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Original Article

Development and Application of a Brush-Spray Derived from a Calligraphy-Brush-Style Synthetic Hair Pen for Use in ESI/MS

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The development of a novel type of a sampling/ionization kit for use in electrospray ionization/mass spectrometry is reported. Using a small calligraphy-brush-style synthetic hair pen (nylon-brush), and analogous to paper-spray mass spectrometry, the analytes can be collected, elution/desorption and then ionized from the surface of the nylon-brush. The body of the kit was produced by means of a commercial 3D-printer, in which ABS (acrylonitrile butadiene styrene) was used as the starting material. Meanwhile, a small nylon-brush was embedded inside a 3D-printed plastic cell, in which a solvent was supplied to rinse the brush by means of capillary action. The size and weight of the kit were 1 g and 4 cm, respectively. The kit is disposable and it has various functions, including non-invasive sampling, sample-evaporation and ionization. As a result, when a type of pesticide was selected as the test sample (dimethoate; $C_5H_{12}NO_3PS_2$), the limit of detection was determined to be 0.1 μg/mL. Collecting the pesticide from a leaf-surface (lettuce) was also successful. The process for fabricating the nylon-brush kit and the optimized experimental conditions are reported herein.

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INTRODUCTION

A wide variety of ionization methods have recently been developed. Among these methods, ambient ionization mass spectrometry is in widespread use, because it is quite simple and straightforward and also increases the speed of a mass-spectrum analysis.[1–11] Furthermore, since the development of ambient ionization mass spectrometry, so-called paper spray-mass spectrometry (PS-MS) has opened new insights in the field of mass spectrometric analysis and, since its debut on 2010, it has now become a quite popular and important method for use in mass spectrometry.[12] Thus far, PS-MS has been applied successfully in many areas of research, including food science,[13] the analysis of protein complexes,[14,15] biofluid samples,[16,17] the online chemical monitoring of cell cultures,[18] rapid discrimination of bacteria,[19] and drugs of abuse in whole blood or saliva,[20–22] and even in an ambient organic analysis.[23] Some novel alternate techniques based on PS-MS have also been reported, including a 3D-printed paper spray ionization cartridge/continuous solvent supply and the rapid detection of cocaine residues by paper spray ionization coupled with ion mobility spectrometry.[24,25]

Analysis of pesticide residues provides a measure of the nature and level of chemical contamination within the environment and of its persistence. However, it is often difficult to correlate pesticide residues in the environment, since demonstrating whether vegetables or fruits have been exposed to chemicals can be a difficult task. Selected sampling programs can be used to investigate the levels of pesticide in the environment and to rapidly determine the uptake of a pesticide by food chain components.

In this study, dimethoate (*O*,*O*-dimethyl *S*-methylcarbamoylmethyl phosphorodithioate; $C_5H_{12}NO_3PS_2$), a common pesticide, was used as a test sample. We report on a combination of ambient ionization mass spectrometry and a simple sampling method that uses a calligraphy-brush-style synthetic hair pen. In general, there are two main types of brush tips: natural hair, *i.e.*, animal hair, usually a weasel; synthetic hair, which is generally made from nylon. Herein, a commercially available calligraphy-brush-style synthetic hair pen (nylon-brush) was used and modified to fit the kit (a homemade 3D-printed plastic cell), in which a high volt-

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age source can be applied. After obtaining a sample from the target surface using the nylon-brush, it can be directly used in the ESI process, immediately followed by mass spectrometric analysis. Details of the procedures for using the sampling/evaporation/ionization brush-kit and the limit of detection for dimethoate are also reported in detail.

