Application of ion mobility spectrometry for the detection of human urine

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Received: 22 July 2010 / Revised: 18 August 2010 / Accepted: 18 August 2010 / Published online: 5 September 2010
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Abstract The aim of the present study was to evaluate the suitability of ion mobility spectrometry (IMS) for the detection of human urine as an indication of human presence during urban search and rescue operations in collapsed buildings. To this end, IMS with a radioactive ionization source and a multicapillary column was used to detect volatile organic compounds (VOCs) emitted from human urine. A study involving a group of 30 healthy volunteers resulted in the selection of seven volatile species, namely acetone, propanal, 3-methyl-2-butanone, 2-methylpropanal, 4-heptanone, 2-heptanone and octanal, which were detected in all samples. Additionally, a preliminary study on the permeation of urine volatiles through the materials surrounding the voids of collapsed buildings was performed. In this study, quartz sand was used as a representative imitating material. Four compounds, namely 3-methyl-2-butanoine, octanal, acetone and 2-heptanone, were found to permeate through the sand layers during all experiments. Moreover, their permeation times were the shortest. Although IMS can be considered as a potential technique suitable for the detection, localization and monitoring of VOCs evolved from human urine, further investigation is necessary prior to selecting field chemical methods for the early location of trapped victims.

Keywords Ion mobility spectrometry · Volatile organic compounds · Urine markers · Location of trapped victims · Urban search and rescue operations

Introduction

The early location of victims trapped in collapsed buildings is of particular importance for rescue teams after natural or man-made disasters. Currently, the use of canines is the method of choice in urban search and rescue operations [1]. Canines exhibit excellent scenting skills and are able to search relatively large areas in a short period of time. However, search dogs have a number of limitations: the information they provide must be correctly interpreted, their training is time-consuming and expensive and their working time is relatively short. Moreover, at the disaster scene canines can become temperamental, stressed and even frustrated when scenting dead victims [2]. Therefore, a demand exists for novel technical search tools which could complement or even replace their work.
In this context, knowledge of the human scent profile and its interaction with the disaster environment is crucial. Volatile markers of trapped victims can be released from different biological fluids (urine, blood, sweat) or tissues (skin or lungs). Their emission can be influenced by the medical status of the victim prior to and after collapse and the time for which they have been trapped. The resulting human scent may be modified by numerous interactions with the environment. In addition, the concentrations of species specific for human scent are extremely low, thus making their identification a challenging task.

Urine can be an important source of volatile markers of trapped persons. However, relatively few studies have investigated the profile of volatile organic compounds (VOCs) released spontaneously by non-modified human urine [3–5]. Volatile species emitted by human urine belong to numerous classes, such as hydrocarbons, aldehydes, ketones, furans, pyroles, terpenes, sulfur-containing compounds and heterocyclic compounds. In a recent study, a set of 33 volatile markers that are omnipresent in human urine released spontaneously at human body temperature were detected and identified using solid-phase microextraction (SPME) and gas chromatography coupled with mass spectrometry (GC-MS) [3]. This set of species can be considered as an initial library to be used for detection of human urine.

For the detection, localization and monitoring of these VOCs in the field, portable, highly sensitive and selective instruments providing a relatively short response time need to be used. Ion mobility spectrometry (IMS) seems to meet these requirements. Currently, the IMS technique is used in biological analyses [6, 7], medical diagnostics [8–12] and food quality measurements [13, 14]. The IMS devices can be quite small and held in the hand. Portable IMS instruments are commonly used for the detection of chemical warfare agents and illegal drugs [15–17].

IMS consists of an ionization chamber, an ion-molecule injection shutter, an ion drift tube and an ion collector (Faraday plate) [8]. Different methods are used to ionize gas; usually radioactive sources such as $^{63}$Ni are employed [8, 10]. An alternative way is the UV light [18, 19]. A carrier gas, usually air or nitrogen, introduces analyte molecules into the ion source where they undergo ionization. Afterwards, the ions are injected by opening an ion shutter into the drift region and separated according to ion mobility differences [8].

