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Introduction of a novel swabbing material of a wiper and establishment of an optimal method for the collection of organic explosive residues

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Abstract: The identification of explosive residues on specimens obtained from an explosion event is a crucial factor for assessing the cause of the explosion. In order to detect the components of explosives, the explosive residues deposited on surfaces are commonly extracted using swabbing materials pre-wetted with an organic solvent. The residues are then analyzed with analytical instruments such as LC/MS and CE/MS. Most conventionally used swabbing media such as cotton swabs or cotton tip swabs seem unsuitable for extracting explosive residues from the surface of a large area of clothes because the swabbing materials tend to be damaged easily, and because only a relatively small amount of explosives is collected. To overcome these problems, we have introduced a novel wiper (215 × 210 mm, single layer, Yuhan-Kimberly, Republic of Korea) as a swabbing material to recover representative organic explosives, namely, TNT, RDX, tetryl, HMX, PETN, and NG, from a large area of clothes. Different sides of the wiper, which was folded in half five times, was used to swab the surface of a clothing. We compared this novel wiper with a cotton swab and a cotton tip swab in terms of the recovery efficiency for the aforementioned organic explosives by pre-wetting with methanol, acetone, and acetonitrile, respectively. We identified that this novel wiper collected a significantly higher amount of organic explosive residues than a cotton swab or a cotton tip swab when using methanol as an extracting solvent.

Key words: swabbing material, organic explosives, wiper, cotton swab, cotton tip swab

1. Introduction

The detection of explosive residues deposited on the specimens prepared from an explosion incident is an important factor to presume the cause of the explosion. After an explosion, efficient collection of explosive residues from the explosion related surfaces, such as victim's hands or clothes, is very crucial to assess the kind of explosives used. The identification of explosive residues from swabbing media prepared from a victim's hands, clothes, or the location of explosion has evidentiary value because the existence

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of organic explosives in the general living place is rare.[1] Where organic explosive residues are expected to adhere to samples related to an explosion accident, several sampling methods can be applied depending on the kinds of surfaces. The efficiency of the swabbing procedure not only relies on the sampling techniques that carry out on the surface of interest, but also depends on the sampling media and the swabbing solvent used.[2] In order to collect explosive residues efficiently from the explosion related specimens, many swabbing materials have been employed as potential sampling media.[2-7] Most of the previously reported recovery methods have been based on cotton-based material and are still widely employed in most forensic laboratories, due to the low cost and their ease of use. Swabbing procedures must be efficient for the recovery of explosive residues from surfaces and should restrain any losses of volatile residues between the sampling and extraction steps.[8] The use of pre-wetted cotton ball swabs with various solvents including acetone,[9,10] acetonitrile,[11] methanol,[12] and methyl *t*-butyl ether[13] has been reported. Acetone is commonly recommended to moisten swabs because most explosives dissolve well in this solvent.[14] In spite of the fact that the recovery of explosive particles with swabbing media is a crucial procedure that can determine the success of the detection of explosive residues, few studies have been reported on the collection efficiency of explosive residues using different swabbing media and different swabbing solvents.[6,8] Furthermore, since most organic and inorganic explosives have much different physical properties, it is difficult to efficiently extract both explosives simultaneously.[7] In general, it is appropriate to extract organic and inorganic explosive residues by each method to improve the recovery efficiency of corresponding explosives. Previously commonly used cotton swabbing media, which are suitable for extracting explosive components in small areas on smooth surfaces such as hands or faces, may not be applied efficiently to swab large areas of surfaces like explosion-related clothes. So, cotton swabbing materials may not be feasible for collecting organic explosives from the clothes damaged during an explosion because the rough surfaces of clothes can easily damage the cotton material. In order to make up for these problems, we introduced a novel wiper as a swabbing material to recover more organic explosive residues from the rough surfaces of clothes. This novel wiper is strong enough to withstand friction while being swabbed on the surface of clothes. In this study, the recovery efficiency of organic explosive residues with the novel wiper from a clothing-like surface was examined and compared with conventionally used swabbing materials such as a cotton swab and a cotton tip swab, and an optimal recovery method was established to efficiently collect 6 kinds of representative organic explosives.

