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Illicit drug detection with laser 1: investigation of optimal parameters in stomach tissue

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Abstract. The main purpose of this study is to establish radiation-safe scanning of passersby at high security areas, such as airports and customs. The stomach was selected as the organ to be analyzed. In order to determine whether a substance found inside a human body as wrapped in a plastic bag is filled narcotics or not, many substances in white powder form including morphine-HCL were inspected. Inspection was carried out with on-ionizing radiation by irradiating stomach tissue with laser light. Optical transmittance of lamb stomach tissue was analyzed at different wavelengths. We showed that detection by 650-nm diode laser irradiation would be suitable for such a radiation-safe scan. Different materials were also investigated for absorptive properties, and closed system Raman studies were performed. The spectrum of a molecule found inside white powder placed behind the lamb stomach tissue was detected as a fingerprint. This allowed the detection of target substances without any physical contact or damage to the biological tissue. [DOI: 10.1117/1.JBO.19.5.057006]

Keywords: forensic science; photonics; stomach; biomedical lasers; optics; radiation safety; detection; Raman.

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1 Introduction

Being an interdisciplinary area, forensic science has been advancing with the use of biomedical optics. Vibrational and scattering spectroscopic methods have been widely employed in order to detect nonbiologic substances such as fabric fibers,[1] and biologic materials such as body fluids and organic dyes.[2,3] So, this study can be part of forensic biomedical optics. It is possible to see inside the stomach of a human body using harmful (ionizing) x-rays, and usage of x-ray detection takes an important role in daily life, especially at specific places such as airports, customs, and borderlines, for example. In the case of smuggling illicit materials such as drugs and pills in luggage or other forms of boxes, x-rays are very crucial and useful for detection. Moreover, people sometimes swallow illegal materials wrapped in plastic bags for smuggling. Suicidal attacks with explosives hidden in the body should also be considered. Although x-rays can be used for detection, they are risky when the subject is a human body. Principal area of x-ray usage is medical imaging and the search for less ionizing techniques is still going on. Screening the materials with Raman systems brings about recognition of the chemical of interest. Suspicious materials' identification and classification studies related with the Raman techniques have been carried out by Weyermann et al.[4] and Marshall et al.[5] Inspected materials have been classified out of the human body or specific organ. Applied methods were related to the preparation of solutions and scattering analysis. In the literature, there has been no study designed in such a way that the material of interest was placed inside an organ or animal and chemical analysis was performed without physical contact.

On the other hand, the desire to detect hazardous chemicals and low-vapor pressure of common explosives at standoff distances has led to the research and development of many laser-based techniques, with the hopes of rapid applications to the areas of defense, national security, and environmental disasters. Especially in the case of explosives placed in a nontransparent box, it would be much safer to scan the box from outside the possible blast radius. In this case, x-rays can be used to achieve a proper scan of the box, but at close range, a scan with x-rays would be more dangerous. A long-range detection study determined the chemical composition of a substance at standoff distances (>10 m) by femtosecond lasers integrated with mirrors, telescope collecting systems, and coherent anti-Stokes Raman spectroscopy (CARS) detection systems.[5,6]

Taking into account both the distance and harmful radiation makes Raman spectroscopy a better method than IR spectroscopy, considering Raman's scattering signal usage and signal amplification option for the water constituents of matter, such as biological tissues.[7]

This study focuses on the advantages of laser–tissue interaction mechanisms for the criminal issues, where the detection of morphine-HCL wrapped in plastic bags also placed in the stomach is achieved without using hazardous ionizing x-ray radiation. Here, the optimal parameters, which are laser power, laser wavelength, and protein elements of the target tissue, are the main subjects of this article.Therefore, this study was initiated with the search for a proper laser wavelength, for which the target organ, the stomach tissue, would be transparent. The range of optical absorption coefficients (optical window) plays an important role when a biomedical application with laser–tissue interaction is the subject, as shown in Fig. 1.[8–12]

