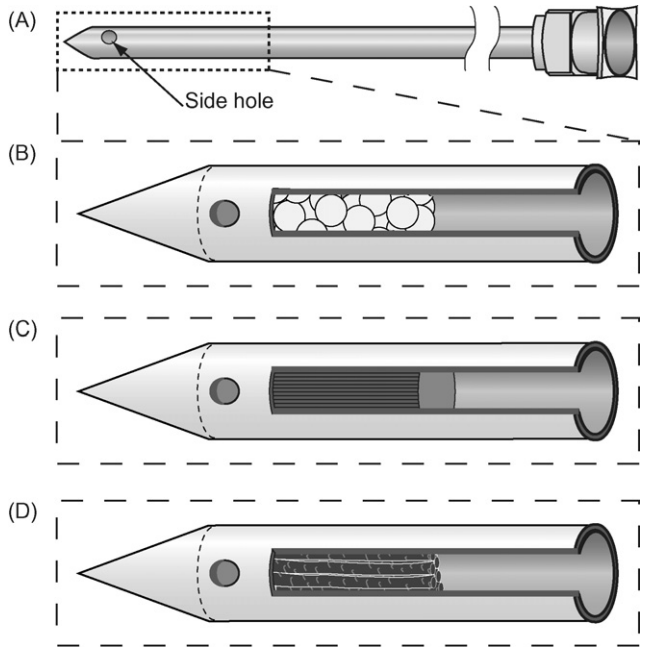

Fig. 1. Illustration of sample preparation needle. (A) Blank needle, (B) particle-packed needle, (C) fiber-packed needle and (D) hair-packed needle.

(EDMA), typically employed as the material for molecularly imprinted polymers (MIPs) [29–31], was synthesized to prepare the extraction medium [27] instead of other polymeric materials such as polystyrene-divinylbenzene (PS-DVB). This is because of a wider selectivity for both polar and non-polar analytes, and a relatively easier synthetic procedure is another advantageous feature of the method. The polymeric beads were packed into a section of a specially prepared needle and employed as the sample preparation device for environmental tobacco smoke (ETS) analysis. Fiber-packed needle [28] was also introduced as the extraction medium for the sample preparation of volatile aldehydes in ETS, where a simultaneous extraction/derivatization was proceeded in the fiber-packed needle containing a derivatization reagent therein.

The analysis of human hair samples was also carried out with the needle device. Similar to the preparation of the fiber-packed needle, some pieces of short hair sample taken from smoker were packed longitudinally into the needle. This is because the determination of the smoking-related compounds in smoker's hair could allow to develop a comprehensive evaluation of the effect of smoking-related compounds on their health.

2. Experimental

2.1. Reagents and materials

All reagents, solvents and sample solutes were of analytical grade and purchased either from Wako Pure Chemical Industries, Osaka, Japan or Tokyo Kasei Kogyo, Tokyo, Japan unless otherwise specified. Water was purified by a Milli-Q Water Purification System (Millipore, Tokyo, Japan). As a heat-resistant fiber, Zylon, poly(*p*-phenylene-2,6-benzobisoxazole), was supplied from Toyobo, Ohtsu, Japan, and the diameter of each filament is about 11.5 μm.

2.2. Preparation of standard samples

Standard gas samples were typically prepared with two-step or three-step dilution of solutes as described previously [27,28]. For the preparation of formaldehyde gas sample, a home-made vaporizer was used, in which solid paraformaldehyde was vaporized to generate the gaseous standard sample followed by a similar multi-step dilution process [28].

2.3. Synthesis of polymer-based beads

The synthesis of polymer-based beads as the extraction medium of particle-packed needle, as shown in Fig. 1B, was carried out with the previously described method [27]. First, 15 g of poly(vinyl alcohol) having a degree of polymerization of 500 were dissolved into 500 mL of water at 50 °C, and then sodium chloride (15 g) was also dissolved. To the solution, the mixture of MAA (2.58 g; 0.03 mol), EDMA (29.7 g; 0.15 mol), di-*n*-butyl phthalate (27.44 g) and azobisisobutyronitrile (0.52 g) was added drop wise over about 3 min, while the solution was kept at 50 °C. Next, the solution was subject to the temperature-programmed heating at the rate of 1.0 °C/min to 85 °C. The polymerization reaction was initiated at about 80 °C. In order to ensure the successful polymerization, the temperature of the reaction mixture was maintained at 85 °C for 1 h with vigorous stirring. After the polymerization reaction was completed, the resulting beads of the copolymer was sequentially washed, for five times each, with hot water, acetone, water and acetone, and then let dried at the room temperature.