2. Materials and Methods

2.1. Swabbing materials, organic explosive standards and chemical reagents

Swabbing materials included a wiper (Kimtech Science wipers medium, 215 × 210 mm, single layer, Yuhan-Kimberly, Republic of Korea), a cotton swab (34 × 27 mm, nonwoven viscose cloth, containing 70 % v/v isopropyl alcohol, PharmsKorea, Republic of Korea) and a cotton tip swab (Maxim, New York, USA). For better understanding, the Kimtech Science wiper will be referred to as the wiper, the cotton swab of PharmsKorea will be represented to as the cotton swab and the cotton tip swab of Maxim will be referred to as the cotton tip swab in the remainder of this article. The cotton swab was used after absorbed ethanol and water were completely dried in an oven (WiseVen, Wisd Laboratory Instruments, Republic of Korea) at 80 °C for 30 min, and the wiper and the cotton tip swab were employed without pretreatment. The wiper, which was folded in half 5 times, was used for easy handling with tweezers. All the swabbing materials except for the cotton tip swab were pinched by tweezers to swab surfaces to collect organic explosive residues; 3 sticks of the cotton tip swab were used for one swabbing. Only one side of the wiper was swabbed completely by unfolding and folding of it to extract organic explosive residues; both sides of the cotton swab were used to collect organic explosive residues; the cotton tip swabs were held with one hand to swab a surface to collect organic explosive residues. Organic explosive standards, which are commonly used for military weapons shown in *Fig*. 1, including 2,4,6-trinitrotoluene (TNT) at 1000 μg/mL in methanol: acetonitrile (1:1), hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX), 2,4,6,*N*-tetra-nitro-*N*-methylaniline (tetryl), and octahydro-1,3,5,7-tetranitro-1,3,5,7-triazine (HMX) each at 100 μg/mL in methanol:acetonitrile (1:1), pentaerythritol tetranitrate (PETN) at 100 μg/mL in methanol and nitroglycerin (NG) at 100 μg/mL in ethanol, respectively, were purchased from Accu-Standard (New Haven, CT, USA). Stock solutions at 20 μg/mL were diluted with acetonitrile to the desired concentrations. All standards were serially diluted with mobile phase to determine the limit of quantitations (LOQs) and construct calibration curves for the 6 organic explosives. Laboratory reagents including water (J.T. Baker, USA), methanol (J.T. Baker), acetonitrile (Duksan, Korea), and acetone (J.T. Baker) were LC/MS grade. Ammonium nitrate (99.5 %, Sigma-Aldrich, St. Louis, USA) and Florisil (magnesium silicate, activated, Mesh: 60-100/PR, 0.150 ~ 0.180 mm particle size) were both laboratory grade and purchased from Sigma-Aldrich.

2.2. Liquid chromatography (LC) and quadruple time-of-flight mass spectrometry (QToF-MS) for the analysis of organic explosives

A Waters Acquity Ultra Performance Liquid Chromatography (Waters, Massachusetts, USA) employing Waters Acquity UPLC BEH C_{18} (1.7 μm, 2.1 × 100 mm) column, which is a silica-based reverse phase column, was used for the analysis of 6 kinds of organic explosives. As shown in *Table* 1, the solvent program comprised a water:methanol (0.05 mM ammonium nitrate) system with a flow rate of 0.2 mL/min and a column temperature of 25 °C. The solvent program started at 70 % water for 2 min, changing to 50 %, 30 %, and 60 % water at 2 min, 5 min, and 9 min, respectively and then to 70 % water over the next minute. Injection volume was set at 10 μL with a total run time of 10 min.

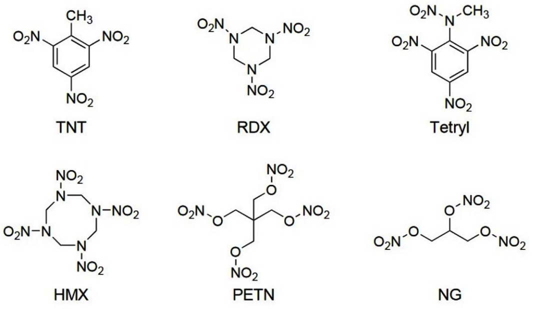

Fig. 1. Chemical structures of 6 kinds of organic explosives.

Table 1. Eluent gradient to separate organic explosives

Time (min)	Flow (mL/min)	%A	%B
Initial	0.20	70	30
2	0.20	50	50
5	0.20	30	70
9	0.20	60	40
10	0.20	70	30

Eluent A and B: 0.05 mM ammonium nitrate in 10 % and 90 % aqueous methanol solution, respectively.

A Waters Q-Tof Premier Mass Spectrometer using Water Mass Software version MassLynx V4.1 was utilized. Sample ionization was achieved using an electrospray Ionization (ESI) interface in negative ion mode. Gas and vaporizer temperatures were set at 350 °C, with a drying gas flow rate of 10.8 L/min. The capillary voltage was set to 3.70 kV in the source with a collision energy setting of 1.0 kV in the collision cell. *Table* 2 shows analytical specific data involving formula, observed spectral molecular weight, proposed precursor species, retention time and LOQ for the six analyzed organic explosives. The identification of organic explosives was performed by retention time and accurate mass of the precursors because no characteristic fragmentation patterns were obtained for these explosives.

