Forensic Science International: Reports 4 (2021) 100221

Contents lists available at ScienceDirect

Forensic Science International: Reports

journal homepage: www.sciencedirect.com/journal/forensic-science-international-reports

General Forensics

Investigation of condom evidence in cases of sexual assault: Case studies

Céline Burnier [a,*], Maire Kelly [b], David DeTata [c], Kari Pitts [c]

[a] Ecole des Sciences Criminelles, University of Lausanne, Switzerland
[b] Sexual Assault Resource Centre, Women and Newborn Health Service, Subiaco, Western Australia, Australia
[c] Forensic Science Laboratory, ChemCentre WA, Bentley, Australia

ARTICLE INFO

Keywords:
Py-GC-MS
Silicone
Polyethylene glycol
Condom

ABSTRACT

Previous research has established analytical frameworks and discrimination models for the analysis of commercial silicone-based and water-based lubricants, but there has been no report of the application to casework. The analytical framework was first tested on two proficiency trials to validate the methodology on cotton swabs. Then two case samples, where condoms were suspected of having been used, were submitted to the laboratory for analysis. Examination of vaginal swabs for condom evidence was performed, independent of knowledge regarding the presence of seminal fluid or other sources of DNA. Pyrolysis-Gas Chromatography mass spectrometry (py-GC-MS) and Gas Chromatography mass spectrometry (GC-MS) were used to analyze the evidence and compare the chemical profiles obtained to published databases. The protocol was successfully used on two proficiency trials, one in which py-GC-MS chemical profiles were easily differentiated, and the second in which GC-MS was used to identify the source of the chemical profile on the recovered item. Although the application to casework samples was possible, challenges regarding the interpretation of the evidence were highlighted and need to be considered by forensic practitioners.

1. Introduction

When determining the possible prosecution of a sexual assault (rape) case, apart from the witness statements, the main evidence to be considered consists of the medical report, the results of DNA analysis and/or analysis of any physical trace evidence detected [1,2]. Since the 1980's, condom evidence has been investigated in forensic science as a new type of questioned evidence [3,4]. When no male DNA has been recovered from the forensic genito-anal swabs, the use of a condom by the perpetrator is one possible explanation. This may confirm or refute the victim's or suspect's allegations [4]. However, evidence of condom residue is often overlooked, and currently, there are no published or publicly available protocols optimized for condom trace collection for use by forensic nurses, police officers or forensic scientists. Routinely, samples for condom residue are collected by Clinical Forensic Physicians in the same way that DNA swabs are collected [2,5], and the forensic analysis usually involves GC-MS analysis [6–8] or other mass spectrometry techniques [9–14] that may not be readily available in most forensic laboratories. Nevertheless, these current protocols may be inadequate for the full analysis of this type of evidence.

ChemCentre (Perth, WA), in collaboration with the Sexual Assault Resource Centre (SARC) and the West Australian Police Force, has recently implemented advancements in the collection and analysis of this type of evidence. This procedure involves forensic clinicians, as well as police officers and forensic scientists, as they are all part of the forensic investigation. Recently, an analytical and statistical framework was developed, using py-GC-MS and GC-MS, for the analysis and classification of condom residues as well as lubricants and personal hygiene products [15,16]. The application of the method to known casework simulants in the form of proficiency trials is necessary to validate the framework, before proceeding to casework analysis. The implementation of this new framework in Western Australia has generated an increase in case numbers in which condom evidence is submitted and analyzed. Case samples were processed, and gaps that affect the interpretation of this type of evidence highlighted within the current framework.

This paper aims to present and address the challenges for the Clinical Forensic Physician and the Forensic Scientist from the point of condom evidence collection, through the analysis and the interpretation. Data from proficiency trials will be presented to ensure validation of the analytical framework. Then casework examples will illustrate different issues in terms of sample collection and sample analysis. Finally, the

* Correspondence to: Ecole des Sciences Criminelles, Quartier UNIL-Sorge, Bâtiment Batochime, CH-1015 Lausanne, Switzerland.
E-mail address: celine.burnier@unil.ch (C. Burnier).

https://doi.org/10.1016/j.fsir.2021.100221
Received 11 January 2021; Received in revised form 15 June 2021; Accepted 5 July 2021
Available online 8 July 2021

interpretation of the evidence will be discussed.

2. Cases summary

2.1. Proficiency trials

Before progressing to casework samples, the methodology presented in Refs. [15,16] was used to re-analyze previously analyzed proficiency tests. Two proficiency trials were used to validate the procedure, both purchased from Forensic Testing Services (Williamston, USA). The sets of samples typically contain one recovered cotton swab (questioned), one blank cotton swab and three potential source control samples (controls), which can be from either lubricants or condoms.

The first proficiency test provided 1 condom and 2 lubricants samples that were potential sources of the chemical profile observed from the recovered swab. A blank swab was provided for control.

The second proficiency test provided 3 condoms samples that could be potential source/s of the chemical profile observed from the recovered swab. A blank control swab was provided.

2.2. Case 1

Non-consensual penile-vaginal penetration was alleged. The assailant wore a condom, which was not recovered. It is unknown whether the suspect ejaculated inside the condom or intravaginally without a condom. The complainant and suspect were known to each other, had not had prior consensual sexual contact and were not in a domestic relationship at the time. A high vaginal swab only was submitted for analysis. A blank cotton swab was used as a control to ensure the absence of contamination.

2.3. Case 2

The victim and the suspect had consumed alcohol together and wandered away from other people present. The suspect allegedly physically assaulted the female severely and threatened to kill and rape her. The victim escaped and soon afterwards was conveyed to hospital by a family member. There, attending police officers discovered and seized a used condom with visible blood in the victim's jacket pocket. It was not reported if the blood was on the inside or the outside of the condom. The victim had no memory of a sexual assault, as she had lost consciousness at times during the physical assault. A high vaginal swab only was submitted for analysis. A blank cotton swab was used as a control to ensure the absence of contamination.

3. Material and methods

3.1. Chemicals

Hexane (AR grade, Sigma Aldrich, USA) was used as a solvent. Pyrolysis sample holders were Eco-Cups SF and Eco-Sticks SF purchased from Frontier Laboratories.

Methanol (Optima® LC-MS AR grade, Fisher Chemical) and diphenylmethane (99% Sigma-Aldrich) were used as the solvent and internal standard respectively. A solution of 0.1% diphenylmethane in methanol was prepared as the extraction solvent.

3.2. Preparation of samples for analysis

For py-GC-MS analysis, the cotton swabs were individually removed from the swabs with a disposable scalpel. The cotton swab was then placed into a disposable glass vial, soaked in 1 mL hexane and then placed in an ultrasonic bath for 15 min. The batch blank cotton swab was extracted in the same manner to obtain the matrix chemical profile. Thus, non-pertinent peaks were determined. Extracts were stored at less than 4 °C until analysis. Samples were evaporated to dryness using nitrogen. The residues were then dissolved in 100 µL hexane. For each Py-GC-MS sample, 10 µL of the hexane solution was spiked in stainless-steel cups and left to evaporate prior to analysis.

For GC-MS analysis, the recovered cotton swabs were dried and re-extracted using methanol with 0.1% diphenylmethane as an internal standard (IS). 10 µL of the extraction solution was then injected in the instrument for analysis.