In general, the main elements of the tissue to be studied determine the wavelength of laser light to be used. When

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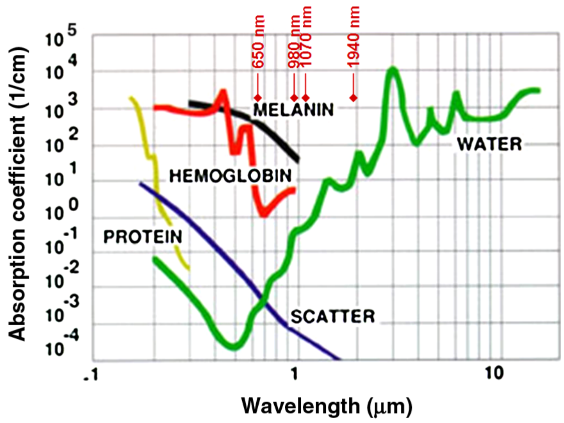

Fig. 1 Optical window.

a photon interacts with organic tissue (turbid medium), scattering, absorption, reflection, and transmission take place, and the optical properties determine the type of interaction mechanism.[8–12] Laser wavelength should be selected from the specific region that has high penetration depth, as seen in Fig. 1. Since the stomach tissue, which has a relatively light color, should be transparent to laser light, a minimal absorption by hemoglobin is expected, although the organ is highly muscular and vascularized even at its peak region from 100 to 1000 nm. Scattering should occur at the relatively lower region, i.e., 600 to 1000 nm. The absorption of water should be as low as possible at the specific wavelength range. If a medical treatment was to be performed on stomach tissue for coagulative purposes, then the wavelength of the laser should be selected in the vicinity of 3000 nm (3 μm).[8–12]

In brief, the main purpose of this preliminary study was to determine if a material placed inside stomach is narcotics or not. The detection of morphine-HCL signal behind stomach tissue was achieved by Raman spectrometry. Transportable Raman devices are known to be used at customs in some airports.[4] So it may be possible to design a comparable multipurpose compact system to be used at crime scenes.

2 Materials and Methods

2.1 *Laser Light Determination*

All the measurements related to laser wavelength determination were performed at Biophotonics Laboratory of Institute of Biomedical Engineering of Bogazici University. The main detection system was composed of double integrating spheres (Labsphere, 4P GPS-033 SL, North Sutton, New Hampshire), four silicon detectors (Labsphere, SDA-050-U-RTA-CX), a sample holder, and a reflection standard. Other components concluding the system were the light source, the lock-in amplifier (Stanford Research Systems, SR510, Sunnyvale, California), and the monochromator (CVI DK 480 ½ meter).

Table 1 Absorptions of plastic bags.

	Empty 1	Layer 2	Layers 4	Layers 8	Layers
Plastic Bag 1	22.8 mV	21.3 mV	21.5 mV	21.5 mV	20.3 mV
Plastic Bag 2	22.8 mV	21.9 mV	22 mV	21.1 mV	20.2 mV

Lasers we tested were 650-nm (DH-650, Huanic Inc., Shaanxi, China) diode laser, 980-nm (OPC-D010-980-FCPS, OptoPower, Tuscon, Arizona) diode laser, and 1070 (YLM-20-9C IPG Laser GmbH) and 1940-nm (IPG Laser GmbH, Burbach, Germany) fiber lasers. Their wavelengths are marked in Fig. 1. Measured signals, exposure power, and exposure duration (application time) for each of the lasers are listed in Table 2.

2.2 *Measurements*

Only the 650-nm diode laser (DH-650, Huanic Inc. PRC) was used, and the laser light was modulated by a reference signal at 436 Hz. Since the laser light is coherent, and the main purpose was to have a longer distance between the modulated light source and the target, the distance between them was fixed at 156 cm. Both the transmitted and reflected light beams were measured as electrical signals in millivolts by double integrating spheres (Labsphere, 4P GPS-033-SL), their detectors (Labsphere, SDA-050-U), and lock-in amplifier (Stanford Research Systems, SR510). The distance between the spheres and samples was 5 mm.

