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Original paper

Antoine Boizet[1], Julien Ognard[1,2], Ons Hmandi[3], Claire Saccardy[4], David Bourhis[1], Douraied Ben Salem[2,5]

Contribution of dual-energy computed tomography in the differentiation of illicit drugs

[1]Department of Radiology, University Hospital of Brest, 29609 Brest Cedex, France
[2]LaTIM-INSERM UMR, Univ Brest, 29238 Brest Cedex 03, France
[3]Department of Legal Medicine Charles Nicolle Hospital, Tunis, Tunisia
[4]Department of Forensic Medicine, University Hospital of Brest, 29609 Brest Cedex, France
[5]Forensic Imaging Department, University Hospital of Brest, 29609 Brest Cedex, France

Abstract

Aim of the study: The objective of this study was to compare the dual-energy behaviour of the main illicit substances as well as their cutting agents in order to be able to differentiate them.

Material and methods: Cocaine, heroin, MDMA, and cannabis as well as 3 adulterants, 2 diluents, and water were scanned at 90 kV and then at 140 kV on a single X-ray tube computed tomography (CT) scanner. The data acquired enabled a mapping of the attenuation values to 90 and 140 kVp as well as a resulting dual-energy index (DEI) mapping.

Results: Drugs, cocaine, MDMA (pill), and cannabis had a positive DEI (0.014–0.008), while heroin and MDMA (powder) had a negative DEI (–0.016 and –0.013). The DEI of water was –0.01 and that of taurine was –0.018. Adulterants had negative DEI, while diluents had a positive DEI. All DEI were significantly different ($p < 0.01$).

Conclusions: Cocaine and heroin can be clearly differentiated using DEI.

Key words: dual-energy CT, dual-energy index, illicit drugs, bodypacking.

Introduction

Drug trafficking is an overwhelming issue which is expanding worldwide [1]. Intracorporal concealment either in the digestive tract and/or in the female genital tract is considered as a major growing business in the chain of illicit drug marketing [2]. English language literature uses the term "bodypacking" for traffickers who hide drug packages within the gastro-intestinal tract [3]. In most cases, intracorporal transport includes cocaine, heroin, or amphetamines and, to a lesser extent, cannabis [4–8]. Regardless of the legal risks the bodypackers are taking, their health status can be compromised. Emergency departments are increasingly confronted with this type of problem, either in terms of diagnosis or therapeutics. In fact, the risk of drug leakage due to the rupture of the package varies with the method of concealment and its context (eg: body stuffers vs. bodypushers) [9]. A better knowledge of the drug would allow clinicians to have a rapid and specific medical response. Consequently, a relevant imaging examination is urgently required in the emergency work-up in this context.

Plain abdominal radiography is the reference method for confirming the presence of packets of

drugs in the digestive tract [5]. However, its diagnostic accuracy is limited due to the different techniques of wrapping, intestinal air, scybala, calcifications, and other foreign bodies [3, 10]. Several studies have demonstrated the superiority of computed tomography (CT) on plain abdominal radiography in the detection of drug packs in the digestive tract [11, 12]. CT scan is indicated in cases of bodypacking with a negative or uninterpretable plain abdominal X-ray or in traffickers suspected of drug package leakage or bowel obstruction [5]. Indeed, the sensitivity of CT for the detection of intracorporal drug package is close to 100% with a specificity of 94% [13].

Differentiation by imagery of intracorporal substances has risen in recent years. As early as 1986, Wackerle *et al.* described the benefit of measuring attenuation in Hounsfield units (HU) to differentiate cocaine from heroin [14]. However, relying solely on attenuation measurements obtained from single-energy CT is limited because HU values are affected by several influencing factors [5, 15]. Using dual-energy CT enables the measurement of the attenuation values of 2 different energy levels, which allows for the differentiation of materials such as urinary acid stones from calcified stones or calcified plaques from iodine [16–18]. Few articles have recorded dual energy in the identification of narcotic drugs. An experimental study by Leschka *et al.* in 2013 focused on cocaine and heroin in a colon model but erroneously used a double-energy index (DEI) formula for material dissolved in water, which did not allow reliable extrapolation of the results [19]. Grimm *et al.* assessed the evaluation of cocaine and heroin in varying degrees of compression, and concluded that the DEI was independent of the degree of compression [15].

No study so far has focused on the differentiation of other narcotic drugs such as amphetamines (MDMA) or cannabis using dual-energy CT. Also, it would be interesting to assess the influence of cocaine and heroin cutting agents on the DEI of cocaine and heroin.

