Research article

Drug Testing and Analysis

Received: 4 July 2010 Revised: 21 August 2010 Accepted: 21 August 2010 Published online in Wiley Online Library: 30 September 2010

(www.drugtestinganalysis.com) DOI 10.1002/dta.179

Non-invasive detection of cocaine dissolved in wine bottles by ^{1}H magnetic resonance spectroscopy

Giulio Gambarota,[a]* Chiara Perazzolo,[a] Antoine Leimgruber,[b] Reto Meuli,[b] Patrice Mangin,[c] Marc Augsburger[c] and Silke Grabherr[b,c]

Recently, a number of cases of smuggling dissolved cocaine in wine bottles have been reported. The aim of the present study was to determine whether cocaine dissolved in wine can be detected by proton magnetic resonance spectroscopy (^{1}H MRS) on a standard clinical MR scanner, in intact (i.e. unopened) wine bottles. ^{1}H MRS experiments were performed with a 3 Tesla clinical scanner on wine phantoms with or without cocaine contamination. The aromatic protons of cocaine displayed resonance peaks in the 7–8 ppm region of the spectrum, where no overlapping resonances of wine were present. Additional cocaine resonances were detected in the 2–3 ppm region of the spectrum, between the resonances of ethanol and other wine constituents. Detection of cocaine in wine (at 5 mM, i.e. ∼1.5 g/L) was feasible in a scan time of 1 min. We conclude that dissolved cocaine can be detected in intact wine bottles, on a standard clinical MR scanner. Thus, ^{1}H MRS is the technique of choice to examine this type of suspicious cargo, since it allows for a non-destructive and rapid content characterization. Copyright © 2010 John Wiley & Sons, Ltd.

Keywords: cocaine; drug smuggling; magnetic resonance spectroscopy; wine

Introduction

Cocaine is among the most common drugs of abuse. A large number of imaginative techniques for smuggling cocaine through border controls has been reported in recent years.[1–5] One of the latest techniques involves smuggling cocaine dissolved in wine.[6–7] In order to detect cocaine-contaminated wine bottles, an immunological test using a drug-test panel is necessary. However, this test requires opening a sample from the cargo, with two major disadvantages. First, contaminated cargo can be overlooked, since it is not possible to check a large number of samples. Second, cargo with expensive wine cannot be systematically sampled at a reasonable cost. Thus, a 'non-invasive' approach is of interest, as it would allow for an increase in sampling rate, without alterations to the cargo itself.

An earlier study[6] described a radiological approach based on Multi Detector Computed Tomography (MDCT) to detect cocaine-contaminated wine bottles, using measurements of the mean value of Hounsfield units. It was found that the mean density of wine with dissolved cocaine was significantly different than that of wine alone. However, measurements of phantoms with other dissolved substances, like sugar for instance, yielded similar differences in mean density. Thus, the technique described[6] is not specific to cocaine and can be used only as a screening test to assess whether a cargo is contaminated, without characterization of the actual contaminant.

Given the limitations of the MDCT approach, we investigated the potential of proton magnetic resonance spectroscopy (^{1}H MRS) as a technique to detect dissolved cocaine, non-invasively. ^{1}H MRS allows for detection of molecules down to mM levels when performed with standard clinical MR scanners.[8] In localized ^{1}H MRS, a voxel of interest (VOI) is chosen within the sample and the signal from this specific VOI is acquired. In the resulting ^{1}H MR spectrum, each peak represents the fingerprints of specific hydrogen nuclei within the molecules of the sample. As such, localized ^{1}H MRS has the potential to detect cocaine molecules in wine.

The aim of the present study was to determine whether it is possible to identify cocaine-contaminated wine bottles with localized ^{1}H MRS on a standard clinical scanner.

Materials and methods

MR experiments were performed on a clinical 3 T Tim Trio Siemens scanner (Siemens Medical Solutions, Erlangen, Germany) using a transverse electromagnetic (TEM) transmit/receive head coil. Multislice gradient-echo MR images were acquired to position a VOI in the sample. ^{1}H MR spectra were acquired using the stimulated acquisition mode (STEAM) sequence[9] and the double spin-echo point resolved spectroscopy (PRESS) sequence.[8] Both the STEAM and PRESS sequences are routinely used for volume

* *Correspondence to: Giulio Gambarota, GSK, Clinical Imaging Centre, Imperial College London, Hammersmith Hospital, Du Cane Road, London W12 0NN, UK. E-mail: gambarota@gmail.com*

a *Physics Department, Swiss Federal Institute of Technology Lausanne, Switzerland*

b *Service of Radiodiagnostic and Interventional Radiology, University Hospital of Lausanne, Switzerland*

c *University Center of Legal Medicine Lausanne - Geneva, University Hospital of Lausanne, Switzerland*