3.3. Instrumental conditions

3.3.1. Pyrolysis-GC-MS

Analyses were carried out using an isothermal oven Frontier Lab py-3030S single shot pyrolyzer device coupled to an Agilent GC 7890B system, interfaced with an Agilent 5977N mass spectrum detector. Software used were respectively Py3030S Control (v. 1.77) from Frontier Laboratories and ChemStation v. F.01.03.2357 from Agilent. Pyrolysis was undertaken at 720 °C for 20 s, under an inert atmosphere with helium as a carrier gas [15].

Separation was achieved on an HP-5MS capillary column (30 m × 0.25 mm × 0.25 µm) using helium as a carrier gas, at a flow rate of 1 mL/min. Injections were carried out in splitless mode, the injector temperature being set at 280 °C. The chromatographic program was as follows: held at 50 °C for 2 min, increased at 10 °C/min to 230 °C, then 20 °C/min to 300 °C, then held for 5 min at 300 °C, making a total acquisition time of approximately 29 min. Considering mass spectral detection, the transfer line was set at 250 °C, the ion source at 230 °C and the quadrupole at 150 °C. Data were acquired in full scan mode (30–550 *m/z*), with a sampling rate of 3.

3.3.2. GC-MS

Analysis was carried out on an Agilent GC 7890B system, interfaced with an Agilent 5977N mass spectrum detector, utilizing Agilent ChemStation v. F.01.03.2357. Separation was achieved on an HP-5MS capillary column (30 m × 0.25 mm × 0.25 µm) using helium as a carrier gas, at a flow rate of 1 mL/min. Injections were carried out in splitless mode, the injector temperature being set at 280 °C. The chromatographic program was as follows: held at 50 °C for 2 min, then ramped at 10 °C/min to 230 °C and 20 °C/min to 300 °C, and a final hold for 5 min at 300 °C (total run time 28.5 min). For mass spectral detection, the transfer line was set at 250 °C, the ion source at 230 °C and the quadrupole at 150 °C. Data was acquired in full scan mode (30–550 *m/z*), with a sampling rate of 3 [16].

3.4. Data processing

3.4.1. Qualitative analysis

Identification of the compounds was undertaken using three different mass spectral databases; NIST18 (*National Institute of Standards and Technology*), PP (*Pyrolysis Products*, in-house pyrolysis library) [17–19] and TOX3 (*Wiley Drug and Pesticides, Wiley138*), as well as comparison with retention time and mass spectra obtained from the analysis of bulk PDMS, and published literature. Only peaks over a threshold value of 30,000A.U were selected.

3.4.2. Semi-quantitative analysis

Using Agilent ChemStation® software, areas of the target ions within all the acquired pyrograms were integrated for each peak. Data were exported to Microsoft Excel, normalized to the area sum, and the double square root calculated, prior to multivariate statistical processing. Data were projected in existing models as presented in Refs. [15,16].

4. Results and discussion

4.1. Preliminary considerations

Condoms provided for the proficiency trials were found to be

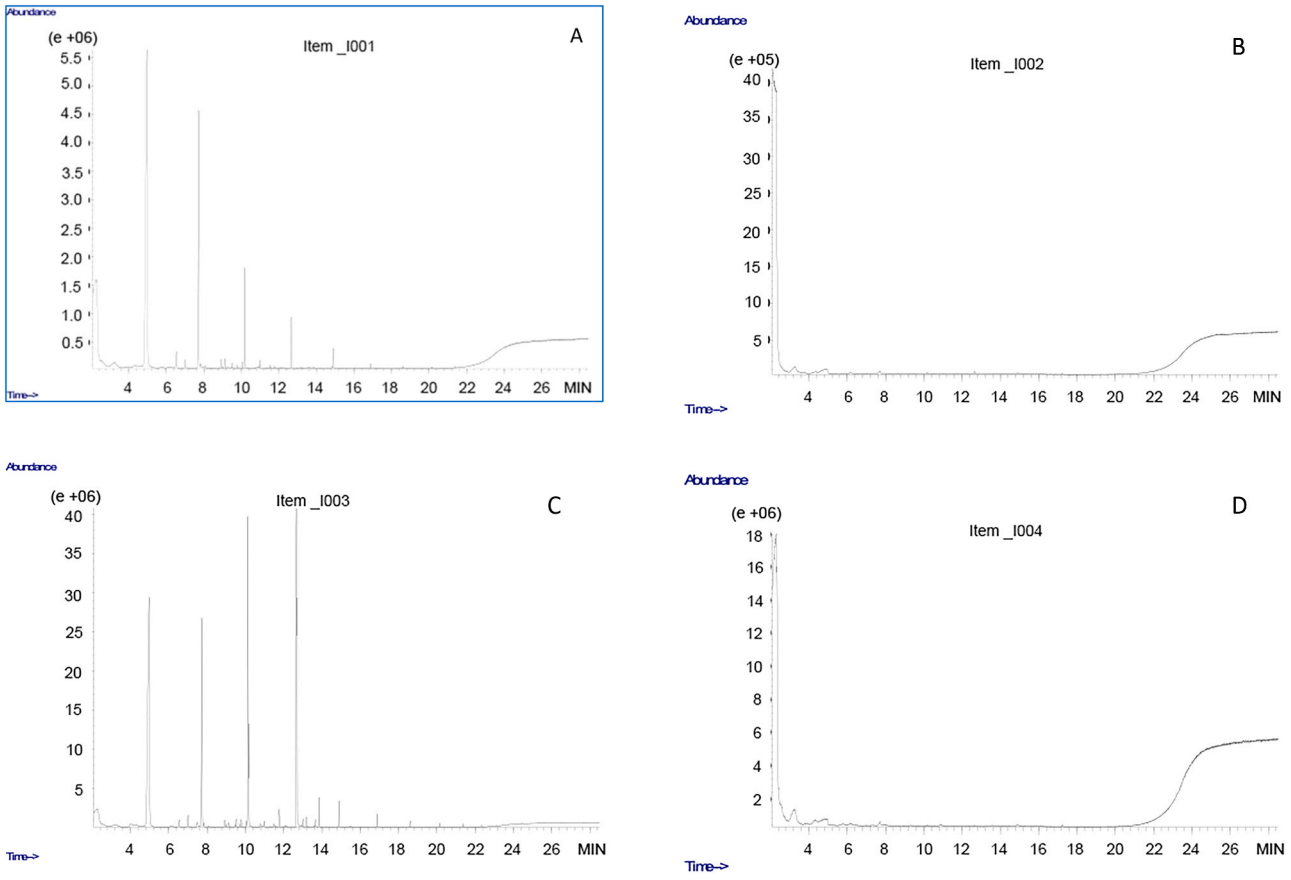

Fig. 1. Chemical profiles obtained for the questioned sample (in blue) and the comparison samples – py-GC-MS analysis. A) pyrogram of item I001(questioned swab) extract; B) pyrogram of item I002 Sliquid Organics® lubricant; C) pyrogram of item I003 Astroglide X lubricant; D) pyrogram of item I004 Lifestyles Warm Lovin lubricant. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

exclusive to the American market. Therefore, their profiles were not included in the database, which was based on products commercially available on Australian, New Zealand and Swiss markets. However, the samples were projected in the discrimination model and were found to cluster with the samples that contain silicone. Therefore, there do not seem to be major differences between condom samples that come from different markets and countries.

Another important consideration is the fact that some samples, more specifically the cotton swabs, were previously extracted using dichloromethane (DCM) as part of the previously used methodology. There was no indication whether only one or both cotton swabs had been used for the extraction. Only one of the swabs was used for hexane extraction, the other being reserved for methanol extraction if needed. Hexane extraction was thought to be possible as Maynard et al. showed that DCM extractions were incomplete [20], suggesting that residues could still be present on the swabs. Chemical profiles were obtained from these hexane extracts, confirming previous observations. A solvent blank was also analyzed to ensure that there was no contamination.