2.3. Comparison of the absorption capacities of organic explosives between the wiper, the cotton swab, and the cotton tip swab

The relative absorption capacity of 6 organic explosives with the wiper was compared to the

Table 2. Analytical specific data including formula, observed spectral molecular weight, proposed precursor species, retention time and limit of quantitation for each analyte examined

Analyte	Formula	Observed spectral molecular weight	Proposed precursor species [M]	Retention time (min)	LOQ[a] (ng/mL)
TNT	$C_7H_5N_3O_6$	226.0106	$[M-H]^-$	5.2	2.5
RDX	$C_3H_6N_7O_9$	284.0232	$[M+NO_3]^-$	3.5	0.2
Tetryl	$C_7H_5N_6O_{11}$	349.0022	$[M+NO_3]^-$	4.9	1.5
HMX	$C_4H_8N_9O_{11}$	358.0346	$[M+NO_3]^-$	2.4	0.1
PETN	$C_5H_8N_5O_{15}$	378.0029	$[M+NO_3]^-$	6.3	1.2
NG	$C_3H_5N_4O_{12}$	288.9909	$[M+NO_3]^-$	5.2	0.3

[a] LOQ=Limit of quantitation (calculated as approximately ten times the signal-to-noise level of the extracted proposed precursor ion)

conventionally used swabbing materials of the cotton swab and the cotton tip swab. Comparison of the relative absorption ability of organic explosives with different swabbing materials is very useful in predicting the extraction efficiency of explosive residues, since the swabbing material that can absorb more organic explosives, can collect more organic explosive particles from the surface of clothes. To identify the absorption ability of the swabbing materials, which were immersed in a 50 mL of a acetone solution at 100 ng/mL of 6 organic explosives for 1 min and pulled out from the solution, and then allowed to dry in a fume cupboard for 15 min to be evaporated of acetone and bound with the explosives. Extraction was performed with methanol to determine the amount of explosives absorbed onto the swabbing materials. The wiper was loaded into a syringe barrel, and 2 mL of methanol was flowed 2 times serially through the syringe barrel to extract the organic explosives completely. Physical agitation involved the repeated pounding of the cotton swab with the end of a Pasteur pipette for 30 sec and the cotton tip swab was swirled with a vortex mixer (Maxi Mix II, Iowa, USA) for 1 min. Absorption capacities of 6 organic explosives with 3 kinds of swabbing materials were compared by the average amount in triplicate.

2.4. Comparison of swabbing solvents in the extraction efficiency of organic explosives

In order to identify a suitable solvent that can efficiently collect organic explosive residues from the surface of clothes, methanol, acetone and acetonitrile were compared in the recovery of organic explosives. The wiper was used to compare extraction efficiencies of organic explosives with 3 different solvents. The recovery efficiency was assessed by measuring the extracted amount of organic explosives bound onto the tissue of the wiper. The wiper was immersed in an acetone solution for 1 min at 100 ng/mL of 6 organic explosives, and dried for 15 min, and then the organic explosives were extracted with 4 mL of methanol, acetone and acetonitrile, respectively. The above procedures were repeated in triplicate and the recovered average amounts of organic explosives were compared.

2.5. Comparison of recovery efficiencies of organic explosive residues between the wiper, the cotton swab, and the cotton tip swab

Three different swabbing materials, the wiper, the cotton swab and the cotton tip swab, were employed to identify the recovery efficiency of organic explosives with a mock sample. To make a mock specimen similar to the surface of clothes, a wiper (Kimtech pure, 290 × 300 mm, polypropylene substance, Yuhan Kimberly, Republic of Korea) was used as a substitute for clothes because the wiper has a curvature on the surface, an excellent absorption ability for organic solvents and water, and a property of adhering fine dust well like the surface of clothes. Since there is much difference in physical characters on the surface of clothes depending on fabric types and chemical compounds, this wiper was selected as a reference surface to give consistent reproducibility.