The main objective of this study was to examine the DEI of different illicit substances in order to differentiate them. The secondary objective was to assess the dual-energy behaviour of some cocaine and heroin cutting agents in order to determine their influence on the DEI.

Material and methods

Drug samples were seized by the Judicial Police Department in several cases. Cocaine samples (5 packages of 10 g), heroin (90 g of powder), cannabis (1 kg of resin), and 3,4-methylenedioxy-methamphetamine (MDMA, 1.3 g of powder and 28 pills) were seized. These samples were provided under judicial seals.

In this survey, sodium bicarbonate, lactose, caffeine, paracetamol, taurine, and distilled water were investigated and were supplied from the pharmacy of our university hospital.

Protocol

Each sample was scanned twice on a single 16-row scanner (Brilliance 16, Philips, Amsterdam, Netherlands) with the following parameters:

- peak voltage tube 90 kVp tube current-time product 400 mAs,
- peak voltage tube 140 kVp tube current-time product 125 mAs.

The tube currents were adjusted to maintain the CT dose index at 26.3 mGy.

Samples were positioned in the centre of the ring to avoid dispersion artifacts. The detector collimation was 16×0.75 mm^2, and the slice thickness was 0.8 mm with an increment of 0.4 mm. The pitch factor was 0.438, and the gantry rotation time was 0.75 s.

The images were reconstructed with a hard kernel and transferred to a dedicated radiological workstation for image processing.

Computed tomography analysis

We performed mathematical operations on images to obtain a mapping of 90 kVp and 140 kVp attenuation values and a DEI mapping using Image J (Bethesda, MD, USA), a processing program for scientific multidimensional images (Fig. 1, 2). 3D segmentation of the samples was done. We thus created a histogram of the set of voxels present in the segmented volumes. A mathematical adjustment of the data with Gaussian function was performed after verifying the normal distribution of the collected values.

DEIs of each voxel were calculated from the attenuation values at 90 kV and 140 kV according to

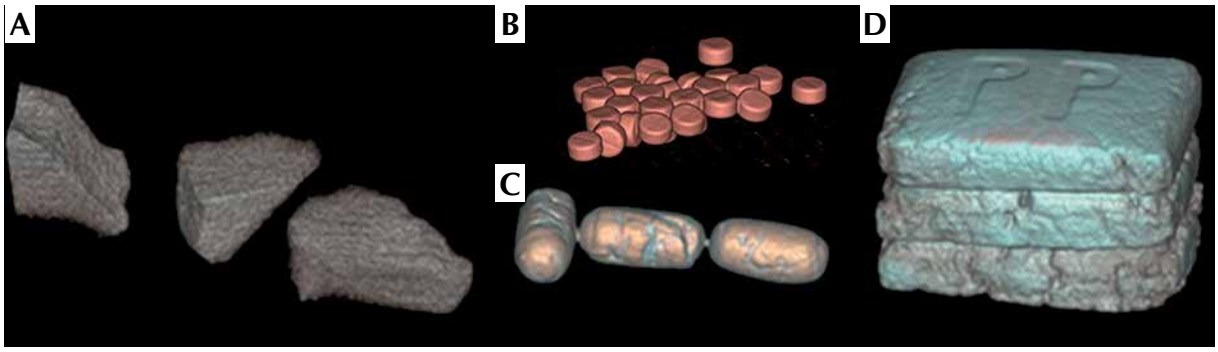

Fig. 1. Example of studied drug samples displayed using volume rendering technique. **A** – heroin, **B** – pills of MDMA, **C** – cocaine, **D** – cannabis

the following formula (1). Mean and peak values of the DEI were analysed.

$$(1)\ DEI = \frac{(Attenuation\ 90\ kVp - Attenuation\ 140\ kVp)}{(Attenuation\ 90\ kVp + Attenuation\ 140\ kVp + 2000)}\ [15]$$

Statistical analysis

Statistics were performed using thousands of voxels for each drug sample using the segmentation pipeline. The reported mean values were computed from all these measurements. The peak is defined as the value for which most voxels are represented in the distribution.

All statistical analyses were conducted using Stata software (version 12, Statacorp, TX, USA). Distribution charts were made using Matlab software (version 2017a, Mathworks, MA, USA). The different samples were compared using an ANOVA test with multiple Bonferroni comparison. $p < 0.05$ was considered statistically significant. Numerical variables are expressed as mean ± standard error.

Results

Segmented volumes of studied substances were as follows: cocaine 39.45 mL, cannabis 337.49 mL, heroin 42.48 mL, MDMA pills 3.32 mL, MDMA powder 1.56 mL, sodium bicarbonate 168.46 mL, distilled water 500.10 mL, lactose 487.90 mL, paracetamol 701.81 mL, taurine 1296. 61 mL, and caffeine 646.82 mL.