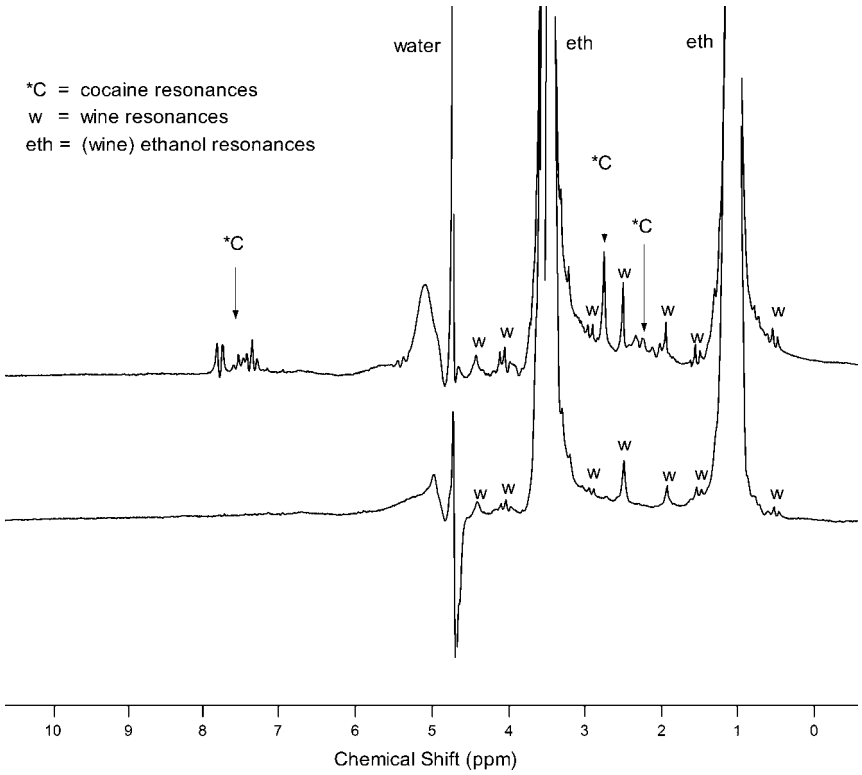

Figure 1. Water-suppressed ^{1}H MR PRESS spectra of a 2.5 × 2.5 × 2.5 cm^3 voxel in a phantom containing wine (bottom spectrum) and wine + 20 mM cocaine (top spectrum). In both phantoms, the dominant resonances are the ethanol resonances (CH_3 at ~1 ppm, and CH_2 at ~3.5 ppm, resonances labelled as 'eth'). A cut-off threshold is applied to the vertical scale, in order to facilitate the visualization of smaller resonances. The resonances labelled with 'w' originate from specific compounds that are present in wine, whereas the resonances labelled with '*C' belong to the cocaine dissolved in wine.

selection in clinical MR spectroscopy.[10,11] Experiments were performed on phantoms with different concentrations of cocaine (0, 1, 5, 10, 15, 20 mM, cocaine hydrochloride, Siegfried Handel, Zofingen, Switzerland) dissolved in water or wine (Montepulciano d'Abruzzo, DOC Selezione F. Tedeschi 2006 0.75 L). Preparation of cocaine phantoms was performed as described by Grabherr *et al*.[6] A number of wine bottles, bought at a local wine shop, were also examined with ^{1}H MRS. Experiments were performed on (1) Aglianico del Vulture, DOC Terre di Orazio 2007; (2) Monbazillac, AOC Pavillon de la Brie 2007; and (3) Gewürztraminer Alsace, AOC Baron de Höen Beblenheim 2007. In all experiments, water signal suppression was applied prior to signal excitation, in order to minimize the deleterious effects of the large water resonance on the nearby resonances.[12]

Results and discussion

The water-suppressed ^{1}H MR spectrum of a wine phantom was compared to the spectrum of a cocaine-contaminated wine phantom (Figure 1). The wine phantom displayed the ethanol resonances (methyl protons, CH_3, at ~1 ppm and methylene protons, CH_2, at ~3.5 ppm, labelled as 'eth'; Figure 1), as well as a number of smaller resonances in the 0–5 ppm region, which originated from wine-specific compounds (resonances labelled as 'w'; Figure 1). A number of additional resonances were detected in the cocaine-contaminated wine phantom, both on the left side (7–8 ppm) and right side (2–3 ppm) of the water peak (Figure 1; resonances labelled as '*C'). The multiplet resonances in 2.1–2.5 ppm and 7–8 ppm region were assigned to the aliphatic ring and aromatic protons of cocaine, respectively. The singlet at ~2.9 ppm was assigned to the methyl group bound to the nitrogen (N-methyl).