2.3 *Sample Preparation*

Samples were five different materials in dust form (white powders), visually resembling each other, two different lamb stomach tissue specimens of different thicknesses, and two transparent plastic bags made of different materials.

2.3.1 *White powders*

White powders were selected to look like morphine; flour, chalk, morphine-HCL, starch, and powdered sugar. Morphine-HCL was obtained with official permission from Istanbul University Forensic Sciences Institute. White powders were placed between two slides (1-mm thick) and signal measurements in millivolts were performed three times at different thicknesses. Powder thickness between the slides was also measured by an electronic caliper. We were unable to observe any difference between the absorptions of plastic bags and slides at 650 nm.

White powders were wrapped with a stretch film on a slide during the Raman measurements in order to keep the substance together inside the device. Since the presence of a tiny particle of morphine powder is enough for detection while working with the Raman device, data from one measurement was accepted as sufficient.

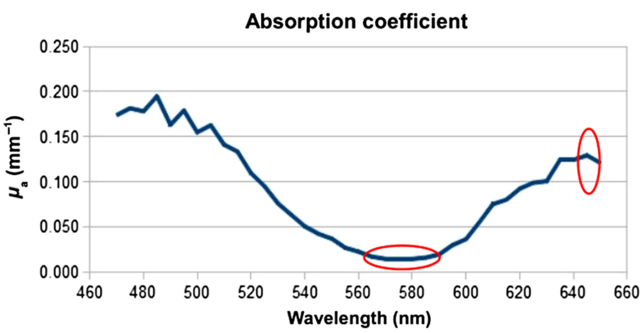

Fig. 2 Graphic of measured optical properties of stomach tissue, absorption coefficient versus wavelength.

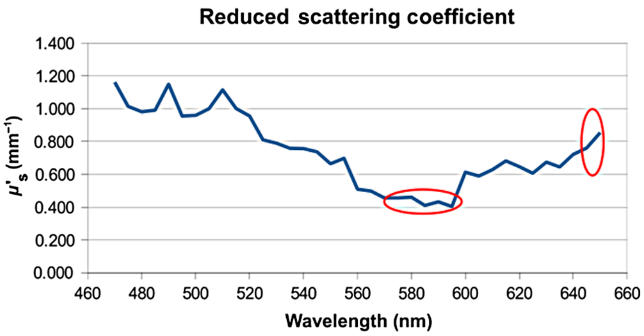

Fig. 3 Graphic of measured optical properties of stomach tissue, reduced scattering coefficient versus wavelength.

2.3.2 *Tissue specimens*

Lamb stomach (abomasum part) was selected because the human stomach is generally modeled with it.[13] Tissues were supplied from a local slaughterhouse for the first experiment and placed in a cool box (0 to 4°C) within the first 15 min after slaughter. Tissues were transported to the laboratory in that cool box. There was not a single drop of blood inside the box when opened, which means the tissue's blood did not spill around. The blood of tissues that were used the next day after slaughter had not spilled around either.

Experiments were performed on the same day, or one day after at most, of slaughter in order to prevent the optical properties of the stomach tissue from altering. Tissues were cut by lancet (surgical type, no.: 11) in dimensions of 40×50 mm. These small tissue parts were rolled inside the larger part of the stomach in order to keep samples humid while waiting for measurements to be taken.

2.3.3 *Plastic bags*

Measurements with empty apparatus set as reference values were performed before any of the plastic bags were inserted into the apparatus. In order to compare absorption differences between both situations (with and without the plastic bags), the folded plastic bags were also measured as seen in Table 1.