The polymer-beads were sieved to obtain the spherical beads having the diameter between 150 and 180 μm. The specific surface area (SSA) measured by the nitrogen adsorption method was 390 m^2/g. The beads were packed into the specially-designed needle, 85 mm × 0.5 mm i.d., 0.7 mm o.d., where a section of about 20 mm length was packed with the copolymer beads as shown in Fig. 1B. To place the beads in the appropriate position in the needle, a small amount of a heat-resistant polymer fiber [18,27] was also packed at the both end of the packed section. The typical amount of beads packed in the needle is about 1.3 mg.

2.4. Preparation of polymer-coated fiber-packed needle

Prior to the packing process into the needle-shaped device, the polymer-coated filaments have been prepared as the same procedure as previously described [18–20], where the coating treatment was made in a conventional fused-silica capillary of 1 m length packed with a bundle of the filaments. A bundle of Zylon filaments (166 ± 2 filaments) was longitudinally packed into the fused-silica capillary of 1.0 m × 0.32 mm i.d. To ensure the reproducible preparation of fiber-packed capillary, the total number of packed-filaments was precisely counted before and after the packing process. As the coating material for the preparation of polymer-coated filaments, HR-1, 100%-methyl-

polysiloxane (Shinwa Chemical Industries, Kyoto, Japan) was employed.

First, a fiber-packed capillary was connected to the pressure-proof vessel containing 10 mL of acetone and washed with the solvent pumped by N_2 gas at the pressure of 500 kPa. After the same volumes of the following solvents; water, acetone and chloroform, were pumped in the similar manner, the capillary was allowed to dry at room temperature for about 2 h using N_2 gas flow. Second, the capillary was subject to heating in a GC oven with the flow of N_2 gas. The temperature was programmed from room temperature to 300 °C at 2 °C/min and then held for about 10 h. Next, the solution of the coating material (3%) in *n*-hexane containing a cross-linking reagent (0.8% to the polymer), benzoyl peroxide, was pumped through the packed capillary. After the total volume of the polymer solution (0.5 mL) was pumped, the N_2 flow was maintained for more than 5 h. Then, the column was installed in the GC oven again and the programmed heating was carried out as follows: from 40 to 300 °C at 0.5 °C/min and then hold for more than 48 h to ensure the complete reaction.

The successful polymer-coating treatments were confirmed by the separation of a standard sample containing *n*-dodecane, *n*-tetradecane and *n*-hexadecane on the polymer-coated fiber-packed capillary as a GC column, and the relative standard deviations (R.S.D.s) for the retention factors were less than 2.0% on three capillaries separately prepared with the same coating, where the average values of the retention factors for three consecutive runs on each capillary were used for the calculation. The R.S.D.s for multiple injection onto the same capillary were less than 1.5% ($n = 3$) for all the capillaries studied.

For the preparation of the extraction needle, a bundle of the polymer-coated Zylon filaments was taken out from the capillary, and packed into the needle, where a section of about 20 mm length was packed with the filaments, and one end of the packed section was positioned just before the side hole of the needle as illustrated in Fig. 1C. The number of filaments packed was 830, and the corresponding R.S.D. ($n = 5$) was less than 1.5%. To ensure the parallel alignment of all the polymer-coated filaments in the needle, the packing was carried out with the same procedure as reported previously [28].

2.5. Packing procedure of hair samples to the needle device

The hair samples taken from male volunteers were cut into approximately 20 mm length after removing the section of about 20 mm from the scalp, where the hair samples were rinsed with methanol before the cutting. Nine pieces of the above short hair samples, 20 mm length, were packed into the needle as depicted in Fig. 1D. The typical total weight of the hair samples loaded was about 1.0 mg. After the packing process, the hair-packed needle was rinsed again with methanol and water several times.

2.6. GC measurements

An Agilent 6890N gas chromatograph (Yokogawa Analytical Systems, Musashino, Japan) with a split/splitless injector and a HP 5972A mass selective detector was used for all the GC/MS measurements, while another Agilent 6890N gas chromatograph with a split/splitless injection port and a flame ionization detector (FID) was also employed if needed. All the injections were made by split mode. As the carrier gas, either helium in GC/MS or nitrogen in GC/FID was used, and the carrier gas and air were supplied from the respective gas cylinders through the cartridge packed with molecular sieve.