The dual-energy behaviours of the different substances are summarized in Table I, Figure 3 for drugs and Figure 4 for cutting products.

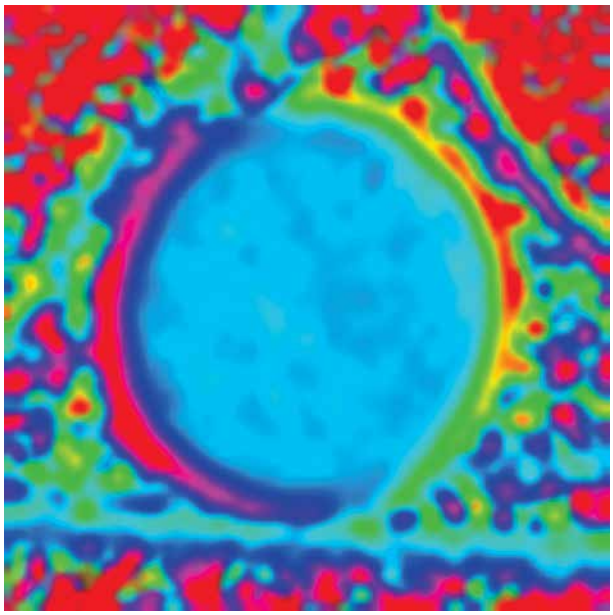

Fig. 2. Dual-energy index mapping (in the axial plane) of a cocaine sample using Image J Software

Heroin had higher attenuation at high voltage (–99 HU at 90 kVp to –69 HU at 140 kVp, DEI = –0.016) while cocaine had a lower attenuation (263 HU at 90 kVp to 204 HU at 140 kVp, DEI = 0.023).

There was a significant difference between the overall DEI of MDMA powder (–0.013) and that of MDMA pills (0.008).

Of the 5 cutting products studied, bicarbonate, lactose and taurine had positive DEI (DEI = 0.02, 0.013, and 0.026, respectively) whereas paracetamol and caffeine had negative DEI (–0.024 and –0.02, respectively). The water had a negative DEI at –0.01.

ANOVA determined that the mean DEI for all drug samples and cutting agents were significantly

Table I. Attenuation in Hounsfield units at 90 kVp and 140 kVp and the resulting dual-energy index (DEI), with corresponding standard error, according to the drugs and cutting agent samples. Note that there is no difference between average DEI and DEI peak of heroin and cannabis. Note that the table displays the gap between the DEI peak of water (–0.018) and the DEI peak of the studied substances. With this presentation, 2 groups are represented: the heroin group with a DEI close to that of water and the cocaine-MDMA-cannabis group, with a more distant DEI

Substance	Attenuation at 90 kVp		Attenuation at 140 kVp		DEI mean		DEI peak	
	Value in HU	SE	Value in HU	SE	Value	SE	Value	Gap with water DEI peak
Drugs								
Cannabis	104.099	0.039	71.514	0.077	0.014	7.31E–06	0.014	0.032
Cocaine	263.883	0.193	204.502	0.188	0.023	7.46E–05	0.013	0.031
Heroin	–99.096	0.071	–69.437	–0.064	–0.016	3.20E–05	–0.016	0.002
MDMA-pill	24.836	0.968	–31.886	1.365	0.008	2.52E–04	–0.005	0.013
MDMA-powder	236.885	1.285	270.766	0.619	–0.013	5.71E–04	–0.009	0.009
Cutting agents								
Sodium Bicarbonate	–24.161	0.227	–74.354	0.191	0.026	1.37E–05	0.008	0.026
Water	–39.386	0.048	–19.903	0.06	0.01	7.45E–06	–0.018	Reference
Lactose	–301.317	0.248	–318.783	0.214	0.013	5.32E–05	–0.007	0.011
Paracetamol	–245.894	0.073	–233.754	0.112	–0.024	4.33E–05	–0.023	–0.005
Taurine	–84.837	0.084	–221.706	0.031	0.026	2.91E–05	0.039	0.057
Caffeine	–608.801	0.152	–597.688	0.172	–0.02	6.81E–05	–0.035	–0.017