2.4 *Target Detection with Raman Signals*

Target detection was performed with a Raman spectroscope at Fatih University, R&D Center of BioNano Technology. The Raman device (Thermo Scientific, DXR Raman Microscope, Massachusetts) was a dispersive, closed, and integrated system, with a 780-nm solid state laser. The tissue is transparent enough for 780 nm. The distance between the target and laser light source was about 1 to 2 mm, because a closed system Raman device was used. Signals from the target substance (morphine-HCL) were measured without the tissue at first and then from behind the tissue.

Table 2 Lasers and optimal parameters.

Lasers (nm)	Duration (s)	Laser Power (mW)	Measured Signal (mV)
650	10	5	25.6
980	10	3600	256
1070	10	3200	830
1940	10	1500	–

3 Results and Discussion

Scattering and absorption coefficients of biological tissues (turbid media) can be determined by optical setups like a double integrating system. Various factors related with tissue composition such as water content and specific chromophores affect optical characteristics which can be calculated by implementing IAD software developed by Prahl.[14] Related graphs (Figs. 2 and 3) were drawn for stomach tissue obeying information written in the instruction manual of IAD program.

After the optical properties of the stomach tissue were measured, it has been predicted by using the optical window (Fig. 1) that the stomach tissue would behave transparently to lasers of wavelengths between 550 and 800 nm. After performing the first few experiments, it was shown that the wavelengths between 550 and 800 nm would be convenient. Then, the transparency effects of the medical lasers having 650, 980, 1070, and 1940-nm wavelengths were observed and listed in Table 2. In addition to the wavelength, the power level is also important for biomedical applications. So, among tested lasers, the 650-nm laser with the least power usage (5 mW) was selected. Maximum signal gain is also supplied (Table 2).

It was evaluated that the stomach tissue behaves almost transparently to 650 nm because of the high penetration of the laser at this wavelength. No signal was detected from the 1940-nm laser. Since there is an absorption peak of water near 1940 nm, as seen in Fig. 1, it is expected that almost the whole energy of light beam is converted to heat, which creates coagulation mostly by the water constituent of stomach tissue. Coagulation is an unwanted effect and does not serve the purpose of this study as it means serious damage to the tissue itself. The absorption peak of water near 1940 nm explains the thermal damage observed (Fig. 4) when the laser is applied.

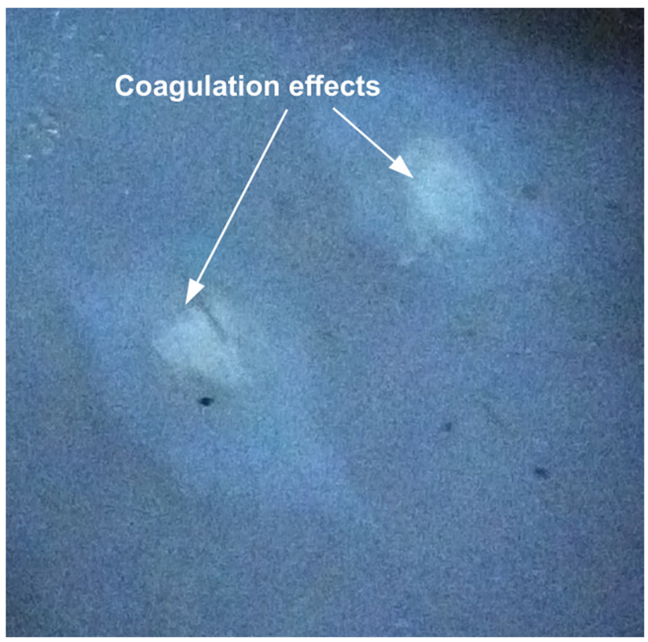

Fig. 4 Thermal damage of 1940 nm.

Table 3 Reflected and transmitted electrical signals.