Fused-silica capillary column having a PDMS coating, DB-1 (30 m × 0.25 mm i.d., $d_f = 0.25$ μm; J&W Scientific, Folsom, CA, USA) was employed for the GC separation with an appropriate preconditioning before the use. The mass spectrometer was operated either total ion monitoring mode (TIM) or selected ion monitoring mode (SIM) with electron impact (EI) ionization. The ionization voltage was 70 eV. The other separation conditions such as carrier gas flowrate, column head pressure, and temperature programs were determined by the results of preliminary experiments for each samples. All GC measurements were done at least three times, and the relative R.S.D.s for the retention times were less than 1.0%. The data collection was made with Borwin Chromatography Data Handling Software (Jasco, Tokyo, Japan) running on a personal computer.

3. Results and discussion

3.1. Determination of smoking-related compounds with particle-packed needle

Fig. 2 shows the typical separation of smoking-related organic compounds in tobacco smoke. These samples were first collected with a home-made gas sampling box containing a polymeric gas sampling bag (1.0 L) which was made of a copolymer of tetrafluoroethylene and hexafluoropropylene (GL Sciences, Tokyo, Japan). The sample collection was carried out with a similar procedure as described previously [28], where the main stream of one cigarette was introduced to the home-made sample collection device at a constant flowrate similar to that of typical smoking by a volunteer. In the case of side stream sampling, the collection device (sampling volume: 1.0 L) positioned above a cigarette was used. Smoker's breath was also sampled with the polymeric gas sampling bag of 1.0 L, where the breath was directly introduced to the bag from the smoker's mouth.

For the extraction process the polymeric particle-packed needle, Fig. 1B, was attached to a commercially-available vacuum sampling device (Komyo Rikagaku Kogyo, Tokyo, Japan), and then inserted into the gas sampling bag, and next, the sample gas was introduced to the vacuum sampling device *via* the extraction needle. The conditions for the extraction and desorption were optimized in the preliminary experiments as reported in our previous report [27].

Typical sampling volume was 50 mL, and it takes about 6 min to complete the sampling with the vacuum sampling device. The completion of the gas sampling for each run was confirmed by the indicator equipped in the vacuum sampling device. After the extraction, the needle was attached to a glass syringe (1.0 mL) containing N_2 gas of 0.5 mL, and inserted to the GC injection port at 200 °C. The desorption and injection were made simultaneously by injecting the N_2 through the needle at the heated injection port, where the needle was heated for 10 s before the

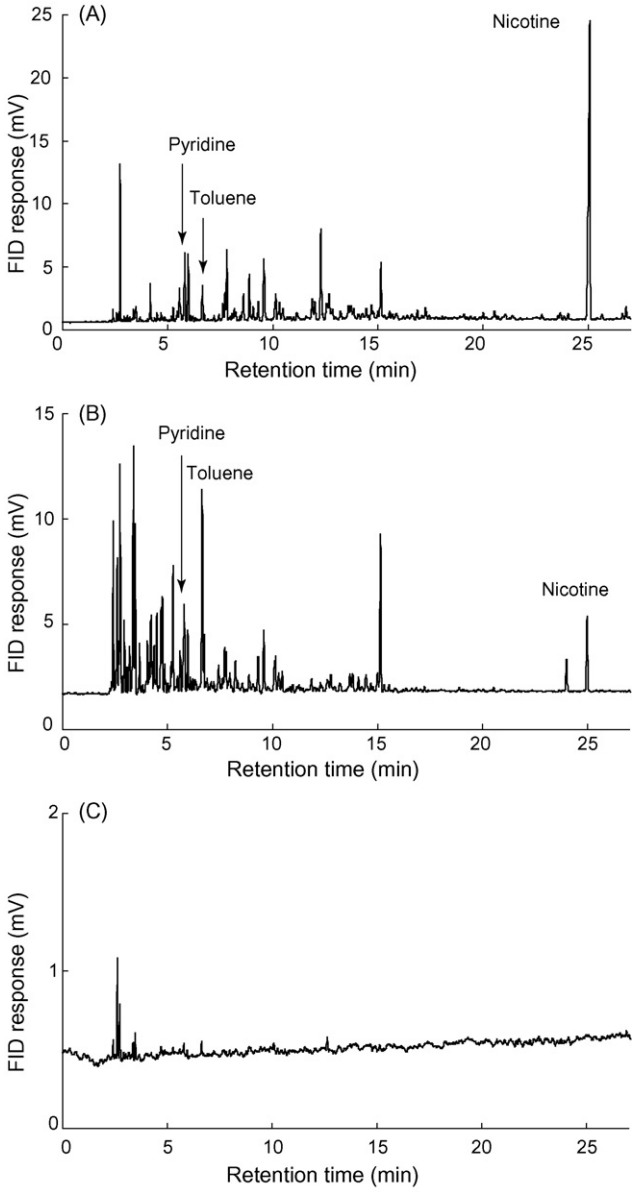

Fig. 2. Tobacco smoke analysis by the needle packed with polymeric particles. (A) Side stream, (B) main stream and (C) smoker's breath during smoking. Chromatographic conditions: column, DB-1; column temperature, 50–200 °C at 5 °C/min; column head pressure, 50 kPa; split ratio, 5:1; injector and detector (FID) temperature, 200 and 250 °C, respectively. Other conditions are described in the text.