DEI – dual-energy index, HU – Hounsfield units, SE – standard error

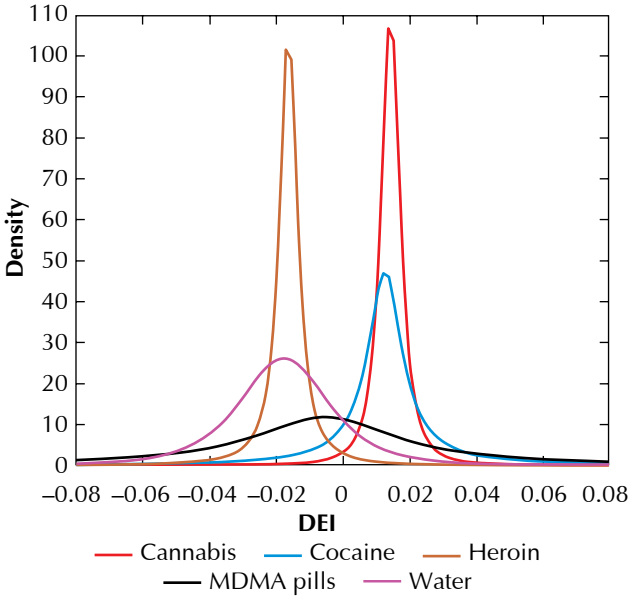

Fig. 3. Fitted distributions (density of the number of considered voxels having a specific value) of dual-energy index of the drugs (cocaine, heroin, cannabis, MDMA – pills and water). This graph shows 2 very distinct peaks of heroin and cannabis. We can also differentiate between the peak of heroin and cocaine

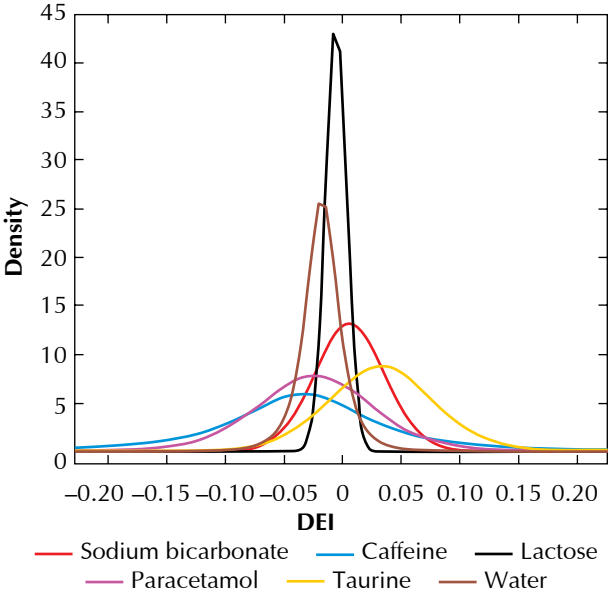

Fig. 4. Fitted distributions (density of the number of considered voxels having a specific value) of dual-energy index of the cutting agents (sodium bicarbonate, caffeine, lactose, paracetamol, taurine, and water)

different ($p < 0.001$). A post-hoc analysis using Bonferroni's correction revealed that all substances were significantly different from each other ($p < 0.001$ for each comparison) and therefore could be differentiated.

Discussion

This is the first study to widen the differentiation between cocaine, heroin, cannabis, and MDMA and to focus on cutting products. Instead of relying on the attenuation of water, which can change from one scanner to another, we chose to measure the difference between the DEI of water and the DEI of drugs in order to obtain results, independently from the scanner manufacturer. Distilled water was chosen as a standard, like in chromatography. The theorical DEI of water should be 0, but in practice there is some variation depending on the type of scanner and the age and calibration of the X-ray tube [20].

The attenuation values found for cocaine as well as for heroin were within the range of the values found in the literature. In fact, the literature shows a significant variation in the corresponding attenuation values [7, 11, 14, 15, 19, 21, 22]. Pache *et al.* found attenuation values for cocaine between 17 and 154 HU [21]. For Wackerle *et al.* attenuation values of heroin were around –520 HU and for cocaine, approximately –220 HU [14]. Factors explaining these variations include the following: the degree of packet compression, the percentage of moisture, the substance form (powder, resin, or liquid), the packing method, or the proportion of adulterants [5]. Cutting agents, either diluents or adulterants, are components added to drugs at any step from their manufacturing until consumption [23, 24]. The most frequently encountered adulterants are paracetamol and caffeine for heroin and caffeine for cocaine. Lactose and sodium bicarbonate are commonly encountered as diluents [23, 24]. Although adulterants seem to be added at production and at the high level of distribution, the purity of cocaine and heroin decreases in the lower chain of distribution [23]. Our samples of cocaine and heroin should have a high purity because they were seized in the context of drug importation, especially in cases of bodypacking.