4.2. Proficiency trials results

4.2.1. Proficiency I

This proficiency test provided 1 condom (I003) and 2 lubricants (I002 and I004) that were potential sources of the chemical profile observed from the recovered swab (item I001). Item I005 was a blank swab provided for control.

From a qualitative point of view, pyrograms obtained from item I001 (recovered swab) presented at least 6 visible peaks characteristic of siloxane degradation (Fig. 1A). Degradation of siloxane patterns including D3-D7 oligomers was observed. Pyrograms resulting from items I002 and I004 did not present any relevant chemical patterns. These observations suggest that neither items contained any silicones and GC-MS analysis would be recommended to evaluate the profile of the samples (Fig. 1B and D). The pyrogram obtained from item I003 presented at least 6 visible peaks characteristic of siloxane degradation (Fig. 1C). Degradation of siloxane patterns including D3-D7 oligomers was observed. The pyrogram obtained from item I005 did not present any pattern. The pyrogram obtained for the blank swab is provided in Supplementary information.

Based on these observations, samples can be compared to each other to assess, which of the collected items is a potential source of the profile observed on item I001. These comparisons indicated the following:

- Comparison of the pyrograms obtained from items I001 and I005 showed that all the peaks observed in the profile of item I001 come from the trace, and not from the cotton swab itself.
- Comparison of the pyrograms of I001 and I002 showed visually different chemical profiles. Extraction of target ions confirmed the observations. It can be stated that Item I002 is not the source of the chemical profile observed from I001.
- Comparison of the pyrograms of I001 and I003 showed visually consistent chemical profiles. The number of peaks and their position was not differentiated. Extraction of target ions showed indistinguishable patterns.
- Comparison of the pyrograms of I001 and I004 showed visually different chemical profiles. Extraction of target ions confirmed the observations. It can be stated that Item I004 is not the source of the chemical profile observed from I001.

From a semi-quantitative point of view, projection of the results in

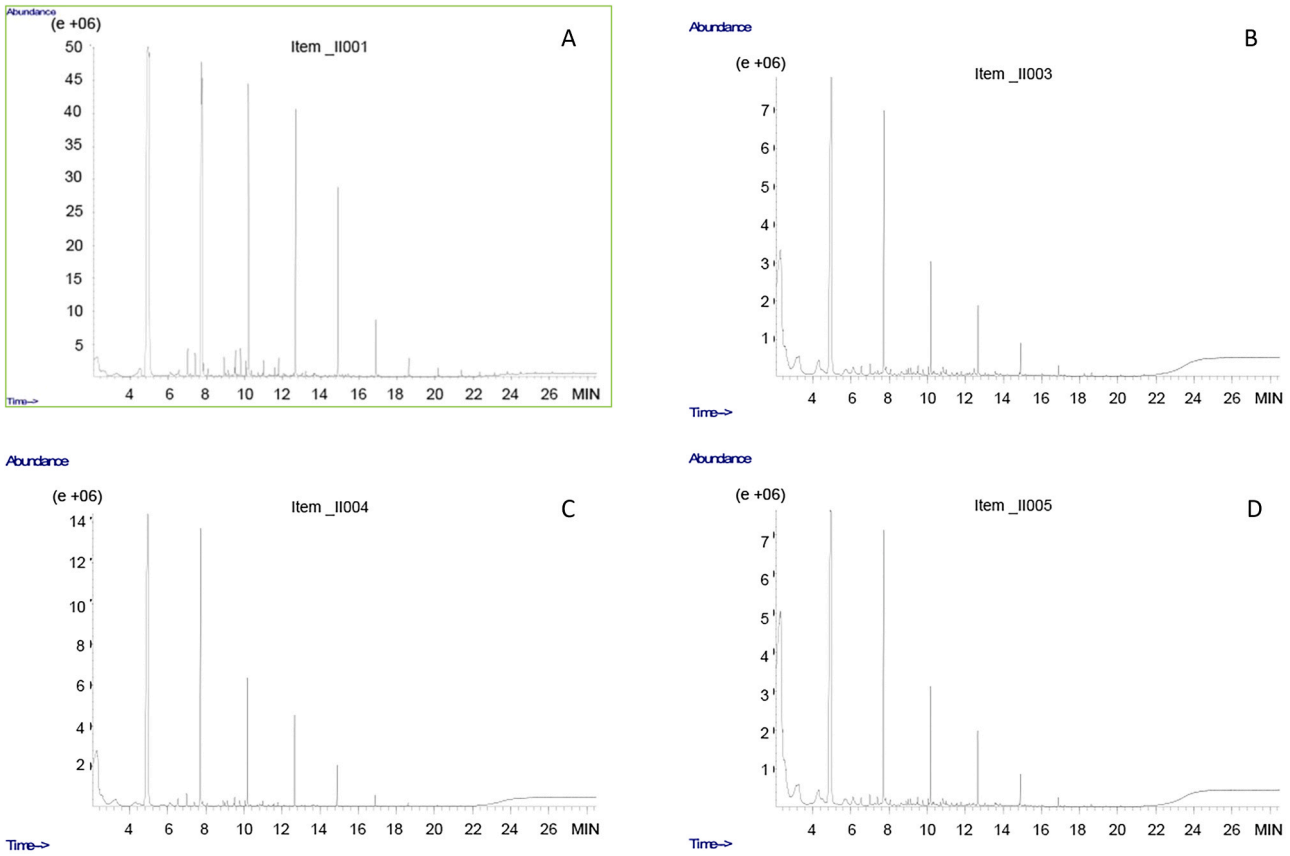

Fig. 2. Chemical Profiles obtained for the questioned sample (in green) and the comparison samples – py-GC-MS analysis. A) pyrogram of item II001(questioned swab) extract; B) pyrogram of item II003 Durex Intense Sensation latex condom; C) pyrogram of item II004 LifeStyles Ultra Sensitive latex condom; D) pyrogram of item II005 Trojan Ultrathin Lubricated latex condom. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

the discrimination model built for py-GC-MS [15] (see Supplementary material) outlined that items I001 and I003 were clustered together, whereas items I002 and I004 clustered together but strongly distinguished from the other samples (see Supplementary material). Therefore, based on the visual and statistical observation of the results, it appears more likely that item I003 is the source of the chemical profile observed from I001. I002 and I004 can be excluded as sources of the chemical profile. This evidence makes it more likely that item I003 is the source of the chemical profile observed from I001, rather than if item I002 or item I004 are the source of the chemical profile observed.

The manufacturer-supplied result of the proficiency test was that the questioned swabs (Fisherbrand Cotton-Tipped Swabs) from Item 1 were prepared by sampling a package of Astroglide X brand lubricant directly with the swabs. The swabs were then sealed in capped test tubes (BD Falcon 5 mL polystyrene round-bottom tubes) for shipping. Item 2 and Item 4 were correctly eliminated as a source for Item 1. Item 3 was correctly identified as a source for Item 1.

4.2.2. Proficiency II

This proficiency test provided 3 condoms that could be potential source/s of the chemical profile observed from item II001.

From the qualitative point of view, pyrograms obtained from Item II001 (Fig. 2A) presented at least 8 visible peaks characteristic of siloxane degradation. Significant peaks were also observed after 18 min. Siloxane pattern D3-D10 was visible in the pyrograms. The pyrogram obtained from Item II002 (Blank swab) did not present any pattern (See Supplementary information).

