TNT Explosive Residue Detection: An Investigation of Swabbing Substrates and Solvents Across Witness Materials Using GC-MS

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INTRODUCTION

Casework involving explosives continues to pose significant and evolving challenges for forensic practitioners around the world, making accurate identification of the explosive type used in an IED essential. Prior research has largely focused on intact explosives and substrates artificially spiked with target analytes, leaving investigations into sampling methodologies for the recovery and detection of authentic post-blast explosive residues relatively limited [1]. This study assesses swab and solvent combinations to determine the most effective sampling approach based on the type of material recovered following detonations involving organic secondary high explosives, specifically 2,4,6-trinitrotoluene (TNT). TNT was selected due to its well-characterized properties, allowing focus on the efficiency of the various sampling materials tested. Its moderate insensitivity to shock and friction enables stability during transportation and exposure to elevated temperatures. Additionally, this study evaluates the suitability of the different materials for the retention of post-blast residues.

MATERIALS & METHODS

Standards and Materials – A 200 ppm diphenhydramine (DPH) standard was used as a positive control. Authentic TNT was provided by the Montgomery County Fire Marshal's Office (MCFMO).

Construction, Detonation, and Collection of Explosive Devices – Four simulated IEDs were constructed. The explosive charges (2 oz.) were placed in a plastic toolbox with different witness materials, including six wooden paint sticks, five cotton fabric squares, and twelve strips of electrical tape (**Figure 1A**). The devices were placed in a 2 x 2 square of cinderblocks (8 in x 8 in x 16 in) to assist with the containment of the debris (**Figure 1B**). The device was detonated and only the debris within the bounds of the cinderblocks (**Figure 1C**) was collected in unlined aluminum paint cans.

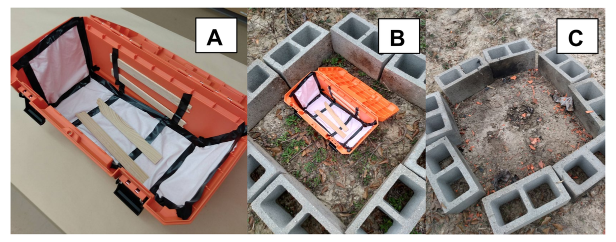

Figure 1. *Simulated IED construction (A) initial setup (B), and after detonation (C).*

Post-Blast Debris Sampling – Three replicates of each witness material were sampled for each explosion (**Figure 2**). Each piece of debris was swabbed using a cotton swab, three types of solvated swabs (methanol, acetone, and 1:1 methanol:DI water), and a dry cotton ball.

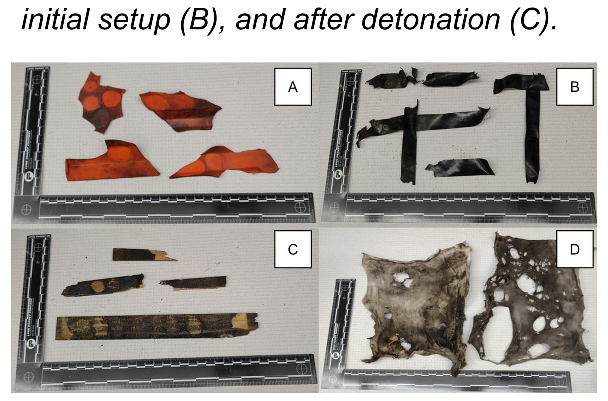

Figure 2. *Witness materials sampled for residues (A) plastic, (B) tape, (C) wood, and (D) fabric.*

The cotton swabs were extracted into 2 mL of a 50 ppm solution of DPH in acetone for 30 minutes. The cotton ball was extracted in ~10 mL of acetone and 0.5 mL DPH for 30 minutes and then dried down to 2 mL using a Turbovap. All acetone extracts were filtered through a VWR syringe filter (PTFE, 13 mm, 0.22 µm) into a GC-MS vial.

Instrumental Method – Extracts were analyzed using an Agilent 7890A GC coupled with a 5975C MS. A DB-5 column (30 m x 250 µm × 0.25 µm) was used with helium as the carrier gas (1 mL/min). Samples (1 µL) were injected with a 20:1 split. The initial oven temperature was 50 °C, which was ramped at 18 °C/min to 200 °C, held for 1 min, then ramped at 45 °C/min to 260 °C and held for 1 min. The MS operated at 70 eV in scan mode (*m/z* 29-500).