IMS is often coupled with standard gas chromatographic columns [18] or multicapillary columns (MCC) [8] for enhancing the separation of analysis. MCC characterize comparatively high flow rate and high sample capacity in comparison to single narrow columns [8].

The main goals of this study were firstly the evaluation of the suitability of the IMS technique for the detection of human urine emitted VOCs with or without permeation through quartz sand imitating trapment materials and secondly the selection of the most promising volatile urine markers which could be detected with this technique.

Experimental

Instrumentation

An ion mobility spectrometer (ISAS-Institute for Analytical Sciences, Dortmund, Germany) with a radioactive ionization source ($^{63}$Ni) was applied for urine analysis. The principal parameters for the IMS are summarized in Table 1.

The device was equipped with a 20-cm-long polar multicapillary column (MCC; OV-5, Sibertech, Novosibirsk, Russia). The MCC consists of approximately 1,200 capillaries, with an inner diameter of 40 $\mu$m and a film thickness of 0.2 $\mu$m coupled to the $^{63}$Ni-IMS system. The flow rate of the carrier gas was 100 mL/min. Separation of analytes was performed isothermally at 30 °C. Gas samples were injected using a 10-mL sample loop installed on the six-way valve.

Each final ion mobility spectrum was an average of five measurements recorded for 100 ms with a frequency of 25,000 samples per second. Such a setting provided two ion mobility spectra per second of analysis. Further details on the IMS system applied are given elsewhere [20–22].

Chemicals and standards

Identification parameters (drift times and retention times) were obtained on the basis of calibration mixtures prepared from pure compounds. An effort was made to prepare a separate standard for each compound. Primary standards

| Parameter                  | MCC–$^{63}$Ni–IMS |
|----------------------------|-------------------|
| Ionization source          | $^{63}$Ni (550 MBq) |
| Length of the drift tube   | 120 mm            |
| Electrical field strength  | 333 V/cm          |
| Drift voltage              | 4 kV              |
| Shutter opening time       | 300 $\mu$s        |
| Drift gas                  | $N_2$ (99.9999%)  |
| Drift gas flow             | 100 mL/min        |
| Temperature (IMS)          | 23 °C (ambient)   |
| Pressure                   | 950 hPa (ambient) |
| Stationary phase of the MCC| OV-5 (polar)      |
| Temperature (MCC)          | 30 °C             |
were prepared in a 1-L glass gas bulb (Supelco, Canada). Prior to use, the bulb was thoroughly cleaned with methanol and dried at 70 °C for at least 12 h. Afterwards, it was purged with pure nitrogen (99.9999%) for 20 min. Then, the bulb was evacuated using a vacuum pump and approximately 1 μL of pure compound was injected through a rubber septum. After the evaporation of the compound, the bulb was balanced with nitrogen. The final standard was prepared by transferring an appropriate volume of primary standard into a 3-L Tedlar bag (SKC, USA) filled with 1 L of pure nitrogen. The final concentrations of the analytes under study in secondary standards ranged from 20 to 80 ppb. A number of standards were purchased from Sigma-Aldrich (Vienna, Austria); 2-heptanone (98%), 2-methyl-1-propanal (99%), 3-hexanone (98%), 3-methyl-2-pentanone (99%), dimethyl disulfide (99%), ethyl acetate (99.9%), furan (99%), hexanal (98%), methyl acetate (99.5%), pentanal (97%) and toluene (99.8%). 2-Butanone (99.5%), 2-methylbutanal (99%), 2-pentanone (99%), 3-methyl-2-butanoate (98.5%), 4-methyl-2-pentanone (99.7%), dimethyl sulfide (99%), dimethyl sulfoxide (98%) and isoprene (99.5%) were obtained from Fluka (Sigma-Aldrich, Vienna, Austria). Moreover, 2-methyl-2-butenal (96%), 3-penten-2-one (better than 70%) and dimethyl trisulfide (98%) were provided by SAFC (Vienna, Austria), 3-methylfuran (98%), 4-heptanone (98%) and propanal (97%) were provided by Acros Organics (Fisher Scientific, Vienna, Austria), acetone (99.5%) by was provided by Merck (Merck, Vienna, Austria) and 1,2,3-trimethylbenzene (98%) was purchased from ChemSampCo (Vienna, Austria).