MATERIALS AND METHODS

Acetonitrile, methanol and acetone were purchased from Merck (Darmstadt, Germany). Dimethoate was obtained from Riedel-de Haen (Seelze, Germany). Analytical-grade *n*-dodecane was purchased from Alfa Aesar (Heysham, England). Lettuce (test sample) and calligraphy-brush-style synthetic hair pens were purchased from a local supermarket and a local art supply store (model, #8), respectively. A small bundle of synthetic pen hair (nylon) was cut to a length of 2 cm, and the resulting bundle of nylon hairs was imbedded in a piece of plastic tube (PE) to produce the nylon-brush, as shown in Fig. 1A. The seal cap (not shown), fixed cover, solvent cell (inside the body; capacity, 0.1 mL) and the body itself were fabricated by a 3D-printer, respectively. All of these parts are then combined to produce a kit that can be used in sampling and ionization. The length, diameter and weight of the finished products are 3.5 cm, 1.0 cm and 1.1 g, respectively. Before use, the kit was cleaned by ultrasonication (Branson 3510), using deionized water and then methanol, each for 15 min. The 3D-printer was purchased from GoHOT (Model, UP! Plus). The mass spectrometer (Finnigan LCQ Classic LC/MS/MS) used in this study was the same instrument that was used in our previous study.[11,20–22] The mass signal was recorded under the full scan mode (*m/z* 100–400). An Xcalibur data system was used for data collection, and the data were converted into an ASCII text file. The capillary temperature and spray voltage were set at 200°C and 4.5 kV, respectively. The tube lens offset and capillary voltage were set at –36 and 36 V, respectively.

RESULTS AND DISCUSSION

Figure 1A shows a schematic drawing of the brush-kit. As reported above, the seal cap, fixed cover, solvent cell and the body were all prepared by means of a 3D-printer. The resulting kit is economical, disposable and makes sampling easy. When the seal cap was installed, it can be used sampling for the purpose for measuring the nature and level of any type of chemical contaminant. The volume of the solvent cell for loading can hold 0.4 mL of methanol. In fact, it was possible to continuously rinse the nylon-brush, when methanol (at a rate of 6 μL/min), as an auxiliary liquid, was passed through the ESI needle. In order to investigate the sampling and ionization effect, various types of hair samples, *i.e.*, nylon, from horse and weasel, respectively, were examined, and the findings indicated that a nylon-brush provided the most satisfactory results. This is because nylon-brush hairs are very smooth, tough and hydrophobic, which permits to ionization to occur within a very short period of time. It was found that when a 3 μL sample solution was loaded onto the brush by normal pipetting, a major peak appears during ~0.1 sec, while a high voltage was applied. In contrast to this, when a chromatography paper was used, the ion intensity was weaker and decreased very slowly (up to ~5 min). When vitamin B_2 was selected as the test sample, the liner range of vitamin B_2 was found from 0.1 to 100 ppm. Meanwhile the correlation coefficient was 0.98. The optimum ESI voltage for the procedure was also investigated. The ideal distance between the tip of the nylon-brush and the mass inlet was

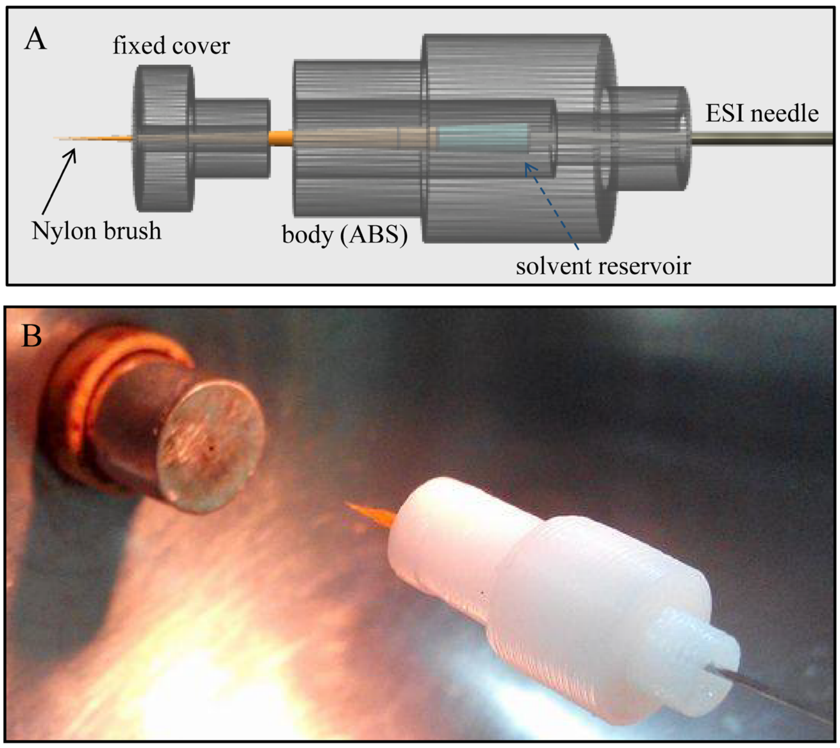

Fig. 1. Upper drawing, schematic drawing of the brush-kit; bottom photo, actual situation for the mass inlet and the sampling/ionization kit used in this study.