The pyrograms obtained from items II003 (Fig. 2B), II004 (Fig. 2C) and II005 (Fig. 2D) presented at least 8 peaks characteristic of siloxane degradation. II003 also presented small peaks in the region after 18 min. No significant peaks were noted in the region 14–28 min for II004 and II005. Siloxane pattern D3-D10 as reported in Ref. [15] was visible in the pyrograms for all samples.

Comparison of the pyrograms obtained from item II001 and II002 determined that all the peaks observed in the profile of sample II001 come from the trace to be investigated, and not from the cotton swab itself.

As items II003, II004 and II005 were all condoms, the first step was to see if the items could be qualitatively differentiated by assessing the three chromatograms acquired using py-GC-MS. No visual differences in terms of siloxane pattern were observed with D3 – D10 detected in any of the items. Small variations within the chromatographic content was observed on item II003, compared to the other two items, as it presented different minor compounds, especially at the end of the chromatograms.

These observations illustrate the different chemical profiles from items II003, II004 and II005. II004 and II005 could not be visually distinguished. The obtained overlaid pyrograms are available in Supplementary material. Therefore, the visual comparison with II001 was based mainly on the patterns observed at the end of the chromatogram. Overlay of the chromatograms of II001 with II004 and II005 showed generally corresponding visual chemical profiles. The number of peaks and their positions could not be differentiated in the region of up to 18 min. After 18 min, differences were observed, as II004 and II005 had no peaks whilst II001 presented several important peaks, being assessed to D10 to D13 oligomers coming from the degradation of the pyrolysis. Overlay of the chromatograms of II001 and II003 again showed generally corresponding visual chemical profiles. The number of peaks and their positions could not be differentiated in the region of up to 22 min

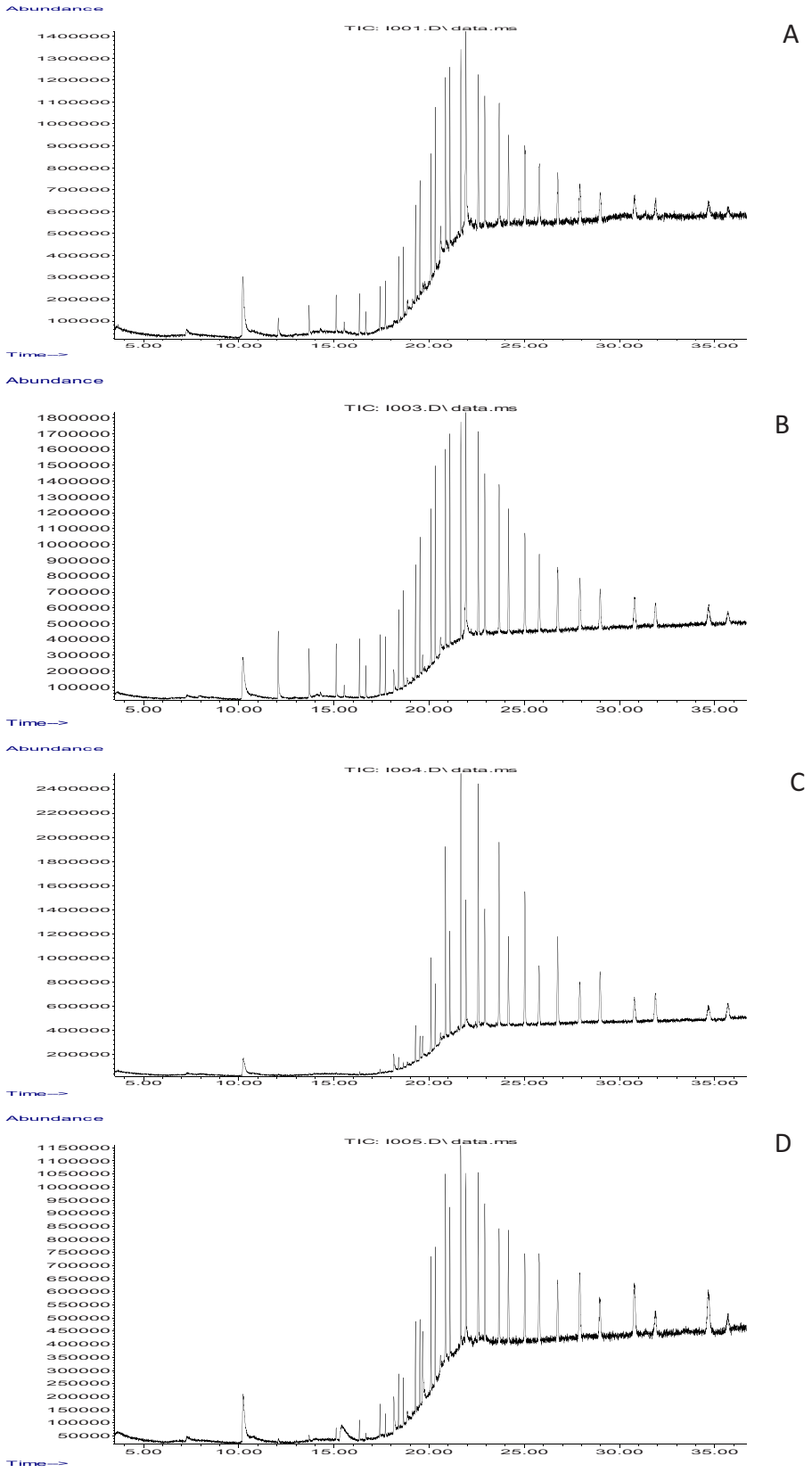

Fig. 3. Chemical Profiles obtained for the questioned sample and the comparison samples – GC-MS analysis. A) chromatoogram of item II001(questioned swab) extract; B) chromatoogram of item II003 Durex Intense Sensation latex condom; C) pyrogram of item II004 LifeStyles Ultra Sensitive latex condom; D) chromatoogram of item II005 Trojan Ultrathin Lubricated latex condom.

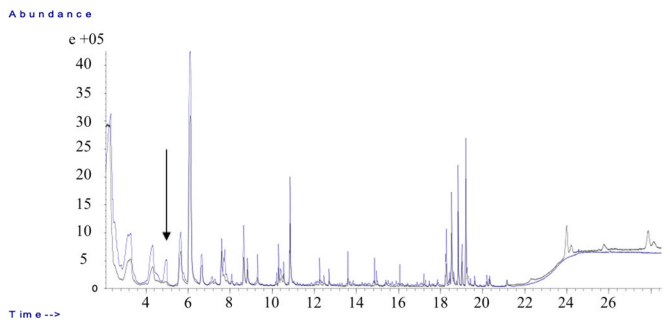

Fig. 4. Overlay of TIC chromatograms of pyrolyzed residues. The black arrow highlights the D3 oligomer. Blue pyrogram represented the questioned cotton swab and the black pyrogram is the blank swab. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

of elution. After 22 min, differences were observed, as II003 did not present any peaks and II001 presented several important peaks. Visual observations of the chromatograms did not allow any conclusions to be drawn at this point. Statistical evaluation was required to evaluate the potential discrimination between the samples.

Projection of all the samples in the database showed that all the items, including II001, were clustered together within the high viscosity silicone pattern, known to be from condoms. Classification indicated all the samples were from a condom.

Therefore, samples were re-extracted using a polar solvent (i.e. methanol) and GC-MS analysis was performed.