**Urine sampling**

The urine collection was approved by the Ethics Commission of Innsbruck Medical University. Volunteers’ urine was collected in three 10-mL plastic urine monovette vessels (Sarstedt, Germany), immediately after the volunteers had urinated. Prior to their use, urine monovettes were rinsed for 4 h with purified air at 50 °C to reduce possible contaminant emission during transport and storage. An effort was made to limit the urine storage in the urine monovettes to 3 h. Two types of urine were sampled: morning urine, which is expected to exhibit higher VOCs levels as it is more concentrated (particularly when the subject is dehydrated), and spontaneous urine.

**Detection of VOCs in the headspace of human urine**

To investigate the possible interaction (e.g. overlapping, signal suppressing) between evolved urine VOCs, a series of measurements of the urine headspace was performed. They were accomplished using 1-L glass flasks. The flasks were thoroughly cleaned prior to the experiment and flushed with pure nitrogen to remove contaminants. Afterwards, 2 mL of urine sample was transferred from the monovette into the flask. The temperature of the glass flask was maintained at 36–37 °C to investigate the emission of VOCs at human body temperature. After 5 min, 10 mL of the headspace gas was introduced into the sample loop and analysed by MCC/IMS. Each measurement was repeated three times.

**Detection of VOCs permeating through debris material**

In the ruins of collapsed buildings, volatiles are carried out by air currents and spread as plumes throughout the rubble; these plumes are either constant or transient. Consequently, interactions of VOCs with the debris materials (e.g. dust, wood, plastic, glass) are expected to significantly modify the urine scent. In this context, the permeative properties of urine markers have a crucial influence on the success of the search and rescue operation. A preliminary study on this aspect was done with a filling chamber as presented in

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**Table 2** Demographic data of volunteers

|                     | Male | Female |
|---------------------|------|--------|
| Number of volunteers| 20   | 10     |
| Mean age (range) (years) | 34 (22–53) | 27 (23–29) |
| Number of smokers   | 2    | 2      |
| Urine type           |      |        |
| Morning urine        | 12   | 9      |
| Spontaneous urine    | 7    | 2      |