determined to be 8 mm. Of course, this arrangement dependents on different conditions, and the actual value would likely change, depending on the analytical parameters in use. Figure 1B (photo) shows the actual situation for the mass inlet when the sampling/ionization kit described above was used in this study. The kit is very light, so it can be held by an ordinary stainless ESI needle, in which a high voltage is applied. The ESI needle was attached to a metric XYZ translation stage, and for this reason, axial alignment was readily achieved. Figure 2 shows 4 photos of the nylon-brush when various high voltages were applied (frames a–d; 3.5, 4.0, 4.5, and 5.0 kV, respectively). It can be seen that the Taylor cone is not clear when 3.5 kV was used. It should also be noted that the 3.5 kV was applied to the ESI needle, but not to the tip of the nylon-brush. The actual voltage would be expected to be lower, but the actual value was not measured. On the other hand, when the voltage was increased to 5.0 kV, multiple Taylor cones were observed. Hence, the optimized voltage was found to 4.5 kV in this case. In Fig. 3, frame A shows a typical mass spectrum of the test sample (dimethoate) obtained using nylon-brush-spray/mass spectrometry. Herein, a 15 mL aliquot of an aqueous stock solution, which was placed in a 20 mL sample vial, contained 1.0 ppm of dimethoate. By using a micropipette, the sample solution (3 μL of the dimethoate solution) was dropped on the nylon-brush, which was then subjected to direct detection by the mass spectrometer, in which a +4.5 kV high voltage power supply was used; an auxiliary solvent was not needed in this case. An ion intensity of 4.31×10^5 counts was observed, in the case of the above analysis. Using the kit, it was possible to detect amounts of dimethoate as low as 3 ng (absolute weight). Meanwhile, the peaks at *m/z* 199 and 252 are assigned to the main fragment and $[M+Na]^+$, respectively. The inset, in Fig. 3A bottom, shows the MS/MS spectrum of the parent ion, indicating that the peak at *m/z* 199 indeed was the main fragment is belong to the parent ion. The other inset, in Fig. 3A, shows a lower concentration level of dimethoate. As can be seen, a minor peak is also observed, *i.e.*, the design of the brush-spray in ESI/MS, by using a calligraphy-brush-style nylon-hair pen, was successful, even though the concentration of the analyte was extremely low. To examine the sampling effect from a "leaf surface" by the nylon-brush, a procedure that could be used to analyze pesticide residues

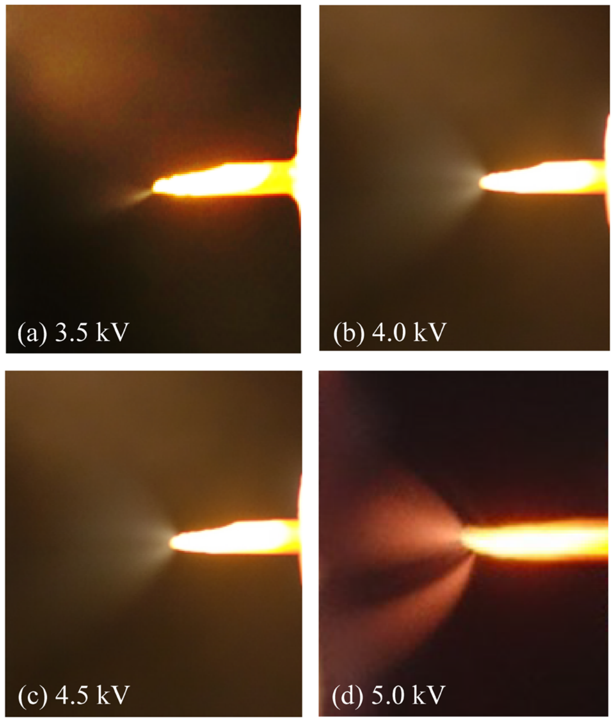

Fig. 2. Photos show the nylon-brush when various high voltages were applied (frames a–d; 3.5, 4.0, 4.5, and 5.0 kV, respectively).