As this proficiency trial had previously been analyzed using dichloromethane extraction and GC-MS analysis, data were collected and studied (Fig. 3). Chromatograms of II001 (Fig. 3A), II004 (Fig. 3C) and II005 (Fig. 3D) were overlaid and showed significant differences in the chemical pattern, especially between 10 and 20 min, with the absence of the major, specific peaks in the chromatograms of II004 and II005, that were present in II001. Overlay of II001 and II003 (Fig. 3B) showed indistinguishable chemical profiles along the entire chromatogram. Therefore, the chromatographic evidence makes it more likely that II003 is the source of the chemical profile observed on II001, rather than if II004 or II005 are the source of the chemical profile observed.

4.3. Case 1 – results

The overlay of the acquired chromatograms of the blank swab and the recovered swab is presented in Fig. 4. Observation of the chromatograms revealed the presence of D3 oligomer (black arrow in Fig. 4) in the recovered item, which is an indicator of silicone residues. This peak was absent from the blank swab and the solvent analysis. Therefore, it can be determined that it comes from the sample itself. Comparison of the mass spectrum of this peak with D3 mass spectrum obtained from reference PDMS as illustrated in Fig. 5 allowed to conclude that silicone was present.

An Extracted Ion Chromatogram (EIC) procedure was run on both concentrated samples (blank swab and recovered item) to confirm the presence of siloxane degradation residues. Fig. 6 presents the EIC for the recovered item. Extracted ions were m/z 73, 147, 221 (siloxane monomer, dimer and trimer respectively), 207, 281 and 355 (D3, D4 and D5 indicators). As illustrated in Fig. 6, all these ions were found to be present in the recovered item. In addition, extraction of the peak areas of the compounds used to build the discrimination model presented in Ref. [15] revealed that all were present in the sample. The presence of silicone from a condom in the sample can therefore be certified.

Projection of the sample into a discrimination model would help to assess the dedicated class to which the recovered sample belonged. Therefore, the areas of the 50 target compounds were extracted and normalized to the sum followed by double square root preprocessing, before projecting the sample in the discrimination model built. The chemical profile collected from the recovered evidence is clustered with condom samples. Therefore, it can be stated that the chemical profile collected from the recovered evidence is consistent with that of condom lubricants. The sample is, therefore, more likely to originate from a condom than from any other silicone-based sample.

4.4. Case 2 – results

Pyrolysis-GC-MS analysis did not detect any silicone-based residues after subtracting the blank swab peaks, nor after extracting relevant ions from the mass spectrum. No peaks were present and were therefore not integrated for projection in the model. Data are shown in Supplementary material. These observations are consistent with the absence of condom lubricants or silicone-based lubricant products in the swabs. However, the initial mission was to determine if lubricants were used, hence polar lubricants might be present, methanol extracts of the swabs were analyzed with GC-MS.

GC-MS results did not show evidence of glycerin, polyethylene glycol, propylene glycol or benzocaine, after subtracting blank swab peaks nor after extracting relevant ions from the mass spectrum. These four main components were sought as a priority, as they were found to be the most common constituents of water-based condom lubricants. These results are also consistent with the absence of evidence related to lubricant, oil and/or personal hygiene product use, as no other water-based residues were detected.

As the condom seized from the victim's jacket was not sent for analysis, it is impossible to establish the composition of the sample and therefore to comment on the absence of evidence. The interpretation of the evidence may change if the composition of the condom is known, given that transfer and persistence of water-based and silicone-based condom residues are different [7,20–22], assuming that the condom is silicone or water lubricated.

4.5. Challenges

The two casework examples have highlighted that the main question of interest is whether a lubricant trace is detected or not. There is rarely discussion of comparative examinations that could lead to a Bayesian assessment to interpret scientific evidence. In addition, both cases were investigative, with no proposal given. According to the data from the ENFSI (European Network of Forensic Science Institutes) guideline [23], it is therefore not possible to ask for an evaluation level under these conditions. From an investigative point of view, only the presence or absence of traces are evaluated.

Regarding the interpretation of the presence of traces, it is possible to say that there has been the use of a product whose content is silicone-based. The use of the discrimination and classification model also makes it possible to determine the origin of the samples, and thus to provide investigative information. On the other hand, in the instance where a victim had consensual sex using a condom, it would not be possible to differentiate subsequent sexual activity also using a condom based on the chemical profile, since all condoms are not statistically differentiable. The relevance of the trace must be studied. This is usually done using background population studies (i.e. the presence for legitimate reasons within a population), studies that have not yet been published. The preliminary results presented in the publication [24,25] have highlighted that there is a priori no trace of silicone-based residues in the vaginal matrices. However, this is a preliminary study that only targeted silicone-based residues.

Regarding the interpretation of the absence of traces, several parameters, described by Ref. [21] must be considered. First of all, the characteristics of the donor (i.e. condoms) are to be investigated. It has been shown in published studies [15,16] that most condoms on the market have either a silicone-based or aqueous-based profile. These two types of lubricants have a variable persistence according to the