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**Fig. 1** The filling chamber. **IMS** ion mobility spectrometer
| Name                        | CAS no.     | Proton affinity (kJ/mol) | Peak | Retention time (s) | Reduced ion mobility (cm²/Vs) |
|-----------------------------|-------------|--------------------------|------|--------------------|-------------------------------|
| 1,2,3-Trimethylbenzene      | 526-73-8    | no data                  | I    | 41.4               | 1.77                          |
| 2-Butanone                  | 78-93-3     | 827.3                    | I    | 5.5                | 1.87                          |
|                             |             |                          | II   | 5.6                | 1.61                          |
| 2-Heptanone                 | 110-43-0    | No data                  | I    | 19.1               | 1.57                          |
|                             |             |                          | II   | 19.1               | 1.47                          |
|                             |             |                          | III  | 19.1               | 1.23                          |
| 2-Methyl-1-propanal         | 78-84-2     | 797.3                    | I    | 6                  | 1.74                          |
|                             |             |                          | II   | 6                  | 1.66                          |
| 2-Methyl-2-butenal          | 1115-11-3   | 843.7                    | I    | 8                  | 1.81                          |
|                             |             |                          | II   | 8                  | 1.48                          |
| 2-Methylbutanal             | 96-17-3     | No data                  | I    | 7                  | 1.66                          |
| 2-Pentanone                 | 107-87-9    | 832.7                    | I    | 8                  | 1.77                          |
|                             |             |                          | II   | 8                  | 1.58                          |
|                             |             |                          | III  | 11.3               | 1.46                          |
| 3-Hexanone                  | 589-38-8    | 843.2                    | I    | 9                  | 1.71                          |
|                             |             |                          | II   | 8                  | 1.44                          |
|                             |             |                          | III  | 9                  | 1.38                          |
| 3-Methyl-2-butanone         | 563-80-4    | 836.3                    | I    | 5                  | 1.8                           |
|                             |             |                          | II   | 5                  | 1.65                          |
|                             |             |                          | III  | 5.5                | 1.48                          |
| 3-Methyl-2-pentanone        | 565-61-7    | No data                  | I    | 8.3                | 1.69                          |
|                             |             |                          | II   | 8.3                | 1.35                          |
| 3-Methylfuran               | 930-27-8    | 854                      | I    | 9                  | 1.87                          |
|                             |             |                          | II   | 8.3                | 1.79                          |
|                             |             |                          | III  | 8.3                | 1.57                          |
|                             |             |                          | IV   | 8.3                | 1.45                          |
| 3-Penten-2-one              | 625-33-2    | 864.7                    | I    | 8                  | 1.71                          |
|                             |             |                          | II   | 8                  | 1.44                          |
|                             |             |                          | III  | 8.9                | 1.38                          |
| 4-Heptanone                 | 123-19-3    | 845                      | I    | 15.6               | 1.62                          |
|                             |             |                          | II   | 18                 | 1.48                          |
|                             |             |                          | III  | 14.5               | 1.27                          |
| 4-Methyl-2-pentanone        | 108-10-1    | No data                  | I    | 8.9                | 1.7                           |
|                             |             |                          | II   | 6.7                | 1.55                          |
|                             |             |                          | III  | 7.8                | 1.36                          |
| Acetone                     | 67-64-1     | 812                      | I    | 5.6                | 1.78                          |
| Allylthiocyanate            | 57-06-7     | No data                  | Not measured |
| Dimethyl disulfide          | 624-92-0    | 815.3                    | In RIP area |
| Dimethyl sulfide            | 75-18-3     | 830.9                    | In RIP area |
| Dimethyl sulfone            | 67-71-0     | No data                  | In RIP area |
| Dimethyl trisulfide         | 3658-80-8   | No data                  | In RIP area |
| Ethyl acetate               | 141-78-6    | 835.7                    | I    | 6.6                | 1.49                          |
| Furan                       | 110-00-9    | 812                      | Not detected |
| Hexanal                     | 66-25-1     | No data                  | I    | 8.5                | 1.56                          |
|                             |             |                          | II   | 10                 | 1.29                          |
| Isoprene                    | 78-79-5     | 826.4                    | I    | 44.2               | 1.65                          |
|                             |             |                          | II   | 44.2               | 1.53                          |
| Isothiocyanocyclohexane     | 1122-82-3   | No data                  | Not measured |
Fig. 1. The chamber consists of a stainless steel cylinder with an open upper end having an internal diameter of 102 mm and a height of 81 mm. Steel gauze (mesh size 1 mm) divides the chamber into two parts (each 40 mm high). The top part was loosely packed with mimicking debris quartz sand (Euroquarz, Germany) having a bulk density of 1.6 g/cm³ and a particle of density 2.65 g/cm³. Three sizes of grain were tested: 0.5–1 mm, 1–2 mm and 4–8 mm. In the wall of the bottom part, an additional rubber septum (Supelco, Canada) was installed. The

| Name             | CAS no. | Proton affinity (kJ/mol) | Peak | Retention time (s) | Reduced ion mobility (cm²/Vs) |
|------------------|---------|--------------------------|------|--------------------|-------------------------------|
| Methanethiol     | 74-93-1 | 773.4                    |      | Not detected       |                               |
| Methyl acetate   | 79-20-9 | 821.6                    | I    | 6.1                | 1.68                          |
| N-Methylpyrrole  | 96-54-8 | No data                  |      | Not measured       |                               |
| Octanal          | 124-13-0| No data                  | I    | 43                 | 1.4                           |
|                  |         |                          |      |                    |                               |
|                  |         |                          |      |                    |                               |
| Pentanal         | 110-62-3| 796.6                    | I    | 6.7                | 1.64                          |
|                  |         |                          |      |                    |                               |
| Propanal         | 123-38-6| 786                      | I    | 1.1                | 1.75                          |
|                  |         |                          |      |                    |                               |
| Pyrrole          | 109-97-7| 875.4                    | I    | 45.5               | 1.21                          |
| Toluene          | 108-88-3| 784                      |      | Not detected       |                               |