^{1}H MR spectra acquired with the PRESS sequence (TE = 30 ms, 1 min scan time) allowed for the detection of the cocaine resonances in phantoms containing wine and cocaine (5, 10, and 20 mM; Figure 2). Overall, the total time required to assess 5 mM cocaine contamination in wine was less than 3 min. This time included: (1) positioning of the phantom inside the scanner; (2) MR imaging (approximately 1 min), necessary to locate the VOI within the phantom; and (3) the MR spectroscopy acquisition (1 min).

Spectra acquired at different echo times showed a substantial signal modulation of the aromatic resonances due to J-coupling, with a signal inversion of the resonant peak at the TE of 120 ms (Figure 3). A signal reduction due to T2 relaxation losses and J-modulation dephasing was also observed with increasing TEs (Figure 3).

Spectra acquired in wines bought at a local shop displayed no detectable resonances in the 7–8 ppm region, where the aromatic protons of cocaine resonate. In addition to the dominant ethanol resonances, each wine displayed characteristic resonances in the 0–5 ppm region. Notably, the MR spectrum of Monbazillac, a rich *liquoreux* sweet white wine, showed resonances of sugar compounds in the spectral region from 3 to 4 ppm, adjacent to the methylene resonances of ethanol (data not shown).

The results of the current study demonstrate that it is possible to detect non-invasively dissolved cocaine in wine, within the mM range and in a short measurement time. The ^{1}H resonances of cocaine can be divided in three main groups: the aliphatic ring, methyl, and aromatic proton resonances. The aliphatic ring protons

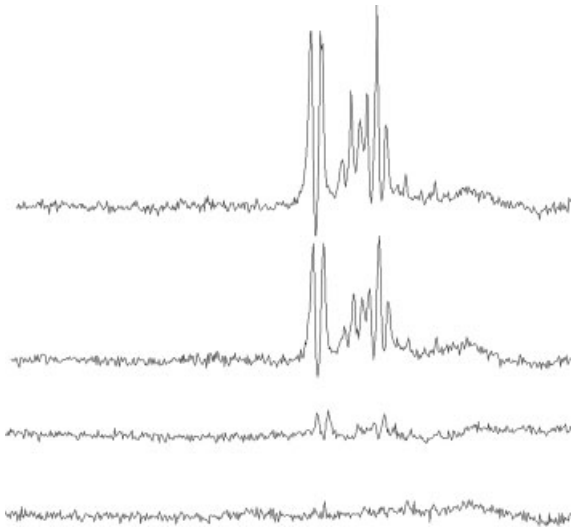

Figure 2. Water-suppressed ^{1}H MR PRESS spectra (6–9 ppm region) of a 2.5 × 2.5 × 2.5 cm^{3} voxel in four phantoms containing wine + cocaine (20 mM, 15 mM, 5 mM and 1 mM, top to bottom, respectively). The measurement time for each spectrum is 1 min. The cocaine aromatic resonances are clearly visible above the noise in the phantoms contaminated with 20 mM, 15 mM and 5 mM of cocaine.

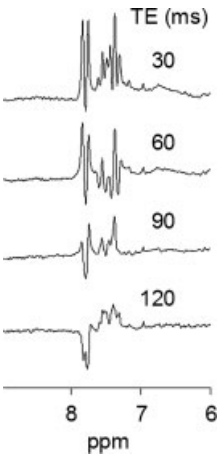

Figure 3. Water-suppressed ^{1}H MR PRESS spectra of a 2.5 × 2.5 × 2.5 cm^{3} voxel in a phantom containing wine + 20 mM cocaine, acquired at different echo times (TE = 30 to 120 ms, top to bottom). The J-modulation of the aromatic resonances results in a complete signal inversion at TE = 120 ms.

generate multiplets in the spectral region between approximately 2.0 and 5.4 ppm. However, due to water suppression and overlap with ethanol, these resonances are not detectable, with the exception of the multiplet at 2.0–2.6 ppm. The methyl group resonances appear as singlets, at ~3.6 ppm (O-methyl) and 2.9 ppm (N-methyl). The O-methyl singlet cannot be clearly detected since it overlaps with the larger signal of ethanol, whereas the N-methyl group is well observable. Finally, the aromatic protons resonate as multiplets at 7–8 ppm, where no resonances of wine are present. As a consequence, these latter resonances represent the obvious fingerprints for cocaine detection in wine. Taken together, the most relevant features of cocaine (the benzoic acid component, the N-methyl group and part of aliphatic ring) are thus visible in the spectra and the relative frequencies and intensities of the observable resonances are sufficient to identify dissolved cocaine in wine, even in the mM concentration range.