		Reflection (mV)			Transmission (mV)		
Matter	Thickness (μ)	Alone	Tissue 1	Tissue 2	Alone	Tissue 1	Tissue 2
Powdered Sugar	420	10.01	8.4	7.45	9.15	6.15	6.01
	600	10.16	7.7	7.35	9.24	5.44	5.65
	870	10.35	8.53	7.38	9.6	6.81	6.03
Flour	550	9.51	8.24	7.34	8.5	6.02	5.74
	640	9.65	8.29	7.47	8.99	5.99	6.12
	1050	9.92	8.36	7.39	9.2	6.28	6.07
HCL-morphine	410	8.69	7.81	7.27	8.41	4.57	5.02
	780	9.33	8.04	7.35	8.84	5.72	5.76
	840	9	8.01	7.35	8.8	5.71	5.83
Chalk	440	10.33	8.06	7.52	9.82	5.8	5.95
	630	10.02	8.21	7.43	9.61	5.98	5.82
	1030	9.82	8.42	7.56	9.59	6.35	6.27
Starch	610	10.02	8.18	7.52	9.21	5.76	5.94
	710	10.01	8.29	7.46	9.33	5.84	5.91
	900	10.12	8.34	7.45	9.55	5.98	5.92

After the selection of the 650-nm wavelength, electrical signals from white powders are measured as the next step. Reflectance and transmittance were measured as electrical signals in millivolts (Table 3). As the powder between two slides thickened, the transmitted part of the signal decreased while the reflected part increased as expected. Although the purpose of this part of the study was to determine the reflected signal if any, some interesting results were obtained. For example, chalk powder, the only inorganic substance, created so little difference that was nearly impossible to measure.

This part of the study was not mandatory but it was hard to find a Raman device. So, we had to be sure about the reflection (reflected signals) before Raman trials, since the main principle of a Raman system is based on reflectance.

The last part was to detect the characteristic signals of morphine-HCL behind the tissue. The Raman device matched

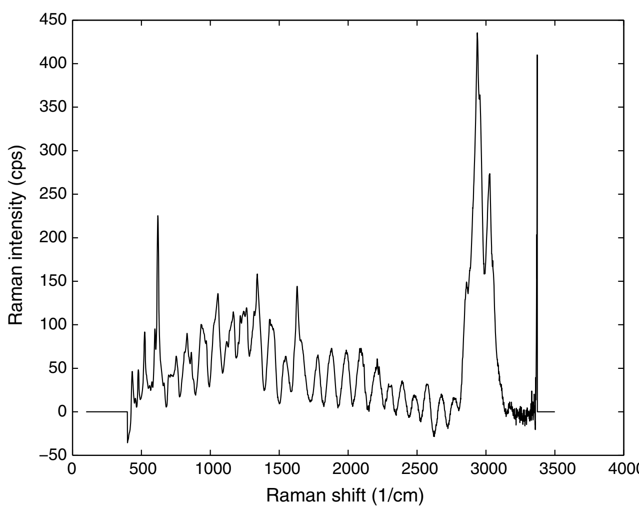

Fig. 5 The spectrum of morphine-HCL matched with codeine 355.

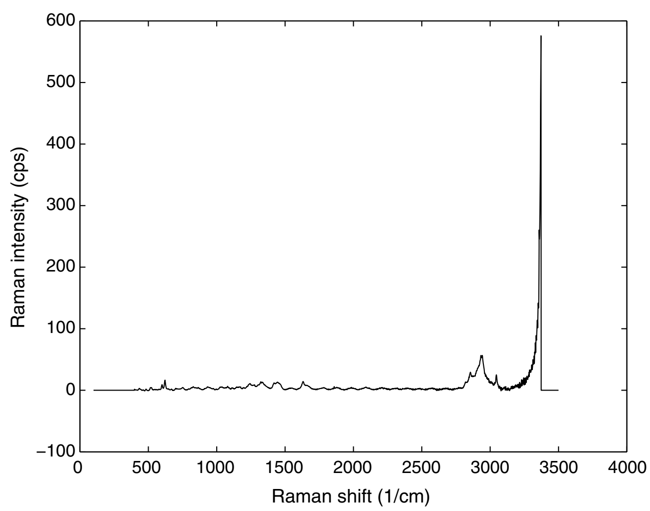

Fig. 6 Morphine-HCL spectrum obtained behind tissue.