Table 4 VOCs identified in the headspace of human urine

| Compound                  | Male | Female |
|---------------------------|------|--------|
|                           | Morning urine (12 samples) | Spontaneous urine (7 samples) | Morning urine (9 samples) | Spontaneous urine (2 samples) |
| Acetone                   | I 12 | 7      | 9      | 2         |
| Propanal                  | I 12 | 7      | 9      | 2         |
| 3-Methyl-2-butanone       | I 12 | 7      | 9      | 2         |
| 2-Methylpropanal          | I 12 | 7      | 9      | 2         |
| Pentanal                  | I 10 | 2      | 2      | 1         |
|                           | II 8 | 3      | 3      | 2         |
| 2-Pentanone               | I 2  | 3      | 4      | 1         |
|                           | II 10| 6      | 7      | 2         |
| 2-Butanone                | I 5  | 2      | 2      | 1         |
| 3-Penten-2-one            | I 9  | 5      | 5      | 1         |
|                           | II 11| 6      | 7      | 2         |
| Hexanal                   | I 10 | 7      | 8      | 2         |
| 4-Heptanone               | I 12 | 7      | 9      | 2         |
|                           | II 12| 7      | 9      | 2         |
|                           | III 12| 7     | 9      | 2         |
| 2-Heptanone               | I 12 | 7      | 9      | 2         |
| 1,2,3-Trimethylbenzene    | I 6  | 5      | 8      | 2         |
| Isoprene                  | I 8  | 2      | 3      | 0         |
|                           | II 5 | 5      | 5      | 1         |
| Octanal                   | I 12 | 7      | 9      | 2         |
bottom of the filling chamber was kept at 30–31 °C. At the onset of the experiment, 1 mL of urine sample was injected through the septum. Permeation of VOCs through the quartz sand was studied by the MCC/IMS analyses of the headspace samples taken approximately 1 cm above the sand layer in the direction of the central axis of the chamber. The time instants for drawing the samples were defined as follows: one sample was taken before the urine injection; the next ones were drawn every 10 min for 180 min. For each size of grain, five experiments with urine of different volunteers were performed.

Human subjects

A cohort of 30 healthy normal volunteers (20 males, 10 females) was recruited. All subjects gave informed consent to participate and completed a questionnaire describing their food and drug intake, health status, smoking status, etc. None of volunteers had urological diseases. Demographic data for the volunteers are presented in Table 2.

Results and discussion

Identification parameters

In a recent study, a set of 33 potential volatile urine markers released from unmodified human urine at human body temperature using SPME-GC-MS was identified [3]. The markers within this group were omnipresent in human urine with incidence higher than 80%. Consequently, the present study focused on the identification of VOCs from this group. The identification parameters—retention times and reduced ion mobilities—are presented in Table 3. The identification parameters for allylisothiocyanate, isothiocyanocyclohexane and N-methylpyrrole were not estimated owing to the lack of pure substances. Peaks for sulfur-containing compounds, namely dimethyl trisulfide, dimethyl sulfone, dimethyl sulfide and dimethyl disulfide, overlapped with the reactant ion peak. Consequently, these compounds could not be measured with the MCC/IMS system. However, under favourable conditions signals for these compounds could be extracted from the reactant ion peak using sophisticated algorithms. Furan, toluene and methanethiol were not detected. Finally, the original set of 33 potential urine markers was constrained to 23 compounds detectable with the IMS instrument. This set of VOCs served as a basic marker library for further investigations.