In a previous study, a radiological approach based on MDCT was investigated to distinguish between bottles containing wine and bottles containing wine with dissolved cocaine.[6] By comparing the density of the samples, the MDCT approach allows for detection of dissolved substances in a liquid – provided that a sample of the same liquid without any contamination is available – without, however, the possibility of identifying the substance itself. In the present study we show that dissolved cocaine can be identified with ^{1}H MRS because it produces distinctive resonances in the MR spectrum. Thus, compared to an MDCT screening, the MRS examination can confirm with higher specificity the presence of cocaine in the sample. This assessment can be performed either after an MDCT measurement or directly, as the overall MRS procedure can be performed in only 3 min. Clearly, this proof may be very important in legal affairs, especially if expensive police investigations are necessary to track a delivery.

The detection limit of 5 mM is reached here with a standard clinical MRS setup. A 5 mM concentration of dissolved cocaine (corresponding to approximately 1 g of cocaine in a 750 mL bottle of wine) is well below the actual cocaine concentration of approximately 400 mM, which has been found in smuggled wine bottles.[6] Therefore, the current approach provides a detection limit that is exquisitely sensitive for its intended application. This detection limit is also in line with the sensitivity of ^{1}H MRS performed on clinical scanners, where *in vivo* detection of metabolites down to 1 mM is feasible in a scan time of a few minutes.[13] The PRESS sequence is the method of choice for sensitivity, because it provides a higher signal-to-noise ratio compared to the STEAM sequence.[9,10] Data acquisition performed at the short TE of 30 ms further improves the measurement sensitivity, by reducing signal losses due to T2 relaxation and J-modulation dephasing.

One limitation of our technique is that the spectral quality, and therefore the detection limit, might be degraded by the presence of metal in the carrier. For instance, wine bottles might be surrounded by a metallic net, or might have metal caps, or the wine might be stored in aluminum-coated containers. Overall, a number of artifacts can arise when metals are part of the package; depending on the package and metal, the presence of artifacts could raise the detection threshold or even prevent the measurements. It is also noteworthy that the MRS measurements proposed here require a close collaboration between law enforcement officials and hospital authorities. Finally, although the investigation can be performed in every hospital that has an MR scanner, experiments need to be conducted by MRS-trained staff in order to ensure proper data acquisition and analysis.

In conclusion, dissolved cocaine can be detected in intact wine bottles on a standard MR scanner. Thus, ^{1}H MRS is the technique of choice to examine suspicious cargo, since it allows for a non-destructive and rapid investigation that demonstrates the presence of cocaine in wine.

Acknowledgements

Supported by the Centre d'Imagerie Biomédicale (CIBM) of the UNIL, UNIGE, HUG, CHUV, EPFL, and the Leenaards Jeantet Foundation.

References

[1] H. Vogel, D. Haller, C. Laitenberger, A. Heinemann, K. Püschel, *Arch. Kriminol.* **2006**, *218*, 1.
[2] *Microgram Bulletin* **2003**, *36*, 272. Available at: www.usdoj.gov/dea/programs/forensicsci/microgram/mg1203/mg1203.html [7 November 2007].
[3] *Microgram Bulletin* **2003**, *36*, 271. Available at: www.dea.gov/programs/forensicsci/microgram/mg1203/mg1203.pdf [7 November 2007].
[4] R. Jellema, *Microgram* **2001**, *34*, 183.
[5] S. D. McDermott, J. D. Power, *J. Forensic Sci.* **2005**, *50*, 1423.
[6] S. Grabherr, S. Ross, P. Regenscheit, B. Werner, L. Oesterhelweg, S. Bolliger, M. J. Thali, *AJR* **2008**, *190*, 1390.
[7] *Microgram Bulletin* **2005**, *48*, 38. Available at: www.dea.gov/programs/forensicsci/microgram/mg0305/mg0305.html [7 November 2007].
[8] P. A. Bottomley, *Ann. N Y Acad. Sci.* **1987**, *508*, 333.
[9] J. Frahm, K. D. Merboldt, W. Hanicke, *J. Magn. Reson.* **1987**, *72*, 502.
[10] P. S. Allen, R. B. Thompson, A. H. Wilman, *NMR Biomed.* **1997**, *10*, 435.
[11] G. Gambarota, M. van der Graaf, D. Klomp, R. V. Mulkern, A. Heerschap, *J. Magn. Reson.* **2005**, *177*, 299.
[12] R. J. Ogg, P. B. Kingsley, J. S. Taylor, *J. Magn. Reson. B* **1994**, *104*, 1.
[13] R. Mekle, V. Mlynárik, G. Gambarota, M. Hergt, G. Krueger, R. Gruetter, *Magn. Reson. Med.* **2009**, *61*, 1279.