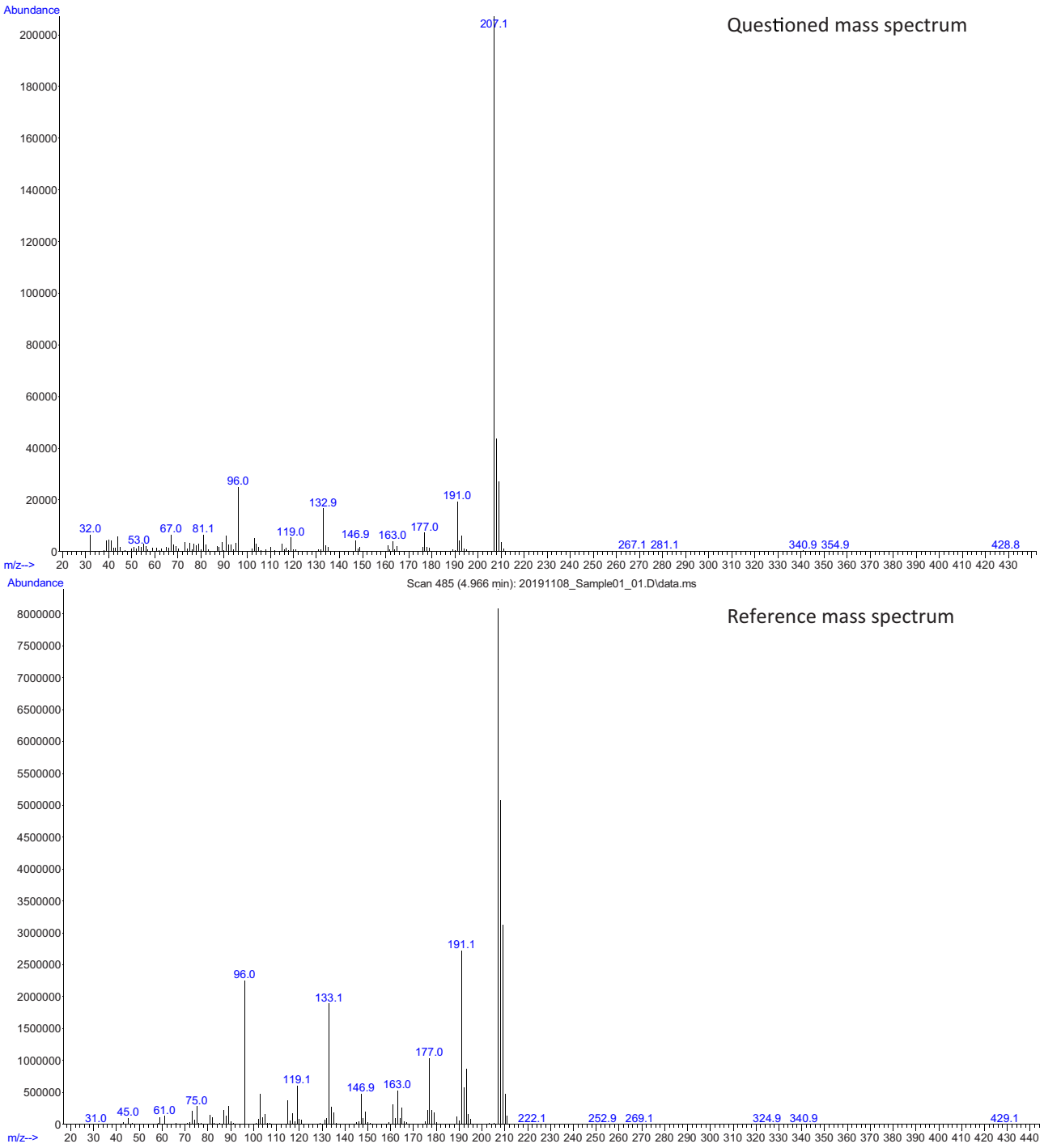

Fig. 5. Mass spectral pattern of the D3 oligomers, from the recovered swab (top) and reference material (bottom).

literature, between 12 and 24 h for silicone-based samples, and between 8 and 24 h for water-based samples. However, there is a third type of condom that are non-lubricated and make up less than 1% of the condom market over the international market [16,21,26]. These condoms have a composition mainly based on solid particles (i.e. cornstarch, polyethylene powder). Samples taken from non-lubricated condoms present a blank profile regardless of the analytical technique used. Thus, a negative profile can also be explained by the absence of lubricant on the condom used, for example in the case of a dry condom (e.g. FairSquared Sensitive Dry).

Characteristics of the receiver have been discussed in Ref. [21] and a recent paper investigated the prevalence of silicone in the vaginal matrix [25]. Variations in the vaginal matrix can be observed, but they do not seem to significantly affect the profiles of the silicone-based samples [7, 25]. It is unknown if variations in the vaginal matrix affect the profiles of water-based condom lubricant. Menstruation, however, can significantly affect the profiles, with significant loss of traces.

The contact is important as noted by Locard's exchange principle [27]; contact with a condom should leave a trace. The absence of a trace can be explained by the absence of contact with a condom, as well as by the aforementioned criteria.

One key parameter influencing the detection of a trace is the time elapsed between the transfer and the evidence collection. Therefore, it is important to know the time interval to assess the persistence of the

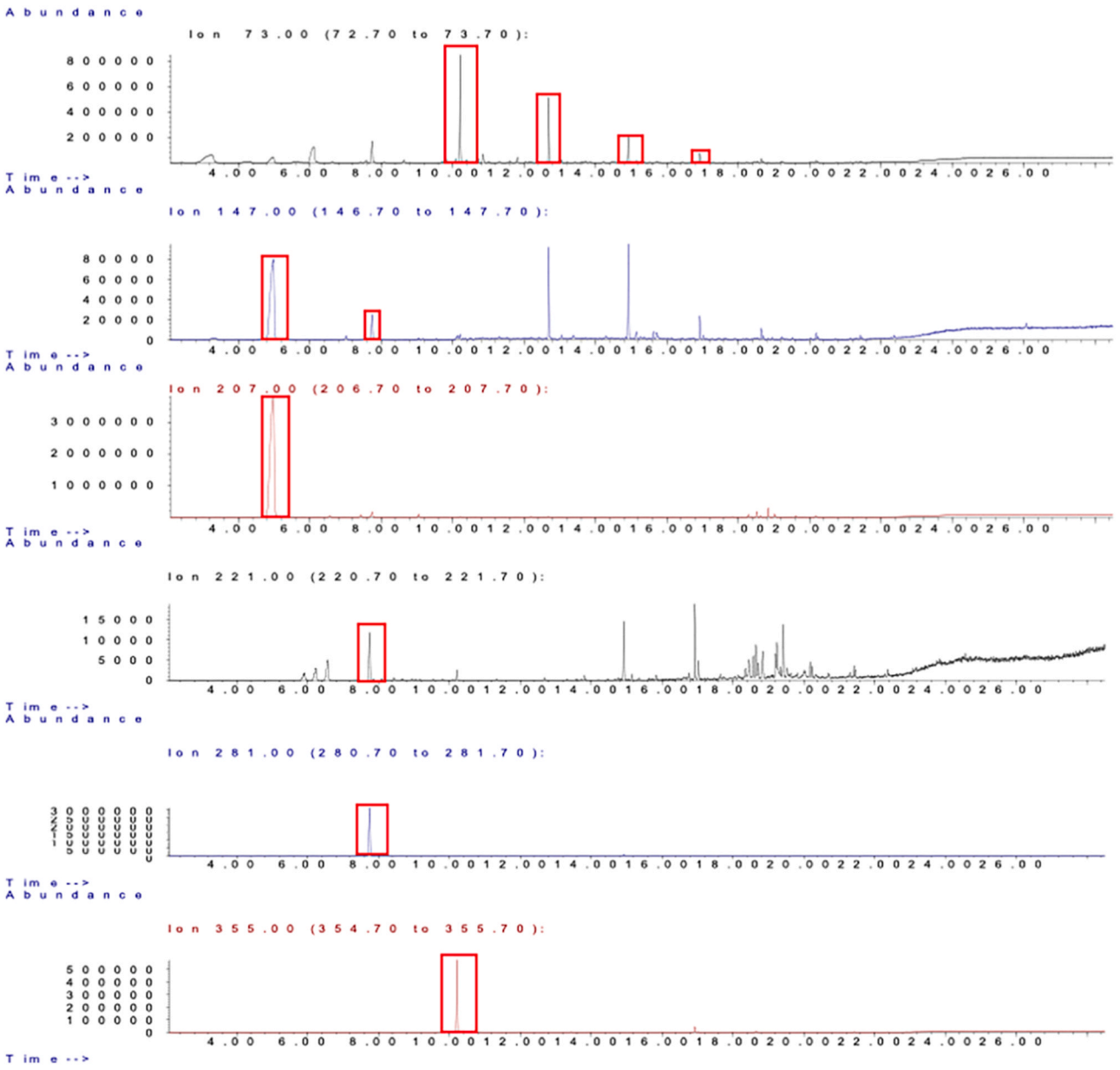

Fig. 6. Extracted Ion Chromatogram (EIC) of siloxanes degradation *m/z* in the recovered sample. Red boxes indicate peaks characteristics of siloxanes degradation. Ions have been attributed based on results published in Ref. [15]. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

traces. Studies such as Tottey et al. [7] help to interpret the persistence of traces. However, as noted by Ref. [21], persistence times reported in the literature vary significantly. A silicone compound such as PDMS could be detected between 12 and 48 h post-coitus, while aqueous-based compounds, such as glycerin or propylene glycol type, could be detected up to 48 h in the vaginal matrix [21] and up to 24 h on skin [21].

Victims of sexual assault may often either dispose of their clothes or wash them, possibly at high temperatures. This activity can affect evidence recovery. While the study by Monzò showed that washing underwear, even at 90 °C, did not affect the recovery of silicone-based compounds [28], the effect of victims' activity on the persistence of traces has not yet been extensively studied. The study by Tottey et al. relating to the persistence of traces in the vaginal matrix, unfortunately, did not record the activities undertaken by the volunteers within the studied time intervals [7]. Based on the physico-chemical considerations of the compounds, it seems likely that the water-based compounds would be the most affected by washing activity. Monzò recorded volunteers' activities between intercourse and sample collection: having a shower, performing a dynamic activity (sport) or a passive activity (sleep) or going to the toilet [28]. None of these factors were found to significantly affect the detection of silicone-lubricants. It was observed that the most important factor to affect the transfer and the persistence of the traces was the receiver itself, due to self-sampling techniques used.