Detection of VOCs in the headspace of human urine

The compounds identified in the headspace of urine samples are presented in Table 4 together with their incidence. The compound was considered as detected if it was found at least two times out of three in the volunteer’s urine. Urine of 30 volunteers was analysed: 21 morning urine samples and nine spontaneous urine samples. An exemplary two-dimensional IMS chromatogram of human’s urine is shown in Fig. 2. Fourteen compounds were identified in the urine samples. Seven of them, namely

| Grain size (mm) | No. | Quartz mass (g) | Relative humidity (%) | Temperature (°C) |
|----------------|-----|----------------|-----------------------|------------------|
| 0.5–1          | 1   | 500.0          | 28.9                  | 23.9             |
|                | 2   | 500.0          | 23.4                  | 23.9             |
|                | 3   | 500.0          | 26.3                  | 24.0             |
|                | 4   | 500.3          | 22.0                  | 24.2             |
|                | 5   | 500.0          | 25.3                  | 24.2             |
| 1–2            | 1   | 498.3          | 28.9                  | 22.9             |
|                | 2   | 503.6          | 22.3                  | 23.4             |
|                | 3   | 505.3          | 25.1                  | 22.8             |
|                | 4   | 500.0          | 23.8                  | 23.0             |
|                | 5   | 500.0          | 24.4                  | 23.4             |
| 4–8            | 1   | 503.9          | 20.8                  | 22.6             |
|                | 2   | 503.0          | 23.5                  | 22.6             |
|                | 3   | 501.3          | 26.9                  | 22.8             |
|                | 4   | 500.2          | 25.1                  | 23.3             |
|                | 5   | 500.0          | 21.7                  | 23.8             |
acetone, propanal, 3-methyl-2-butanone, 2-methylpropanal, 4-heptanone, 2-heptanone and octanal, were found in all samples. A further two, hexanal and 2-pentanone, were detected in at least 80% of samples. No significant differences between the morning urine and the spontaneous urine were observed.

Identification of compounds which pass through rubble

In this experiment, the quartz sand was exposed to VOCs released by unmodified human urine. The mass of quartz, the air temperature and the humidity during the experiments are summarized in Table 5. The VOCs detected in the chamber headspace are listed in Table 6 together with their permeation times. The experimental conditions were comparable. Relative humidity ranged from 20.8 to 28.9% (median 24.4%), whereas ambient temperature was between 22.6 and 24.2 °C (median 23.4 °C). Eleven compounds were identified in the air above the quartz layer during the 3-h-long experiments. Ketones were represented by acetone, 3-methyl-2-butanone, 2-heptanone and 4-heptanone. Another well-represented class was aldehydes, also with four representatives: propanal, 2-methylpropanal, hexanal and octanal. Within the remaining species there was one aliphatic hydrocarbon (isoprene), one aromatic hydrocarbon (1,2,3-trimethylbenzene) and one heterocyclic compound (pyrrole). Interestingly, pyrrole, which was not detected in the headspace of urine samples, was found to permeate through the quartz layer. This observation could be explained by a suppression of the pyrrole signal in the IMS owing to the presence of other VOCs with significantly higher proton affinities and a similar retention time. Two compounds, namely 3-methyl-2-butanoate and octanal, were detected during all experiments, and a further two, acetone and 2-heptanone, were detected in all samples but one. The shortest