Data Analysis – The data was analyzed using ChemStation and the peak area of the TNT was recorded.

RESULTS & DISCUSSION

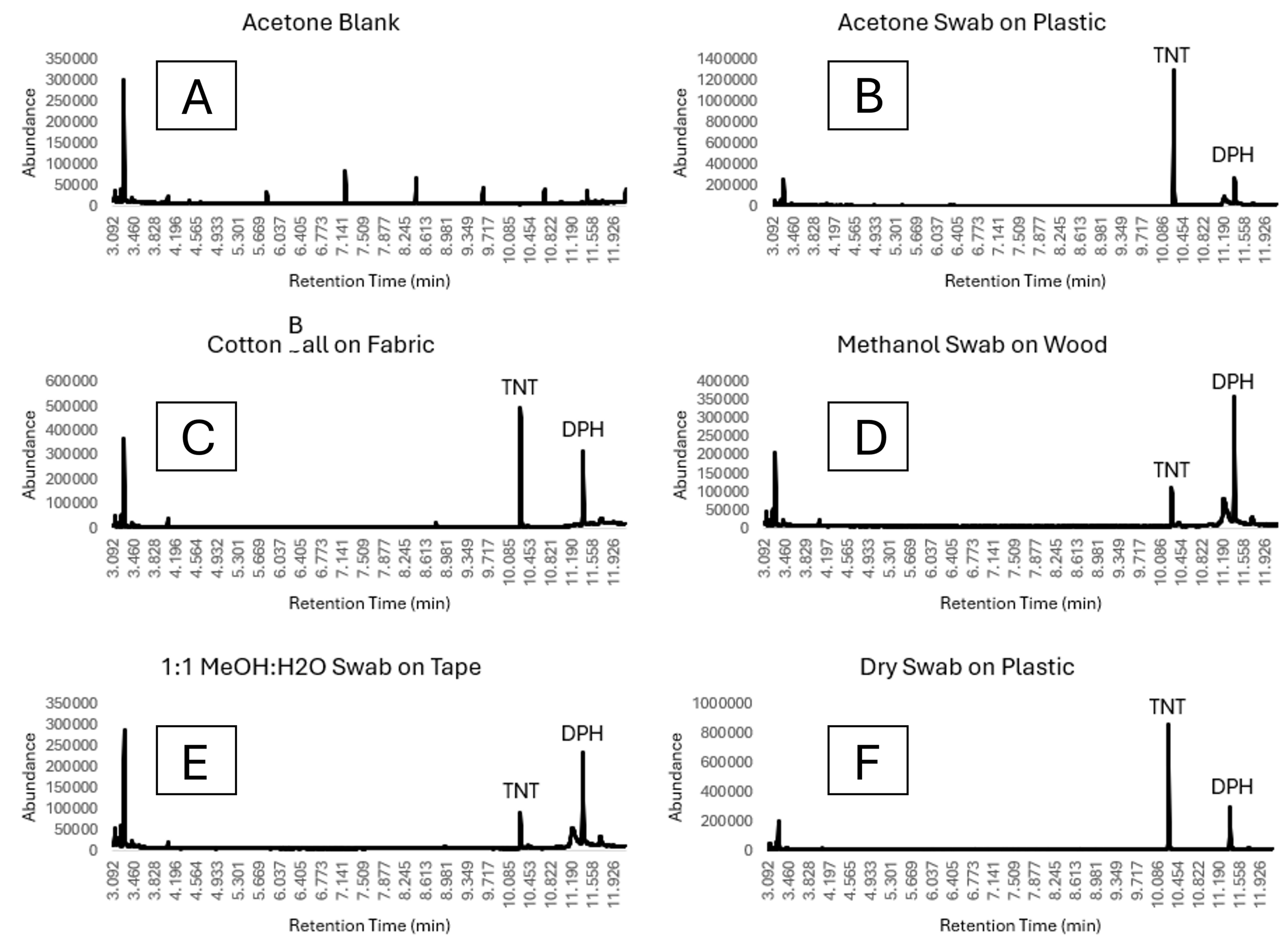

Figure 3. *Total Ion Chromatograms (TICs) of swab extracts with TNT eluting at 10.286 minutes and DPH eluting at 11.384 minutes.*