Finally, sampling can affect the chemical profile, as there are currently no standardized and publicly available protocols for the sampling of condom evidence. Although not recommended by Ref. [5], some medical examiners could use lubricated material for the collection of condom samples. This adds to the variability of the condom sample as forensic operator variability is also to be considered, as the pressure and method used to collect the evidence varies between people. In addition, low concentrated samples might not be fully recovered when collected. However, the main consideration is to evaluate whether sampling is adequately processed, i.e. using appropriate protection to avoid

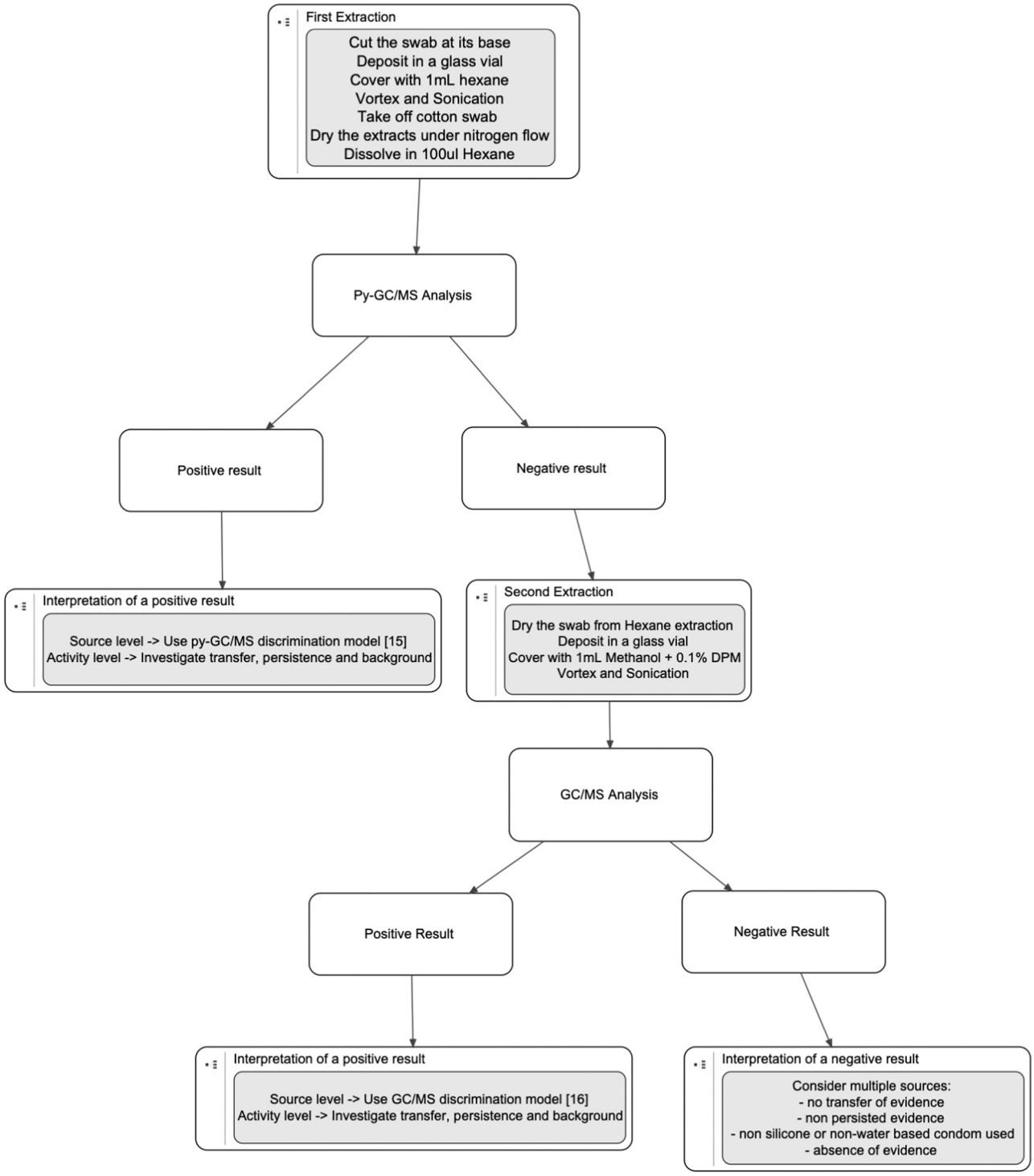

Fig. 7. Flowchart of the procedure recommended for condom evidence analysis in casework.

contamination or loss of evidence. Considering that the evidentiary specimens are usually collected by doctors or nurses (e.g. Sexual Assault Nurse Examiners), sampling can be considered as representative and adequate for condom evidence.

In the second case presented in this paper, the elapsed time between the assault and the time the trace was collected was at least 20 h. The persistence interval was therefore within that defined by the various authors, which is 12–48 h. The activity of the victim between these two events is unknown. It is therefore difficult to interpret the absence of a trace in this case, even at the investigative level.

4.6. Recommendations

The casework presented outlined some needs in terms of condom evidence analysis, but also illustrated some recommendations for practitioners.

Firstly, it is highly recommended that condom evidence is considered when Forensic Physicians examine a complainant alleging a recent sexual assault. The dedicated specimen should be collected with a cotton swab and sent for chemical analysis. Medical examiners should also ask the victim specific questions relating to the use of condoms, lubricants or

personal hygiene products in the past week, and if the victim took a shower prior to evidence collection.

Once the cotton swabs is received by the forensic laboratory, the flowchart previously described by Ref. [26] should be followed. Infrared spectroscopy may be added in the sequence as a screening method, which would indicate the appropriate instrumental analysis (i.e. water-based or PDMS focussed analysis), but the recommended FTIR technique, DRIFTS, might not be available in all laboratories. The flowchart (Fig. 7) is proposed from the present study, and is recommended for condom evidence analysis.

5. Conclusion

This paper has presented the application of published methodologies for condom evidence analysis in practical cases. Evidence of condom residues was detected in one case, but not in the second one.

The analysis of residues from condoms by py-GC-MS makes it possible to obtain a distinctive characteristic chemical profile when silicone products are present. When no silicone profile was detected, GC-MS analysis was able to provide complementary information. This underlines the importance of an approach combining the two instrumental techniques. The various cases encountered in practice have shown that these traces are essentially sought for an investigative purpose. A statistical assessment under two mutually exclusive assumptions for evaluative purposes was not developed, because no assumption was provided in any case, and it was considered too dangerous to position oneself as an expert under these conditions.

Furthermore, it was also shown that the methodology was applicable to trace detection in real cases. However, given that condoms are only alleged to be used by assailants in 20% of sexual assaults, the profiles obtained are likely to be negative more often than not. Similarly, without additional contextual information and in those situations in which a victim has lost consciousness or has no memory, a negative finding would not be unexpected. In these cases, and in particular those including unknown perpetrators, DNA analysis should be prioritized and the analysis for condom residues considered in the case of a negative DNA profile. Thus, awareness and collection of forensic specimens for condom trace evidence should become incorporated into routine practice for sexual assault examiners. Police, forensic scientists, experts in forensic genetics and toxicologists should be aware of condom use as explaining a lack of DNA evidence and ensure evidence is tested appropriately. The interpretation of the evidence and the consideration of transfer, persistence and background residues still need to be further addressed, and further considerations are needed to assist forensic scientists to adequately interpret condom evidence in the forensic context.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. Kari Pitts is on the Editorial Board of FSI Reports and has no access to the peer review reports of this manuscript.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.fsir.2021.100221.