N_2 injection. Under the above optimized conditions, it has been confirmed that the desorption of more than 99.99% of the analytes was made in the first desorption, allowing the practically quantitative desorption.

The chromatograms in Fig. 2 suggest a successful preconcentration of the smoking-related compounds, where it can be seen a significantly lower level of organic compounds in smoker's breath (Fig. 2C). Compared to the side stream (Fig. 2A), nicotine in the main stream seemed to be eliminated mainly by the tobacco filter, however, it still contained various types of organic species as found in Fig. 2B. One can conclude from above comparison that most of the volatile organic compounds generated during the smoking might remain trapped in their respiratory system. Taking into account the sampling volume of 50 mL, the concentration of pyridine, toluene and nicotine in the main stream (Fig. 2B) were determined as 10.0, 61.4 and 37.5 ng/mL, respectively. The estimated recoveries for these analytes were more than 99%, as similar to the previous results [27]. Although the level of these compounds might be different depending on the smoking conditions and the brand of tobacco, the above results clearly suggest the practical applicability of the particle-packed needle to the analysis of ETS by a conventional GC system with FID.

3.2. Simultaneous derivatization/preconcentration for aldehydes with fiber-packed needle

For the derivatization of aldehydes, two types of derivatization reactions were employed as illustrated in Fig. 3. One is the most well-known specific reaction of carbonyl compounds with 2,4-dinitrophenylhydrazine hydrochloride (DNPH) resulting the corresponding hydrazones [32–34], and another is the reaction with *O*-(2,3,4,5,6-pentafluorobenzyl)hydroxylamine hydrochloride (PFBHA) producing the corresponding oximes [35,36]. On the basis of the preliminary experiments for the derivatization in the polymer-coated fiber-packed needle device, an acetonitrile solution of DNPH (0.1 mg/mL) or an aqueous solution of PFBHA (10 mg/mL) was used as the derivatization reaction in the needle. Prior to the sample gas introduction, the derivatization solution was pumped through the needle device at about 10 μL/s for 10 s (total volume pumped: 100 μL), and then the remaining solution was vented by passing N_2 of 1 mL. Similar to the sampling by the particle-packed needle described above, a commercially-available vacuum sampling device was used for the gas sampling by the fiber-packed needle, where simultaneous derivatization/preconcentration could

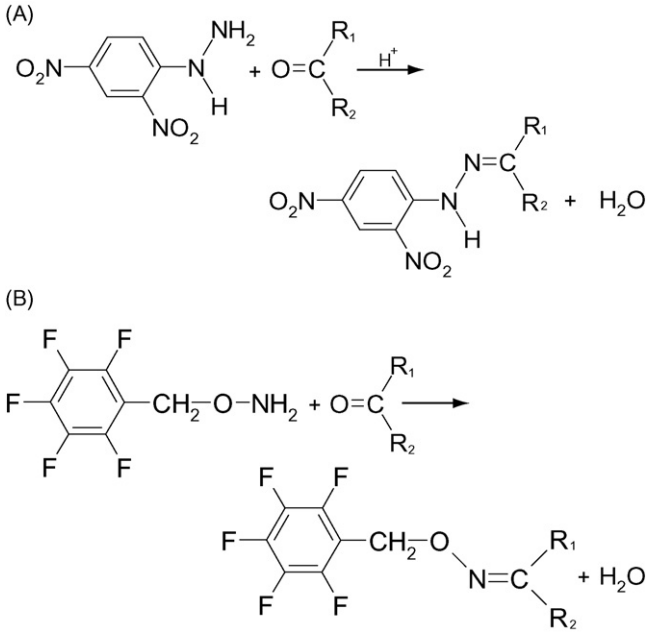

Fig. 3. Derivatization reactions of aldehydes with (A) DNPH and (B) PFBHA.

be proceeded in the needle during the sampling [28]. Typical sampling volume was 50 mL, and it takes about 8 min to complete the sampling with the vacuum sampling device, where the R.S.D. ($n = 5$) for the sampling time was less than 1.0% on the same needle, although the R.S.D. for needle-to-needle was somewhat larger, about 3.0% regarding five needles separately prepared.