Silica gel (Florisil: magnesium silicate, activated, Mesh: 60-100/PR, 0.150 ~ 0.180 mm particle size), which was coated with 6 organic explosives, was employed as explosive particles similar to fine explosive particles produced during an explosion. In order to coat the silica gel with 6 organic explosives, 500 μL of NG and TNT, 200 μL of tetryl, PETN and RDX, and 300 μL of HMX were taken from 20 μg/mL of explosive stock solutions, and put in a beaker, and then diluted with acetone to make 5 mL of the solution. Three grams of silica gel were added to the acetone solution of organic explosives, and then dried over stirring with a glass rod. Taking into consideration of the surface area commonly used to collect organic explosives, 0.2 g of the silica gel coated with 6 organic explosives was evenly applied to the area of 225 cm^2 (15 × 15 cm) of the wiper. When wiping off the explosives from the mock-surface with swabbing materials, the swabbing wiper was pre-wetted with 4 mL of methanol, and the cotton swab and the 3 sticks of cotton tip swab were soaked with 1 mL of methanol, respectively, which is a suitable amount of solvent to saturate the swabbing materials. The silica gel deposited on the surface was swabbed in two orthogonal directions by re-swabbing in duplicate on the same area (225 cm^2 for swabbing area). The wiper was then placed into a syringe barrel and then 2 mL of methanol was added serially in duplicate to extract explosive residues to a 10 mL glass test tube (16 mm × 100 mm, supplied by science, Rowvill Vic, Republic of Korea). For the collection of explosives with the cotton tip swab, the collection was performed by rolling the tip of the swab while rubbing on the surface to secure that the entire surface area of the tip was employed. Each cotton swab and cotton tip swab was then transferred to a 10 mL clear glass tube and 4 mL of methanol was added. The cotton swab was touched with the end of a Pasteur pipette for 30 sec and the cotton tip swabs were swirled with a vortex mixer for 1 min to extract organic explosive residues. The tip of a glass Pasteur pipette was punctured into the tip of the cotton swab and cotton tip swab, respectively, and each extract was drawn through the tip and transferred to a 10 mL glass tube. The extracted solution was concentrated and reconstituted with mobile phase and then passed through a filter (0.22 μm, PTFE membrane, Jet Biofil, China) to be collected in a clear vial (2 mL, Wheaton, USA) for the analysis of organic explosives with LC-MS.

3. Results and Discussion

3.1. Comparison of physical characteristics of the novel swabbing material of a wiper to conventionally employed swabbing materials

Commonly employed swabbing materials of cotton swabs or cotton tip swabs are suitable for extracting organic explosive residues from a small area of hand or face, but are somewhat limited for the relatively large area of rough surfaces like the surfaces of clothes damaged from an explosion. So, this novel wiper has been introduced as a swabbing material suitable for extracting organic explosives from the clothes damaged during an explosion. *Fig.* 2 shows three swabbing materials involving the newly introduced swabbing material, the wiper: from the left, the five folded wiper, the cotton swab, and the cotton tip swab. *Table* 3 contains the data on weight and the surface area of swabbing materials of which the ingredients are all cellulose.

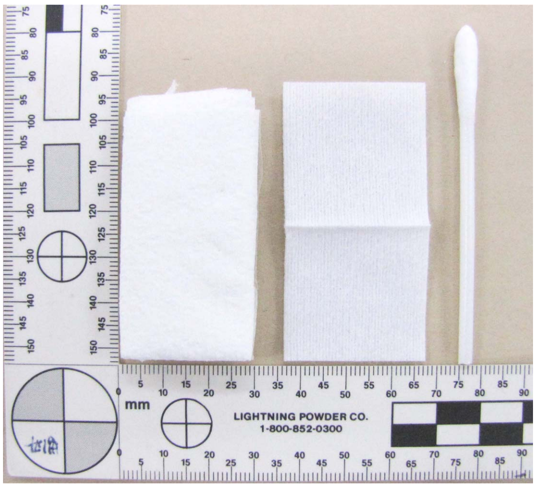

Fig. 2. A photograph of 3 swabbing materials (from the left, the wiper folded 5 times in half, the cotton swab, and the cotton tip swab).

Table 3. The data on weight and the surface area of swabbing materials

Brand	Wiper	Cotton swab	cotton tip swab
Weight (g)	1.0	0.2	0.04
Area (cm^2)	903.0	18.4	-

Considering the thickness of the swabbing materials, the newly introduced wiper can be swabbed with only one side of the surface to collect organic explosive residues because the wiper is too thin to use on both sides. Even though the cotton swab is thick enough to wipe with both sides, its sampling area may be not enough due to a small contact area. Even assuming that the wiper can just be used to extract explosives with only one side of the surface, having about 25 times of more swabbing area and 5 times of more absorptive substance than those of the cotton swab and the cotton tip swab may indicate that the wiper may have much greater extraction efficiency for organic explosive residues than those of the cotton swab and the cotton tip swab.