References

[1] R. Coquoz, J. Comte, D. Hall, T.N. Hicks, F. Taroni, Preuve par l'ADN: la génétique au service de la justice, 2013.

[2] J.O. Savino, B.E. Turvey, J.J. Baeza (Eds.), Rape Investigation Handbook, Elsevier Academic Press, Amsterdam, Boston, 2005.

[3] E.N. O'Neal, S.H. Decker, C. Spohn, K. Tellis, Condom use during sexual assault, J. Forensic Leg. Med. 20 (2013) 605–609, https://doi.org/10.1016/j.jflm.2013.03.023.

[4] R.D. Blackledge, M. Vincenti, Identification of polydimethylsiloxane lubricant traces from latex condoms in cases of sexual assault, J. Forensic Sci. Soc. 34 (1994) 245–256.

[5] R.D. Blackledge, Collection and identification guidelines for traces fomr latex condoms, Crime Lab. Dig. 21 (1994).

[6] L. Kitto, G.P. Campbell, A.L. Gordon, S. Coulson, pyGC-MS of Lubricants & Persistence Studies, in: Clearwater Beach, Florida, 2009. ⟨http://projects.nfstc.org/trace/2009/presentations/6-kitto-pygc.pdf⟩. (Accessed 24 January 2017).

[7] L.S. Tottey, S.A. Coulson, G.E. Wevers, L. Fabian, H. McClelland, M. Dustin, Persistence of polydimethylsiloxane condom lubricants, J. Forensic Sci. 64 (2018) 207–217, https://doi.org/10.1111/1556-4029.13816.

[8] R.A. Musah, A.L. Vuong, C. Henck, J.R.E. Shepard, Detection of the spermicide nonoxynol-9 Via GC-MS, J. Am. Soc. Mass Spectrom. 23 (2012) 996–999, https://doi.org/10.1007/s13361-012-0353-7.

[9] T.P.E. Hollenbeck, G. Siuzdak, R.D. Blackledge, Electrospray and MALDI mass spectrometry in the identification of spermicides in criminal investigations, J. Forensic Sci. 44 (1999) 783–788.

[10] S.E. Spencer, S.Y. Kim, S.B. Kim, K.A. Schug, Matrix-assisted laser desorption/ionization–time of flight-mass spectrometry profiling of trace constituents of condom lubricants in the presence of biological fluids, Forensic Sci. Int. 207 (2011) 19–26, https://doi.org/10.1016/j.forsciint.2010.08.010.

[11] M. Maric, L. Harvey, M. Tomcsak, A. Solano, C. Bridge, Chemical discrimination of lubricant marketing types using direct analysis in real time time-of-flight mass spectrometry: discrimination of lubricant types using DART-TOFMS, Rapid Commun. Mass Spectrom. 31 (2017) 1014–1022, https://doi.org/10.1002/rcm.7876.

[12] M. Maric, C. Bridge, Characterizing and classifying water-based lubricants using direct analysis in real time(®)-time of flight mass spectrometry, Forensic Sci. Int. 266 (2016) 73–79, https://doi.org/10.1016/j.forsciint.2016.04.036.

[13] B. Baumgarten, M. Marić, L. Harvey, C.M. Bridge, Preliminary classification scheme of silicone based lubricants using DART-TOFMS, Forensic Chem. 8 (2018) 28–39, https://doi.org/10.1016/j.forc.2017.12.005.

[14] A.M. Coon, S. Beyramysoltan, R.A. Musah, A chemometric strategy for forensic analysis of condom residues: identification and marker profiling of condom brands from direct analysis in real time-high resolution mass spectrometric chemical signatures, Talanta 194 (2019) 563–575, https://doi.org/10.1016/j.talanta.2018.09.101.

[15] C. Burnier, G. Massonnet, S. Coulson, D. DeTata, K. Pitts, Condom evidence: characterisation, discrimination and classification of pyrolysis-GC-MS profiles, Forensic Sci. Int. 324 (2021), 110793 in press.

[16] C. Burnier, G. Massonnet, S. Coulson, D. DeTata, K. Pitts, Characterization and classification of water-based compounds in condoms and personal hygiene products using GC-MS, Forensic Sci. Int. 317 (2020), 110513, https://doi.org/10.1016/j.forsciint.2020.110513.

[17] J.M. Challinor, A rapid simple pyrolysis derivatisation gas chromatography-mass spectrometry method for profiling of fatty acids in trace quantities of lipids, J. Anal. Appl. Pyrolysis 37 (1996) 185–197, https://doi.org/10.1016/0165-2370(96)00946-1.

[18] J.M. Challinor, Characterisation of rosin-based commercial resins by pyrolysis—and simultaneous pyrolysis methylation—gas chromatography/mass spectrometry techniques, J. Anal. Appl. Pyrolysis 25 (1993) 349–360, https://doi.org/10.1016/0165-2370(93)80054-4.

[19] T.P. Wampler (Ed.), Applied Pyrolysis Handbook, second ed., CRC Press/Taylor & Francis, Boca Raton, 2007.

[20] P. Maynard, K. Allwell, C. Roux, M. Dawson, D. Royds, A protocol for the forensic analysis of condom and personal lubricants found in sexual assault cases, Forensic Sci. Int. 124 (2001) 140–156.

[21] C. Burnier, G. Massonnet, Pre-analytical considerations of condom traces: a review of composition, background, transfer and persistence, Forensic Sci. Int. 302 (2019), 109861, https://doi.org/10.1016/j.forsciint.2019.06.019.

[22] M. Tonkin, L.F. Yeap, E.K. Bartle, A. Reeder, The effect of environmental conditions on the persistence of common lubricants on skin for cases of sexual assault investigation, J. Forensic Sci. 58 (2013) S26–S33, https://doi.org/10.1111/1556-4029.12028.

[23] ENFSI, ENFSI Guideline for Evaluative reporting in Forensic Sciences, European Network for Forensic Sciences, 2015. ⟨http://enfsi.eu/wp-content/uploads/2016/09/m1_guideline.pdf⟩.

[24] C.A. Burnier, W. van Bronswijk, G. Massonnet, Comparison of spectroscopic methods in the detection of silicone-based condom lubricant evidence, Anal. Methods 12 (2020) 657–665, https://doi.org/10.1039/C9AY02471A.

[25] A. Hermelin, L. Fabien, J. Fischer, N. Saric, G. Massonnet, C. Burnier, Analysis of condom evidence in forensic science: background survey of the human vaginal matrix using DRIFTS and pyrolysis-GC/MS, Forensic Sci. Int. 321 (2021), 110724, https://doi.org/10.1016/j.forsciint.2021.110724.

[26] C. Burnier, G. Massonnet, Forensic analysis of condom traces: chemical considerations and review of the literature, Forensic Sci. Int. 310 (2020), 110255, https://doi.org/10.1016/j.forsciint.2020.110255.

[27] E. Locard, L'enquête criminelle et les méthodes scientifiques, Flammarion, Paris, 1920.

[28] M. Monzò, C. Burnier, G. Massonnet, The use of FTIR for the analysis of PDMS in the context of condom traces, École Sci. Crim. (2017).