After the derivatization/extraction process with DNPH, the needle was attached to a glass injection syringe containing pure acetonitrile (30 μL) and N_2 gas (270 μL), and inserted to the injection port of the GC, while a syringe containing pure water (30 μL) and N_2 gas (270 μL) was used for the derivatization reaction by PFBHA. The desorption and injection were made simultaneously by injecting the desorption solvent and N_2 through the needle in the heated injection port. The injection was made immediately after the insertion of the needle to the injector, since it has been confirmed in the preliminary experiments that no pre-heating time was necessary for the effective desorption under the optimized conditions for the desorption temperature and the volume of the solvent injected. For the DNPH derivatives the desorption temperature was set at 180 °C, while for the PFBHA derivatives the temperature was set at 200 °C. In the preliminary experiments, it was also found that the desorption was significantly insufficient without the desorption solvent, that means the desorption could be made with a flow of heated solvent, but not successfully completed only with N_2 gas flow through the heated needle.

Typical GC/MS results for the separation of aldehyde derivatives in a smoker's breath are shown in Fig. 4, where formaldehyde (FA) and acetaldehyde (AA) have been derivatized to the corresponding derivatives: FA-DNPH and AA-DNPH by DNPH, and FA-PFBHA and AA-PFBHA by PFBHA, respectively. As can be expected from the reaction schemes in Fig. 3, two isomeric derivatives [32,36] were observed for AA, and therefore, the sum of these peak areas for each isomer was used for the determination of AA in Table 1, where all the concentrations were calculated as that of underivatized analytes in the air samples. The recoveries for AA and FA with DNPH as the derivatization reagent were 99.2% and 90.0%, respectively, in typical concentration range shown in Table 1.

Table 1
Typical quantification results of volatile aldehydes with fiber-packed needle using two derivatization reagents ($n = 5$)

Derivatization reagent	FA (ng/mL)[a]	AA (ng/mL)[a]
DNPH	0.52	4.9
PFBHA	0.49	4.6

[a] As underivatized aldehyde in smoker's breath during smoking. Conditions are the same as in Fig. 4.

The polymer-coated fiber-packed needle device could be repeatedly used more than 100 times with a simple washing process after the desorption/injection process in the GC injector. The washing process was carried out with 0.5 mL of either acetonitrile for DNPH or water for PFBHA, and practically no carry-over effect was observed as in the case of particle-packed needle described above. Sequential analysis with DNPH and PFBHA as the derivatization reagent in the polymer-coated fiber-packed needle is also possible with the washing procedure, suggesting a promising possibility of the present needle device to include other derivatization reactions that might enhance the analytes' response and improve the separation of the derivatives. Introducing the time-programmed SIM mode as reported earlier [28], the lowest quantification level could be improved more, although a satisfactory determination performance was demonstrated in Table 1. The estimated lowest quantification level for FA and AA could be less than few ng/L with an increased sampling volume such as 100 mL [28].