3.2. Liquid chromatography (LC) and quadruple time-of-flight mass spectrometry (QTOF-MS) for the analysis of organic explosives

The availability of quadruple time-of-flight (QTOF) LC/MS system provides a greater level of analytical information as a result of high resolution and the ability to collect accurate mass information. The applicability of LC-TOF/MS for organic explosives analysis was previously detailed by Kinghorn et al.[15] who reported on the analysis of 19 common organic explosives with a mass accuracy less of than 3 ppm. Current methods for the trace level analysis of organic explosives commonly rely on the use of either liquid (LC) or gas chromatography (GC) based techniques. Liquid chromatography can avoid the relatively high temperatures involved with gas chromatography, which may decompose thermally liable explosives in the injection port, especially certain nitrate esters or nitramines[2,16] Due to its ability to analyze thermally liable compounds such as high explosives and propellants, liquid chromatography (LC) based methods provide an obvious advantage over GC related techniques. Current LC/MS methods have commonly been based on the use of electrospray ionization (ESI) or atmospheric pressure chemical ionization (APCI) with detection in both positive and negative modes which can be applicable to the analysis of nitro-containing explosives.[17,18] To analyze organic explosives efficiently, electrospray ionization (ESI) was chosen in preference to the alternative analytical method of ultraviolet (UV), because of the greater response for the majority of nitro pertaining

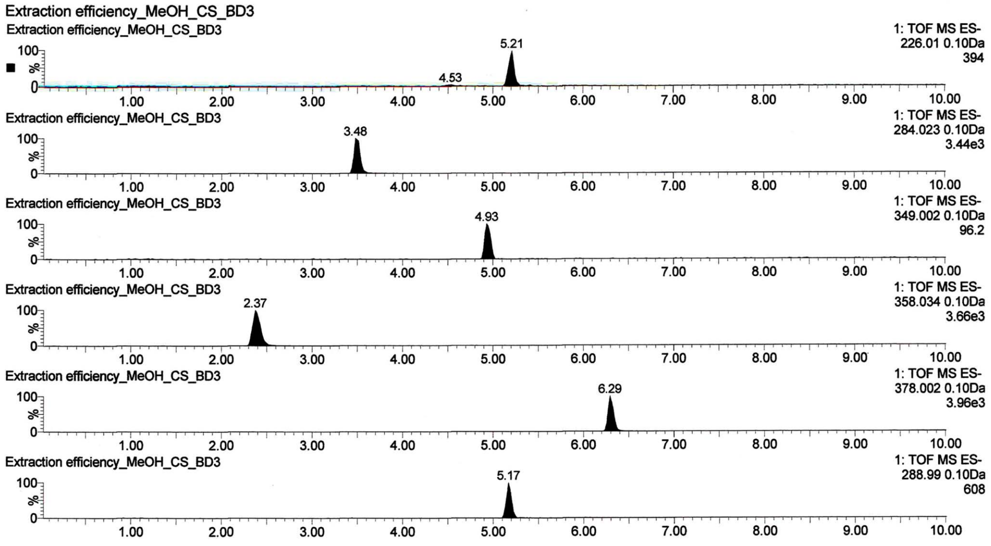

Fig. 3. Extracted chromatograms identifying 6 organic explosives (from the top, TNT, RDX, tetryl, HMX, PETN and NG).

explosives using negative ion ESI.[19] In negative ionization mode, 5 nitro containing explosives were observed as the adduct ions of nitrate to molecular ions $[M+NO_3]^-$ and the deprotonated molecular ion $[M-H]^-$ was observed for TNT. *Fig.* 3 shows the extracted chromatograms of 6 organic explosives which were extracted with observed spectral molecular weight in *Table* 2. Peak identification was possible for all explosive analytes, which was based on retention time with targeted weight of explosives. From the top, TNT was detected at about 5.2 min, RDX at 3.5 min, tetryl at 4.9, HMX at 2.4 min, PETN at 6.3 and NG at 5.3 min. The LOQs (limit of quantitations) for the 6 organic explosives ranged from 0.1 ng/mL to 2.5 ng/mL as shown in *Table* 2, even though there was a little difference in LOQ with the types of explosives. The LOQs were low enough to detect the 6 organic explosives commonly deposited in most explosion incidents.