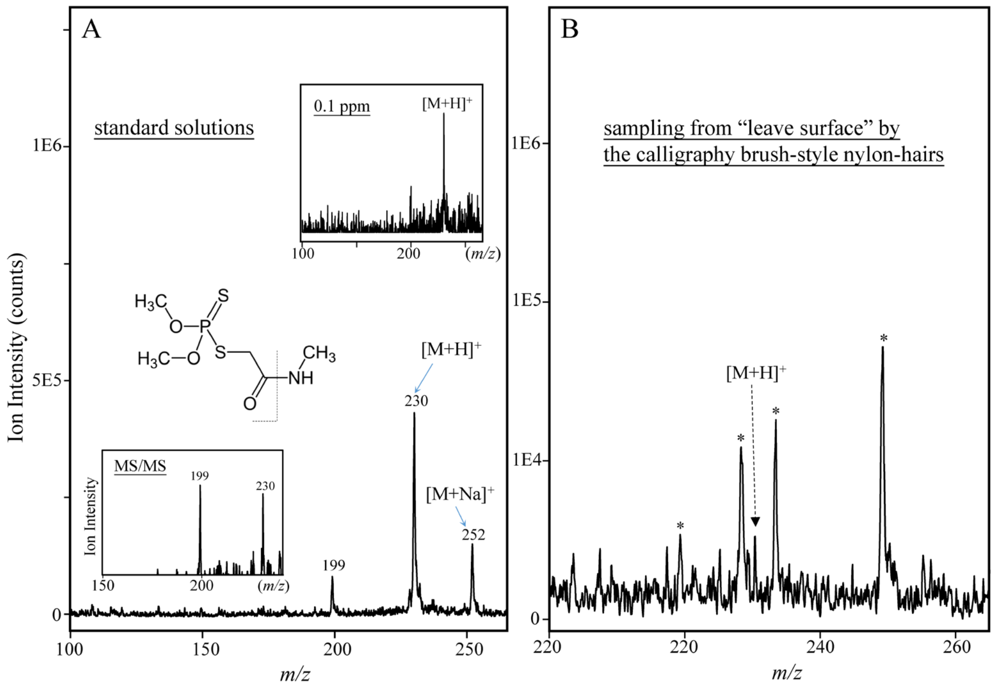

Fig. 3. Frame A, mass spectra of the test sample (dimethoate; concentration level, 1.0 ppm; inset, 0.1 ppm) obtained by nylon-brush-spray/mass spectrometry, respectively; frame B, a nylon-brush sampling/ESI method was performed. Lettuce was selected as the test sample and the spiked concentration and volume were 1.0 ppm and 50 μL, respectively.

on the surfaces of vegetables, lettuce was selected as the test sample. Frame B, in Fig. 3, shows the results obtained when the surface of the lettuce was swept by the nylon-brush; using methanol as the collection solvent. The spiked concentration and volume were 1.0 ppm and 50 μL, respectively. As can be seen, a very minor peak (indicated as $[M+H]^+$) is observed and by comparing it to a blank sample, it is possible to identify it as arising from dimethoate. Furthermore, some additional peaks were also detected in this case, indicated as "*". This indicates that some unknowns, probably some natural components associated with lettuce, were also extracted by the methanol when the nylon-brush was used. However, thus far we have not been able to identify these peaks. Thus, we conclude that the combination of brush-spray/ESI using a nylon-brush kit that was developed in this study, and ambient ionization mass spectrometry provides a new approach for efficiently collecting low levels of pesticide residues that are present on the surfaces of vegetables.

CONCLUSION

The development of a novel method for nylon-brush-spray mass spectrometry by a calligraphy-brush-style nylon hair pen (nylon-brush) is described. By using a commercial 3D-printer, an economical and disposable nylon-brush kit was successfully designed and developed. The nylon-brush kit can be used for non-invasive sampling and the collected analytes can be simultaneously evaporated/ionized when the kit is connected to an ESI needle. This method is simple and economical, and is suitable for use in the rapid screening of pesticides, since it has a high degree of sensitivity. In addition, the operating procedure is simple and an ion signal can be observed immediately. We believe this method has the potential for use in practical analyses and can also be regarded as a helpful tool for use in examining environmental samples. Further applications are currently being explored.

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