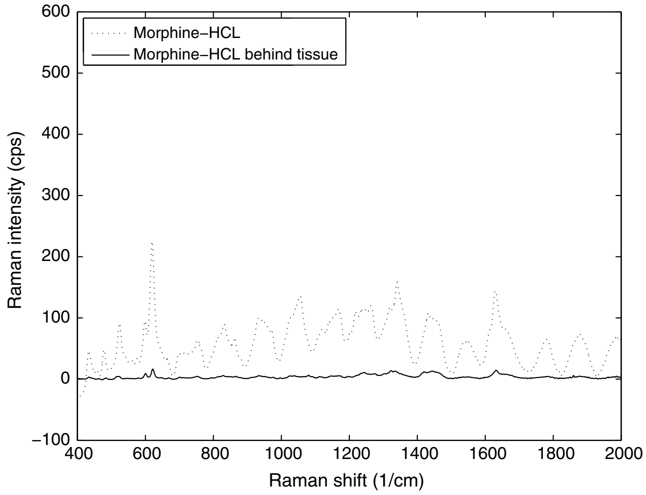

Fig. 7 Overlapping common peaks of morphine-HCL and morphine-HCL behind tissue over the range of 400 to 2000 cm^{-1}.

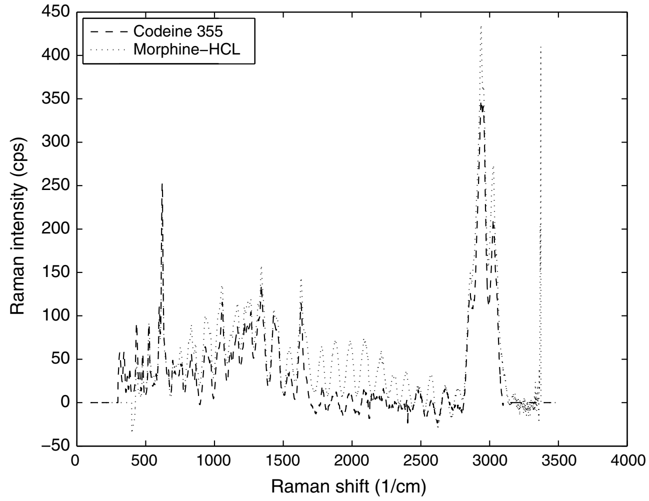

Fig. 9 The device was matched morphine-HCL with codeine 355, overlapping "regional peaks."

morphine-HCL with codeine 355, from its library (Fig. 5) when its spectrum was obtained as the single substance. The intention here is to determine whether a substance is illegal or not, so the detection of "regional peaks," which are common in narcotics in general, is enough to identify a substance (Fig. 7) as morphine-HCL and codeine 355 belong to the same family.[4,7,15] The name of the substance is of no importance after this stage.

At the next step, the morphine-HCL spectrum was obtained again, but now behind the tissue (Fig. 6).

Almost the same characteristic peaks of morphine-HCL without the tissue were observed as seen in Fig. 6.

The most important and deterministic peaks are in the vicinity of 600 and 3000 cm^{-1}. In order to observe the overlapping of these peaks in more detail, morphine-HCL and morphine-HCL behind the tissue are compared separately over the range 400 to 2000 cm^{-1} in Fig. 7, and over the range 2000 to 3500 cm^{-1} in Fig. 8.

These resembling peaks are characteristics of narcotics.[4,7,15] So, if some of these common peaks are detected, the substance analyzed is possibly that of narcotics, namely an illicit material.