3.3. Comparison of the absorption capacities of organic explosives between the wiper, the cotton swab, and the cotton tip swab

The absorption capacity of the wiper for organic explosives was compared to that of the cotton swab and the cotton tip swab. It can be considered that the amount of explosives deposited on a surface of clothes after an explosion may not exceed the limit of absorption capacity of any swabbing materials because most explosive components would have disappeared by a chemical reaction or a blast wind. A large amount of organic explosives can actually be absorbed onto clothes while rubbing with swabbing materials pre-wetted with solvents. Therefore, it is not efficient to repeatedly rub the clothing with the same side of swabbing materials for the collection of organic explosives. In this respect, the wiper can significantly reduce the number of repetitions in swabbing compared to the cotton swab and cotton tip swab. Moreover, it can be assumed that the swabbing material with a higher absorption capacity can extract more organic explosives deposited on a contacted surface. *Fig.* 4 shows that the wiper could absorb much more organic explosives than the cotton swab and cotton tip swab. The relative absorption capacity of organic explosives with the cotton swab and the cotton tip swab was about 7~15 % and 1~2 %, respectively, compared to that of the wiper. The absorption capacity of organic explosives can be somewhat proportional to the weight of the swabbing materials, as shown in *Table* 1. It can be inferred that the extraction efficiency of organic explosives with the wiper is far greater than that of conventionally employed cotton swabs or cotton tip swabs.

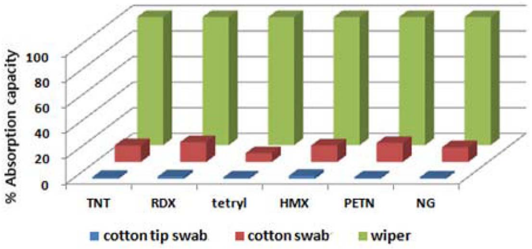

Fig. 4. Average absorption capacity of organic explosives with swabbing materials (n=3).

3.4. Comparison of swabbing solvents in the extraction efficiency of organic explosives

Explosive particles adhered to the surface of clothes can be transferred to a swabbing material and solved organic explosive residues can be absorbed onto the swabbing one. To collect organic explosive residues efficiently, it is crucial to select a suitable solvent and swabbing material. So selecting an appropriate solvent with a strong solubility and affinity for the extracted explosives is crucial. In order to compare extracting performance with solvents, the swabbing material of the wiper absorbed 6 kinds of organic explosives, and then was dried enough to be bound with the explosives. Extraction efficiency of explosives was assessed by obtaining the amount of explosives with syringe barrel extraction over flowing down a respective solvent. Methanol, acetonitrile and acetone were chosen as extracting solvents given their widely reported usage in the extraction of organic explosives residues with their comparative low volatility. Even though water: methanol (1:1) has been employed to extract organic and inorganic explosives together,[7] water pertained extraction solvent can be difficult to be applied for the analysis of explosives with LC/MS due to the difficulty in removing the water. Therefore, the extraction solvent containing water was excluded in this procedure. To estimate the extraction efficiency of organic explosive residues, a wiper spiked with organic explosives was employed. To choose a suitable solvent for the wiper, the organic explosives were recovered with a syringe barrel extraction by using methanol, acetone, and acetonitrile, respectively. Even though the solvents above are widely used to extract organic explosives, acetone is commonly recommended to moisten swabs because most explosives dissolve well in it.[14] However, methanol outperformed acetone and acetonitrile for the extraction of 6 organic explosives with the wiper; over 95 % of extraction efficiency was obtained for most explosives except HMX, about 91 %, as shown in *Fig.* 5. Acetonitrile showed that extraction efficiency of the organic explosives ranged about 21~70 % and acetone about 15~57 %. Acetonitrile showed better extraction efficiency than acetone about 10 % more for all organic explosives. Even though acetonitrile was found to be an effective swabbing solvent to employ with either cotton or polyester swabs in the recovery of both the organic and inorganic representative compounds from the selected glass and plastic test surfaces,[6] acetonitrile demonstrated less performance in the recovery of organic compounds than that of methanol. In case of PETN, decreasing the polarity of the swabbing solvent may have contributed to a higher recovery because of the hydrophobicity of PETN (the octanol/water partition coefficient is approximately 1-2 orders of magnitude higher than those of TNT and RDX).[20] Moreover, acetonitrile should be avoided due to its proven effect in stabilizing organic explosives in soil and water environments.[21] These results are consistent with the data that methanol has the strongest binding effect with organic explosives, followed by acetonitrile and acetone, which is in contrast to the recommendation of using acetone to extract organic explosives from explosion related specimens.[14] In laboratories that have ventilation systems which can prevent examiners from inhalating methanol, methanol can be employed as the most suitable extraction solvent of organic explosive residues.