- TNT abundance associated with each sampling technique and witness material was evaluated using peak areas obtained from the total ion chromatogram (TIC) ***(Figure 3)***.
- Several small peaks in the blank acetone sample ***(Figure 3A)*** are attributed to various hydrocarbons and ketones from acetone degradation.
- A consistent peak at 3.287 minutes in the blank acetone run ***(Figure 3A)*** is attributed to diacetone alcohol, a beta-hydroxy ketone, which is an acetone-related artifact.
- The plastic substrate exhibited the highest TNT abundance rate across all swab types ***(Figures 3B and 3F)***.
- The fabric substrate produced the lowest TNT abundance for most swab types, except for the cotton ball, which demonstrated comparatively higher recovery on fabric ***(Figure 3C)***.
- Although comparatively low, ***Figure 3D*** shows an exemplar chromatogram of the successful detection of TNT on wood using MeOH, likely due to the porous wood surface limiting analyte collection.
- An exemplar chromatogram obtained using MeOH:H_2O mixture on wood, seen in ***Figure 3E***, generated a moderate analyte signal; however, abundance was inconsistent due to the wood's surface characteristics.

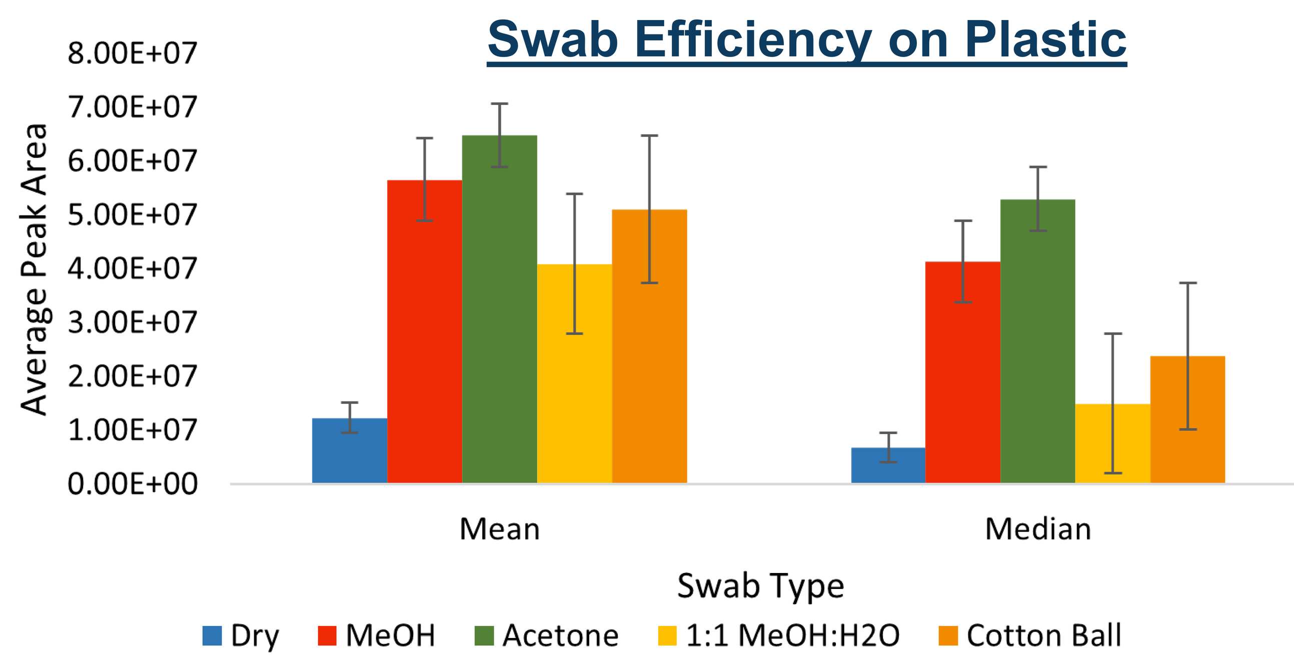

Figure 4. *Efficiency of swab types for plastic witness material. Efficiency error bars were calculated using one standard deviation of the mean from the 12 replicates in each data set.*

- Plastic provides an inflexible, nonporous surface for sampling, in comparison to wood and fabric, which enable better contact with each swab type, contributing to a high rate of analyte recovery.
- Acetone resulted in the highest abundance of TNT from the plastic substrate ***(Figure 4)***.
- Use of a dry cotton swab yielded in the lowest abundance of TNT on plastic, which differs from the results obtained by Song-im et al., who reported higher TNT abundance from plastic when using a dry cotton swab [2].
- This discrepancy could be attributed to differences in the method deposition and the plastic substrates evaluated (polypropylene vs. polyethylene) [2]. While Song-im et al. spiked the substrates with a TNT standard to mimic explosives residue, this study was conducted using authentic post-blast conditions.
- Variation in plastic substrate type may also explain the reported higher TNT abundance using methanol- vs. acetone-solvated cotton swabs [2].