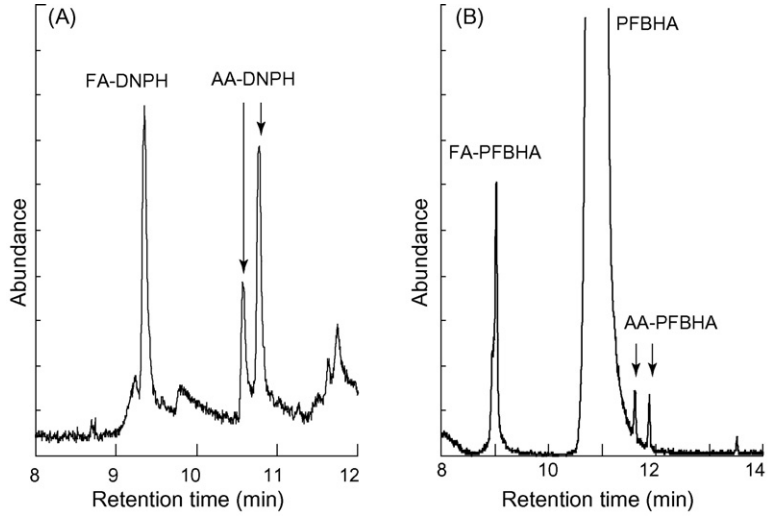

Fig. 4. Typical chromatograms of aldehydes derivatives from smoker's breath in GC/MS. Simultaneous derivatization/extraction was carried out with the polymer-coated fiber-packed needle containing the derivatization reagent: (A) DNPH and (B) PFBHA. The chromatograms were obtained by the TIM mode with the m/z range of between 50 and 255. Column and head pressure, DB-1 and 50 kPa. Split ratio, 5:1. Temperature conditions: (A) column temperature, 150 °C (1.0 min) to 260 °C at 10 °C/min; injector temperature, 180 °C; and (B) column temperature, 50 °C (1.0 min) to 120 °C at 5 °C/min; injector temperature, 200 °C. Other conditions are in the text.

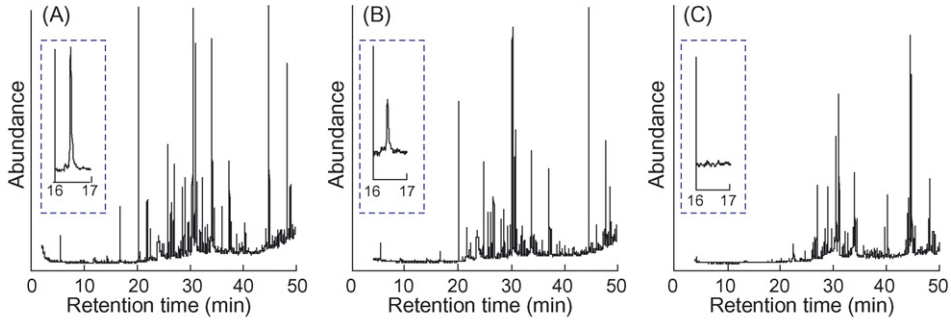

Fig. 5. Chromatograms for the separation of nicotine in hair samples. The hair samples (A) and (B) were taken from male smokers of 40 and 49 years old, respectively, while the sample (C) was from an non-smoker (male, age: 28). The chromatograms were obtained by the TIM mode with the *m/z* range of between 30 and 300. Conditions: column, DB-1; column temperature, 150 °C (1.0 min) to 300 °C at 5 °C/min; injector and detector temperature, 300 °C; column head pressure 50 kPa; split ratio, 25:1; desorption solvent and volume, methanol (25 μL); pre-heating time before the injection of the desorption solvent, 15 s. Other conditions are found in the text.

3.3. Hair analysis with the needle-type sample introduction device

Determination of the smoking-related compounds, especially nicotine, in human body has been regarded as one of the indices to evaluate the effect of smoking [37], and it has been reported that nicotine is contained in the smokers' hair as the same as other drugs [38–40]. Conventional sample preparation for the analysis of drugs and pharmaceutical compounds in hair samples often contains a time-consuming multi-step process, typically a solubilization with an alkaline solution followed by a solvent extraction by an organic solvent [38]. As a rapid and simple sample preparation technique for the hair analysis, the needle device shown in Fig. 1 was introduced. To a blank needle (Fig. 1A), about 1.0 mg of hair sample was packed as illustrated in Fig. 1D, where the solvent washing was carried out for the hair sample as described in Section 2. Similar to the above particle-packed and fiber-packed needle devices, several experimental parameters have been optimized in the preliminary experiments, where methanol was chosen as the desorption solvent.

Fig. 5 shows typical chromatograms of volatile compounds extracted from hair samples using the needle extraction/injection device, where two typical chromatograms, Fig. 5A and B, are the extracts from smokers' hair samples and the peak assigned to nicotine at about 16.4 min was clearly observed. For all the hair samples taken from non-smokers' hair, however, nicotine was not detected as typically shown in Fig. 5C, although the effect of passive smoking should be further studied in detail. The determination of nicotine in smokers' hair samples has been carried out using the SIM mode (Table 2), where three major ions with the *m/z* = 84, 133 and 161 were monitored. The number of cigarettes and the nominal nicotine content in each cigarette are also tabulated along with the age of the smokers. The extraction of nicotine was almost satisfactory because the R.S.D.s for three consecutive runs were less than 5.2% and the amount nicotine found with the present extraction method was about 87% of that determined with the conventional method [38] using alkaline solubilization and solvent extraction. However, no significant trend was observed regarding the correlation between these parameters that might affect the amount of nicotine in the hair sample.