3.5. Comparison of recovery efficiencies of organic explosive residues between the wiper, the cotton swab, and the cotton tip swab

Recovery efficiency of organic explosives with the wiper was investigated and compared to that of the cotton swab and the cotton tip swab. As a replacement of cloth, a wiper (about 150 × 150 mm, Kimtech pure wiper, Yuhan Kimberly, Republic of Korea), with an uneven surface like the fabric of clothes, was used as the mock-surface of clothes because there is a large variety of different surfaces and chemical components for clothing. Even though the efficiency for the recovery of nitroglycerin residues from the surface of hands using cotton balls wetted with acetone was reported by Twibell *et al.*,[8] accurately quantifying the recovery efficiency of any swabbing

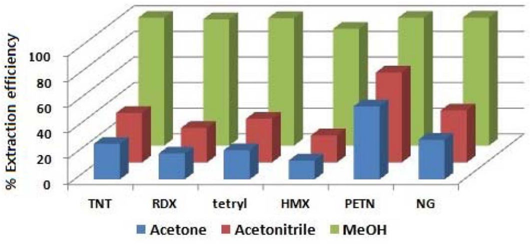

Fig. 5. Extraction efficiency of organic explosives with the wiper using 4 mL of methanol, acetone and acetonitrile, respectively (n=3).

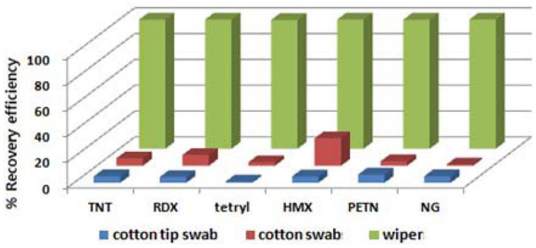

Fig. 6. Comparison of recovery efficiency of organic explosive residues between the wiper, the cotton swab, and the cotton tip swab using methanol combined with syringe barrel extraction or physical agitation (n=3).

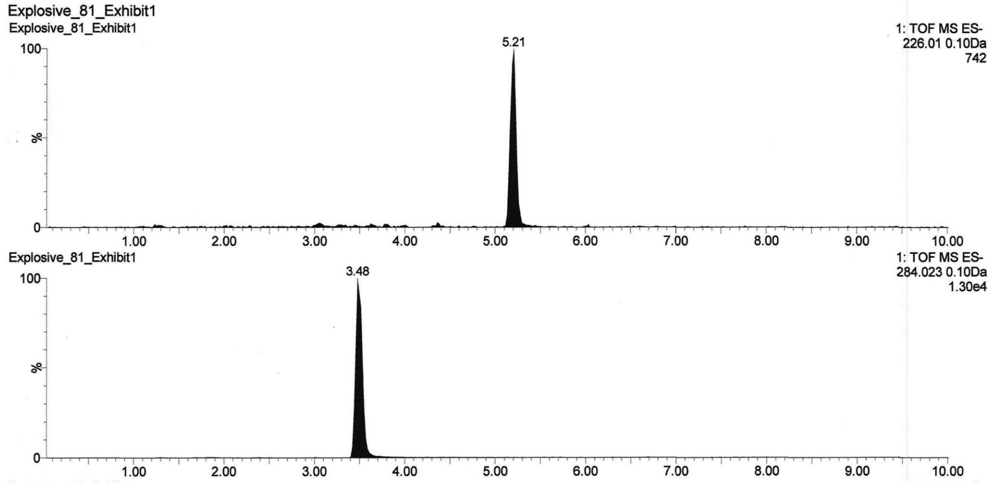

Fig. 7. Extracted chromatograms of organic explosives obtained from the surface of clothes damaged in the explosion incident. TNT (upper peak, 642 ng/swabbed area : about 150 × 150 mm) was detected at 5.2 min, and RDX (lower peak, 1,558 ng/swabbed area) was found at 3.5 min.

process for the collection of organic explosive residues from a surface is difficult considering the variations: the pressure employed during sampling, the swabbed area, the amount of solvent applied, and so on. To extract organic explosives efficiently, methanol was proven that there was no significant difference in the recovery of the representative organic explosives from the test swabs.[22]

Recovery of organic explosives with the wiper was considerably higher than that of the cotton swab and cotton tip swab, as shown in *Fig.* 6. Recovery efficiencies of organic explosives with the cotton swab and cotton tip swab were obtained less than 10 % than that of the wiper, except for HMX which had a little higher recovery efficiency at about 21 % with the cotton swab, compared to that of the wiper. The recovery of tetryl was comparatively lower, with about 3 % with the cotton swab, and with about 1 % with the cotton tip swab, compared to that of the wiper. The comparatively low recovery returned for tetryl may be a result of hydrolysis to n-methylpicramide because of the acidic nature of silica.[23] It showed that swabbing explosives particles with the wiper pre-wetted in methanol can recover significantly higher organic explosives than the cotton swab or cotton tip swab from the surfaces of clothes.

Case: An unpredicted explosion occurred while an excavating operator was making the ground even in a rice field. The operator was seriously injured from the incident. The worker's damaged clothes were submitted to identify and detect the components of explosives for the estimation what type of bomb had exploded.