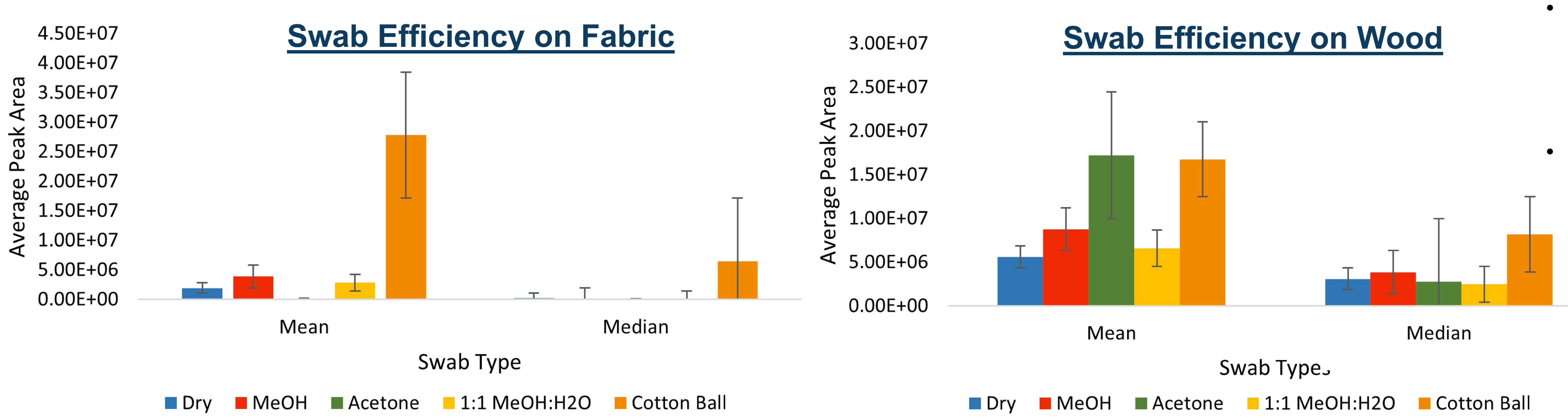

Figure 5. *Efficiency of swab types for fabric and wood witness materials. Efficiency error bars were calculated using one standard deviation of the mean from the 12 replicates in each data set.*

- The wood and fabric substrates ***(Figure 5)*** are both porous materials, though their porosity is based on different properties.
- When solvent-based swabs were applied to the fabric, the solvent was absorbed into the material rather than retained on the swab, resulting in reduced analyte recovery.
- The cotton ball performed better on fabric due to the absence of solvent and its larger contact surface area.
- A small number of wood replicates exhibited unusually high TNT recovery, elevating the overall average and making the acetone swabs appear more efficient than the broader dataset suggests.
- Similar to the fabric, the cotton ball consistently recovered more TNT from the wood than the solvent-based swabs.

CONCLUSIONS

- Plastic yielded a higher abundance of TNT compared to the other materials, especially fabric, indicating that non-porous substrates are more suitable for the collection of TNT residues.
- The fabric and wood substrates yielded the greatest TNT abundance when sampled with a cotton ball, in contrast to solvated swabs.
- TNT recovery from electrical tape provided inconsistent results and was found to depend on the efficiency of the explosion.
- While cotton balls can be recommended overall due to their consistently high performance across all substrates studied, the practical effectiveness of residue collection is also dependent on substrate rigidity and porosity, which were found to significantly impact the abundance of recoverable TNT residues.

REFERENCES

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(2) Song-im N, Benson S, Lennard C. Evaluation of different sampling media for their potential use as a combined swab for the collection of both organic and inorganic explosive residues. Forensic Sci Int. 2012 Oct 10;222(1-3):102-10. https://doi.org/10.1016/j.forsciint.2012.05.006

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