This study found a positive DEI for cocaine and negative for heroin, according to the literature [15, 24]. In the Laberke *et al.* study, only pure cocaine from a pharmacological laboratory showed a negative DEI [24]. The presence of diluents with positive DEI (lactose, bicarbonate, etc.) and a higher concentration of tin (contamination from clandestine laboratories in South America) than in pure cocaine, may explain the positive DEI of the seized cocaine. Furthermore, the average concentration of cocaine in the intercepted packages in 2010 was 48%, with a maximum of 10 adulterants detected [25].

We also investigated the dual-energy behaviour of amphetamines and cannabis. The attenuation values of cannabis and MDMA were highly variable because of their heterogeneous composition. In 1986, Wackerle *et al.* described an attenuation at 700 HU at 125 kV for cannabis, whereas we found an attenuation of 71 HU at 140 kV. This difference in values may be due to different methods of cannabis resin manufacture and/or the use of various cutting products ranging from plant debris to paraffin [26]. We found a significant difference ($p < 0.01$) between MDMA powder and MDMA pills. One explanation for this disparity is the highly heterogeneous combination of amphetamines. In fact, intercepted products generally contain only 10% of MDMA, the rest are cutting agents such as caffeine or paracetamol [26]. Different proportions of caffeine/paracetamol (at negative DEI) may be also responsible for the variation of the DEI [23].

The DEI of the drugs were all significantly different ($p < 0.01$), but when examining distribution curves, there was a significant overlap between the DEIs of cannabis and cocaine, which did not allow us to distinguish them. In fact, this does not affect the value of our conclusions because the 2 substances can easily be distinguished because they do not have the same macroscopic presentation: one is presented as a brown resin (cannabis), while the other is a white powder (cocaine). Moreover, since the legalization of cannabis use in some countries, its intracorporal transport is increasingly rare but still occurs [7].

Taurine has been studied for its cocaine-like effects. It is considered in France as a narcotic. Some traffickers use it as a cutting agent for cocaine and amphetamine [27]. It had a positive DEI, close to cocaine.

The differences observed between the DEI peak and the mean DEI of cocaine, water, and MDMA reside in the shapes of the distribution curves.

For cannabis and heroin, the distribution curves were very narrow, whereas for cocaine, water, and MDMA, the curves were wider. Since the average is not always representative of the sample distribution, it may be more useful to use the maximum values of the distribution curves of the DEI.

In our study, the automatic mapping of the samples via ImageJ made it possible to collect raw data of the attenuation values, the latter functioning by contouring. These values are "contaminated" by the peripheral voxels of the samples because the latter are averaged with air or with the plastic of the sample container. The resulting means are thus influenced negatively or positively. The value of the peak of the DEI distribution provides a more robust estimation of the DEI.

In a forensic environment, DEI-based material differentiation has become a recommended method for the differentiation of foreign bodies, lodged projectiles, or body-worn explosives [28–31]. In the same way, this technique will also certainly find its place in the characterization of illicit substances such as drugs.

The strength of the study was that we used software to obtain automatic mapping of the attenuation values and the DEI, avoiding the subjective character of the regions of interest set up.

The limits of the study were as follows:

- an exhaustive analysis of all adulterants and diluents was not carried out in this study. A more comprehensive later study could be carried out to more accurately assess the impact of cutting products on the DEI,
- we used a limited number of samples with varying, uncontrolled concentrations.

The purity of the samples of drugs could not be assessed in this survey because of administrative difficulties. Although adulterants seem to be added at production and at the high level of distribution, the purity of cocaine and heroin decreases in the lower chain of distribution [23]. Our samples are presumed to be of high purity because they were seized in the context of drug importation, especially in cases of bodypacking

Finally, the values are only valid for the CT scanner used in this study. A subsequent study on other machines from different manufacturers would test the validity of these results. And the analysis of other spectral imaging characteristics like electron density or effective atomic number [28] could enhance drug discrimination.

Conclusions

The results of our study confirm the possibility of differentiating drugs using the DEI. In vitro, these parameters are all significantly different, but considering the general behaviour of the samples studied using mean and peak DEI values, the profile of MDMA differs from cocaine and heroin, while cannabis cannot be differentiated from cocaine. An in vivo study should be considered in order to confirm these results and consequently to improve the management of symptomatic bodypackers.

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Address for correspondence
Prof, MD, PhD Douraied Ben Salem
Forensic Imaging Department
University Hospital of Brest
Boulevard Tanguy Prigent
29609 Brest Cedex, France
e-mail: douraied.bensalem@chu-brest.fr

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