Table 2
Determination of nicotine in smokers' hair samples

Entry	Age	Number of cigarettes[a] (day^{-1})	Nicotine per cigarette[b] (mg)	Nicotine in hair[c] (ng/mg)
A	24	20	1.2	12.1
B	31	10	0.7	11.5
C	40	30	0.4	55.3
D	49	20	0.1	30.5
E	56	15	0.8	9.7
F	63	15	0.1	13.0

[a] Average number of cigarettes declared by each smoker.
[b] The value shown in the box, indicating nominal value of nicotine content determined by the manufacturer.
[c] The R.S.D.s for typical replicate measurements ($n = 3$) were less than 5.2%.

Further studies should be scheduled for the development of a comprehensive evaluation method that can estimate the effect of smoking on our health including the effect of undesirable passive smoking. Additional investigations are also needed to precisely evaluate the effect of degradation products of hair samples possibly generated during the injection process in the heated GC injector and to assign the major components in the chromatograms, although the interference from these pyrolyzed species was not observed in the qualitative and quantitative determinations of nicotine in hair samples.

4. Conclusions

As a versatile extraction device for the analysis of smoking-related organic compounds, specially-designed needle that could be packed either polymeric particle or polymer-coated filaments, was introduced. With these microscale sample preparation needles developed for the extraction/preconcentration of the volatile organic compounds in air samples, as summarized in Table 3, a successful determination of smoking-related organic compounds has been demonstrated without a time-consuming multi-step sample preparation process commonly employed. Preconditioning of polymer-coated fiber-packed needle with either DNPH or PFBHA, as the derivatization reagent for volatile aldehydes, enabled a simultaneous derivatization/preconcentration in the needle.

Table 3
Statistical data for the validation of the needle extraction methods

Needle extraction method	Target compound	Linearity (ng/L)	LOD (ng/L)	R.S.D. (%) ($n=5$)	
				Run-to-run	Needle-to-needle
Particle-packed	Benzene	5–1.1×10^6	1.0	3.6	7.6
	Toluene	10–1.1×10^6	2.0	2.8	8.4
Fiber-packed[a]	FA	10–2.0×10^4	1.2	0.4	5.2
	AA	20–4.0×10^4	3.6	3.5	5.7
Hair-packed	Nicotine	5.0–100[b]	0.9[b]	N/A	5.2

[a] Derivatized with DNPH.
[b] ng/mg hair.

Alternative application of the needle device was also studied by packing the hair samples therein. It can be also concluded that the hair-packed needle device has a good possibility to the future development as the miniaturized sample preparation/injection device for hair analysis (Table 3), including the determination of other pharmaceutical compounds and their metabolites. The history of the drug level over a relatively long period of time, typically more than several months, could be also analyzed with the extraction method developed in this work.

Acknowledgements

A part of this research was supported by a Grant-in-Aid for Scientific Research B (#17350035) and a Grant-in-Aid for Scientific Research C (#17550078) from The Japan Society for the Promotion of Science (JSPS), and a Grant-in-Aid for Exploratory Research (#17651027) from The Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan. The authors would like to thank the technical support from Mr. Kenzo Kotera, Dr. Hiroo Wada and all technical staff of Shinwa Chemical Industries (Kyoto, Japan), and also thank Mr. Daichi Okamoto (School of Materials Science, Toyohashi University of Technology) for his valuable help during the sample collection.