This established protocol was applied for the collection of organic explosives residues from the victim's clothes; TNT and RDX were detected in large amounts from the clothes shown in *Fig.* 7, so we can assume that a kind of bomb made of C4 explosives exploded in the incident. Thus, this novel wiper can be employed as a swabbing material to efficiently collect organic explosives from clothes or shoes related to an explosion.

4. Conclusions

This study investigated the excellence of the novel wiper as a swabbing material to collect organic explosives from the surface of clothes compared to the conventionally used swabbing materials such as cotton swabs and cotton tip swabs. We can infer that this novel wiper is able to recover considerably higher amounts of organic explosive residues from the surfaces of clothes than conventionally employed swabbing materials of the cotton swab and cotton tip swab. It showed that the use of the wiper could be preferred to remove organic explosive residues with greater efficiency than both the cotton swab and cotton tip swab. Moreover, methanol was preferred over acetone and acetonitrile as an extraction solvent combined with syringe barrel extraction to collect organic explosive residues. Thus, employing this novel wiper pre-wetted with methanol for swabbing and syringe barrel extraction can be an optimistic method to recover organic explosive residues from the relatively large and rough surfaces of clothes.

References

1. H. E. Cullum, C. McGavigan, C. Z. Uttley, M. A. M. Stroud and D. C. Warren, *J. Forensic Sci.,* **49**(4), 1-7 (2004).
2. R. Waddell, D. E. Dale, M. Monagle and S. A. Smith, *J. Chromatogr. A*, **1062**, 125-131 (2005).
3. J. S. Wallace and W. J. McKeown, *J. Forensic Sci.,* **33**, 107-116 (1993).
4. M. E. Sigman and C. Y. Ma, *Anal. Chem.,* **71**, 4119-4124 (1999).
5. A. Zeichner, S. Abramovich-Bar, T. Tamiri and J. Almog, *Forensic Sci. Int.,* **184**, 42-46 (2009).
6. N. Song-im, S. Benson and C. Lennard, *Forensic Sci. Int.,* **222**, 102-110 (2012).
7. D. A. DeTata, P. A. Collins and A. J. McKinley, *J. Forensic Sci*., **58**(3), 757-763 (2013).
8. J. D. Twibell, J. M. Home, K. W. Smalldon, D. G. Higgs and T. S. Hayes, *J. Forensic Sci.,* **27**(4), 792-800 (1982).
9. R. D. Voyksner, *J. Chromatogr.*, **354**, 393-405 (1986).
10. P. Kolla, *J. Forensic Sci.,* **36**(5), 1342-1359 (1991).
11. J. C. Oxley, J. L. Smith, E. Resende, E. Pearce and T. Chamberlain, *J. Forensic Sci.,* **48**(2), 334-342 (2003).
12. D. Perret, S. Marchese, A. Gentili, R. Curini, A. Terracciano and E. Bafile, *Chromatographia*, **68**, 517-524 (2008).
13. J. M. F. Douse, *J. Chromatogr.,* **234**, 415-425 (1982).
14. J. Yinon and S. Zitrin, 'The analysis of explosives', p.221, Pergamon Press, Oxford, 1981.
15. R. Kinghorn and C. Milner, 'Analysis of trace residue of explosive materials by Time-of-Flight LC/MS', Agilent Technologies, Wilmington, DE, 2007.
16. M. E. Walsh and T. Ranney, *J. Chromatogr Sci*., **36**, 406-416 (1998).
17. X. Zhao and J. Yinon, *J. Chromatogr. A*, **977**, 59-68 (2002).
18. R. Tachor, V. Pichon, M. B. LeBorgne and J. J. Minet, *J. Chromatogr. A*, **1154**, 174-181 (2007).
19. D. DeTata, P. Collins and A. McKinley, *Forensic Sci. Intl*., **233**, 63-74 (2013).
20. R. Tachon, V. Pichon, M. B. LeBorgne and J. J. Minet, *J. Chromatogr. A,* **1185**(1), 1-8 (2008).
21. T. F. Jenkins, P. G. Thorne, K. F. Myers, E. F. McCormick and K. F. Myers, 'Preservation of water samples containing nitroaromatics and nitramines'. Honover, NJ: US Army Cold Regions Research and Engineering Laboratory, Special Report 93-16, 1995.
22. N. Song-im, 'Explosive residue analysis: evaluation and optimization of sampling, storage and cleanup protocols', PhD Thesis, University of Canberra, Australia, 2011.
23. T. Tamiri and S. Zitrin, *J. Energ. Mater.*, **4**, 215-237 (1986).