| Compound          | Grain size (mm) |
|-------------------|-----------------|
|                   | 0.5–1 | 1–2   | 4–8  |
|                   | 0     | 1     | 2    | 3    | 4    | 5    | 0     | 1     | 2     | 3    | 4    | 5    |
| Acetone           | 40    | 40    | 40   | 40   | 40   | 30   | 30   | 30   | 30   | 30   | 20   | 20   | 20   | 70   | -    |
| Propanal          | 40    | -     | -    | -    | 40   | 30   | 30   | -    | -    | 30   | 40   | -    | -    | -    | -    |
| 3-Methyl-2-butanone| 40    | 40    | 40   | 40   | 40   | 30   | 30   | 30   | 30   | 30   | 20   | 20   | 20   | 40   | 50   |
| 2-Methylpropanal  | 40    | 50    | 40   | 40   | 40   | 30   | 30   | 50   | 30   | -    | 40   | -    | -    | 70   | 110  |
| Hexanal           | -     | -     | -    | -    | 40   | -    | -    | 30   | 30   | -    | 30   | -    | -    | -    | -    |
| 4-Heptanone       | -     | -     | 130  | 110  | 70   | 70   | 70   | 60   | 60   | 60   | 60   | -    | -    | -    | -    |
| 2-Heptanone       | 130   | 90    | 80   | 90   | 40   | 80   | 90   | 80   | 70   | 70   | 50   | 50   | 80   | 110  |
| 1,2,3-Trimethylbenzene | -     | -     | -    | 170  | 100  | 90   | 100  | 90   | 100  | 70   | 70   | 10   | 150  | -    | -    |
| Isoprene          | 150   | -     | -    | 100  | 90   | -    | 110  | 100  | 90   | 100  | 70   | 70   | 10   | 170  | -    |
|                   | 150   | -     | -    | 100  | 50   | 60   | 90   | 100  | 60   | 60   | 70   | 70   | 10   | 150  | -    |
| Octanal           | 40    | 50    | 40   | 50   | 40   | 30   | 30   | 30   | 30   | 30   | 20   | 20   | 20   | 70   | 50   |
| Pyrrole           | -     | -     | -    | -    | 90   | 90   | 120  | 120  | 100  | 70   | 70   | 20   | -    | -    | -    |

* Spontaneous urine

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**Table 6** Compounds detected above the quartz sand layer together with their permeation times in minutes

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**Fig. 3** Three-dimensional view of an ion mobility spectrometry spectrum showing volatile compounds of human urine sample which had passed through the layer of quartz sand (1–2 mm)
permeation times were noted for acetone, propanal, 3-methyl-2-butane and octanal. 4-Heptanon, which is among the most abundant VOCs present in human urine [4, 5], was detected only in nine experiments. In general, the permeation times increased with the decrease of the quartz grain size. However, it must be remembered that the urine samples used during the experiments originated from different volunteers and the initial VOC concentrations were different. An exemplary three-dimensional IMS chromatogram of a human urine sample taken over the quartz sand is presented in Fig. 3.

Conclusion

The present study aimed at evaluating the suitability of IMS for the detection of human urine during rescue operations after earthquakes or other disasters. For this purpose, IMS with a β-radiation source (63Ni) and a MCC was applied. Twenty-three VOCs which are ubiquitous in human urine (according to previous SPME-GC-MS studies [3]) were detected with this technique. Fourteen compounds from this group were found in the headspace of human urine; however, only seven were omnipresent. Additionally, the IMS technique was used to study the permeation of urine vapour through the mimicking rubble quartz sand. Eleven compounds were found to permeate through the quartz layer. Within this group, four compounds, namely acetone, 3-methyl-2-butane, 2-heptanone and octanal, are of particular interest as they were commonly detected above the quartz layer exposed to the urine vapours and additionally exhibited the shortest permeation times. These compounds can be regarded as very promising markers of human urine.

Within this context, IMS can be considered as a potential technique suitable for the detection, localization and monitoring of VOCs evolved from human urine for the location of victims trapped in collapsed buildings. The main advantages of this technique are its good sensitivity (up to parts per trillion level), the short time of analysis and the potential for miniaturization. However, the trapped environment in collapsed buildings and especially in major disasters is extremely complicated and sometimes dominated by dust and smoke. Consequently, further investigation is necessary prior to selecting field chemical methods for the early location of trapped victims.

Acknowledgements

This work was supported by the Foundation for Polish Sciences (FNP) Professor’s Subsidy “Mistrz” and CEEPUS- II scholarship CII-PL-0004-05-0910-M-37834. The research leading to these results has received funding from the European Community’s Seventh Framework Programme (FP7/2007-13) under grant agreement no. 217967 (SGL for USAR project, Second Generation Locator for Urban Search and Rescue Operations, http://www.sgl-eu.org). We appreciate funding from the Austrian Federal Ministry for Transport, Innovation and Technology (BMVI/BMWA, project 818803, KIRAS). We greatly appreciate the generous support of the government of Vorarlberg and its governor Landeshauptmann Herbert Sausgruber.

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