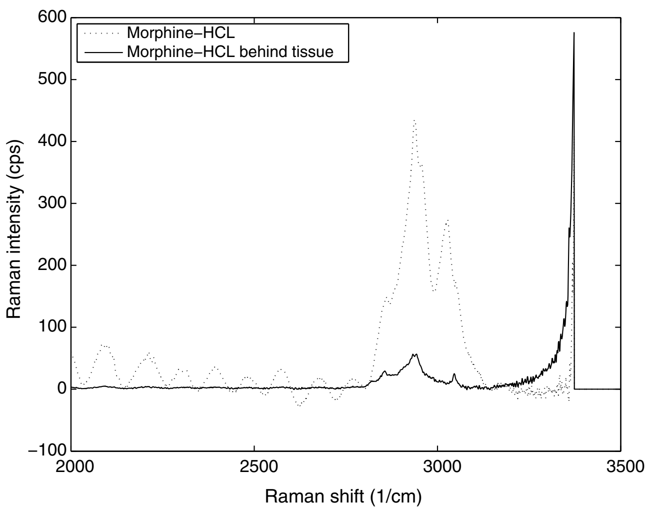

Fig. 8 Overlapping common peaks of morphine-HCL and morphine-HCL behind tissue over the range of 2000 to 3500 cm^{-1}.

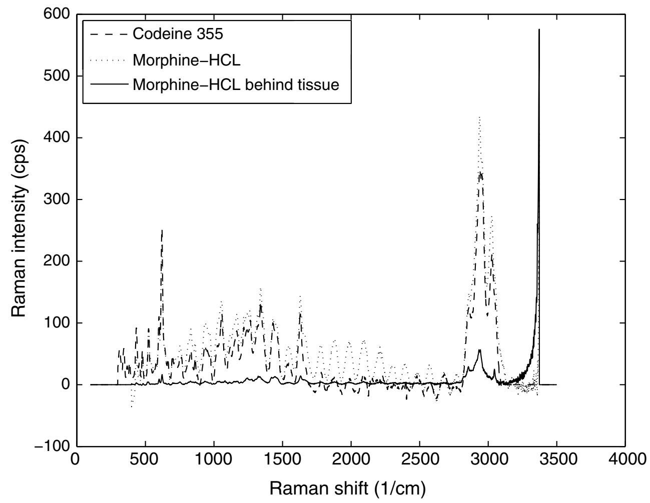

Fig. 10 Comparison of codeine, morphine-HCL, and morphine-HCL behind tissue.

The morphine-HCL spectrum obtained behind the tissue was checked against the device's own library again, and then plotted (Fig. 9). The device matched morphine-HCL with codeine 355.

The common peaks of narcotics were compared with each other as seen in Fig. 9 then a triple comparison was demonstrated in Fig. 10.

4 Conclusion

Raman spectroscopy is based on a weak scattering principal. Although it depends on weak signals, the presence of a tiny particle of the target substance is enough for detection. So, an advantage of Raman spectroscopy is the sufficiency of repeating the measurements a few times. Observation of the common peaks of narcotics even with weak signals is promising, as it is possible to amplify the signals with more advanced apparatus.

As mentioned in the title, this is the first phase of a two phase experiment. The purpose of the next phase is to repeat the same experiments with an open Raman system. The most important difference between the two systems is the effective working distance. The working distance of an open Raman system is higher than the closed Raman system used here. If the open Raman system will be able to identify the target substance with an acceptable accuracy, then the next step would be to work on increasing the detection distance.

Low-power lasers are very important for biomedical applications. From a forensic science perspective, using lasers' unique characteristics in the field of detection for security reasons has been warranted. Thereby, the use of lasers in this field will gain wider relevance compared with x-ray devices.

The most important outcome of this study is the detection of the reflected signals of a narcotic material behind a relatively thick tissue by a low-power laser. Moreover, this was achieved without any physical contact with the tissue and without any physical damage to the tissue. Resulting from the limits of the Raman device used for this study, the presence of the target material was not detected at different distances, but promising results were achieved. So, a transportable system to detect the material behind the stomach tissue may be designed with the help of advancing technology, as it would be similar to what is achieved here. If this system can be realized, it may be possible to achieve faster results, and it may be used not only for biological tissues but also for closed boxes with potential security risks.

Acknowledgments

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