References

[1] D.E. Raynie, Anal. Chem. 78 (2006) 3997–4004.
[2] H. Kataoka, Anal. Bioanal. Chem. 373 (2002) 31–45.
[3] S. Pedersen-Bjergaard, K.E. Rasmussen, Anal. Chem. 71 (1999) 2650–2656.
[4] Y. Saito, K. Jinno, J. Chromatogr. A 1000 (2002) 53–67.
[5] C. Arthur, J. Pawliszyn, Anal. Chem. 62 (1990) 2145–2148.
[6] Y. Saito, M. Kawazoe, M. Hayashida, K. Jinno, Analyst 125 (2000) 807–809.
[7] J.Å. Jönsson, L. Mathiasson, J. Sep. Sci. 24 (2001) 495–507.
[8] J.S. Fritz, J.J. Masso, J. Chromatogr. A 909 (2001) 79–85.
[9] Y. Saito, K. Jinno, Anal. Bioanal. Chem. 373 (2002) 325–331.
[10] Y. Saito, M. Nojiri, M. Imaizumi, Y. Nakao, Y. Morishima, H. Kanehara, H. Matsuura, K. Kotera, H. Wada, K. Jinno, J. Chromatogr. A 975 (2002) 105–112.
[11] Y. Saito, M. Imaizumi, T. Takeichi, K. Jinno, Anal. Bioanal. Chem. 372 (2002) 164–168.
[12] Y. Saito, Y. Nakao, M. Imaizumi, Y. Morishima, Y. Kiso, K. Jinno, Anal. Bioanal. Chem. 373 (2002) 81–86.
[13] Y. Saito, M. Imaizumi, K. Ban, A. Tahara, H. Wada, K. Jinno, J. Chromatogr. A 1025 (2004) 27–32.
[14] R.K. Marcus, W.C. Davis, B.C. Knippel, L. LaMotte, T.A. Hill, D. Perahia, J.D. Jenkins, J. Chromatogr. A 986 (2003) 17–31.
[15] R.D. Stanelle, L.C. Sander, R.K. Marcus, J. Chromatogr. A 1100 (2005) 68–75.
[16] Y. Saito, M. Kawazoe, M. Imaizumi, Y. Morishima, Y. Nakao, K. Hatano, M. Hayashida, K. Jinno, Anal. Sci. 18 (2002) 7–17.
[17] K. Jinno, H. Watanabe, Y. Saito, T. Takeichi, Electrophoresis 22 (2001) 3371–3376.
[18] Y. Saito, A. Tahara, M. Imaizumi, T. Takeichi, H. Wada, K. Jinno, Anal. Chem. 75 (2003) 5525–5531.
[19] Y. Saito, M. Ogawa, M. Imaizumi, K. Ban, A. Abe, T. Takeichi, H. Wada, K. Jinno, Anal. Bioanal. Chem. 382 (2005) 825–829.
[20] Y. Saito, M. Ogawa, M. Imaizumi, K. Ban, A. Abe, T. Takeichi, H. Wada, K. Jinno, J. Chromatogr. Sci. 43 (2005) 536–541.
[21] A. Abe, Y. Saito, M. Imaizumi, M. Ogawa, T. Takeichi, K. Jinno, J. Sep. Sci. 28 (2005) 2413–2418.
[22] M. Ogawa, Y. Saito, M. Imaizumi, H. Wada, K. Jinno, Chromatographia 63 (2006) 459–463.
[23] J. Lipinski, Fresenius J. Anal. Chem. 369 (2001) 57–62.
[24] J.A. Koziel, M. Odziemkowski, J. Pawliszyn, Anal. Chem. 73 (2001) 47–54.
[25] F. Musshoff, D.W. Lachenmeier, L. Kroener, B. Madea, J. Chromatogr. A 958 (2002) 231–238.
[26] V.G. Berezkin, E.D. Makarov, B.V. Stolyarov, J. Chromatogr. A 985 (2003) 63–65.
[27] Y. Saito, I. Ueta, K. Kotera, M. Ogawa, H. Wada, K. Jinno, J. Chromatogr. A 1106 (2006) 190–195.
[28] Y. Saito, I. Ueta, M. Ogawa, K. Jinno, Anal. Bioanal. Chem. 386 (2006) 725–732.
[29] J. Haginaka, C. Kagawa, Anal. Bioanal. Chem. 378 (2004) 1907–1912.
[30] J. Haginaka, Anal. Bioanal. Chem. 379 (2004) 332–334.
[31] H. Sambe, K. Hoshina, R. Moaddel, I.W. Wainer, J. Haginaka, J. Chromatogr. A 1134 (2006) 88–94.
[32] K. Kuwata, M. Uebori, H. Yamasaki, Y. Kuge, Y. Kiso, Anal. Chem. 55 (1983) 2013–2016.
[33] R.R. Arnts, S.B. Tajada, Environ. Sci. Technol. 23 (1989) 1428–1430.
[34] S. Uchiyama, M. Ando, S. Aoyagi, J. Chromatogr. A 996 (2003) 95–102.
[35] B. Cancho, F. Ventura, M.T. Galceran, J. Chromatogr. A 943 (2001) 1–13.
[36] S.W. Tsai, C.M. Chang, J. Chromatogr. A 1015 (2003) 143–150.
[37] P. Dhar, J. Pharm. Biomed. Anal. 35 (2004) 155–168.
[38] B.A. Goldberger (Ed.), Hair Analysis: Drugs of Abuse, Therapeutic Drugs, and Steroids, Preston Publications, Niles, IL, USA, 2001.
[39] Y. Nakahara, K. Takahashi, M. Shimamine, Y. Takeda, J. Forensic Sci. 36 (1991) 70–78.
[40] Y. Nakahara, K. Takahashi, Y. Takeda, K. Konuma, S. Fukui, T. Tokui, Forensic Sci. Int. 46 (1990) 243–254.