The author(s) shown below used Federal funds provided by the U.S. Department of Justice and prepared the following final report:

Document Title: **Improving the Pharmcheck™ Sweat Patch: Reducing False Positives from Environmental Contamination and Increasing Drug Detection**

Author(s): **Melissa Long, David A. Kidwell**

Document No.: **196030**

Date Received: **September 20, 2002**

Award Number: **2000-RD-CX-A038**

This report has not been published by the U.S. Department of Justice. To provide better customer service, NCJRS has made this Federally-funded grant final report available electronically in addition to traditional paper copies.

Opinions or points of view expressed are those of the author(s) and do not necessarily reflect the official position or policies of the U.S. Department of Justice.

FINAL REPORT:
Improving the Pharmcheck™ Sweat Patch:
Reducing False Positives from Environmental Contamination and Increasing Drug Detection

Melissa Long
American University
4400 Massachusetts Avenue, NW
Washington, DC 20016
(202)404-3396
MJL1075@aol.com

David A. Kidwell
Chemistry Division
Naval Research Laboratory
Washington, DC 20375-5320
(202)767-3575
Kidwell@ccf.nrl.navy.mil

Abstract

Drugs externally applied to human skin were shown to bind readily. Drugs deposited on the skin of drug free volunteers several days prior to application of the sweat patch were not completely removed by normal hygiene or the cleaning procedures recommended commercially before application of the sweat patch. These externally applied drugs cause false positives as the volunteers did not use drugs. We term this mode of contamination - Contamination From WithIn (CFWI).

A number of different cleaning procedures were used to remove externally applied drugs. Orange Pumice hand cleaner followed by water and then isopropanol substantially reduced CFWI. However, even with these extensive cleaning procedures, some drugs remained which could cause false positives. We proposed saving the isopropanol cleaning swabs and testing the retained swabs for drugs, if the wearer of the patch denied drug use. We proposed that a ratio >10% of the drugs in the cleaning pads to that found in the patch is indicative of CFWI. A lower ratio or drug-free cleaning pads would indicate drug use by the individual.

Heavy sweating facilitates drug transfer. However, not all drugs placed on the skin are transferred to the patch. The presence of glycerol in the absorptive pad increases transfer 3-6 fold. Also, glycerol increases the wear comfort of the patch.

By employing simple modifications in the use of the patch consisting of (1) more stringent cleaning of the skin prior to patch application, (2) saving the last cleaning swab for testing, if necessary, and (3) incorporation of glycerol into the patch, the patch will be more suitable for detection of drug use in the criminal justice system.

KEYWORDS: sweat, passive exposure, cocaine, heroin, methamphetamine, MDMA, PCP

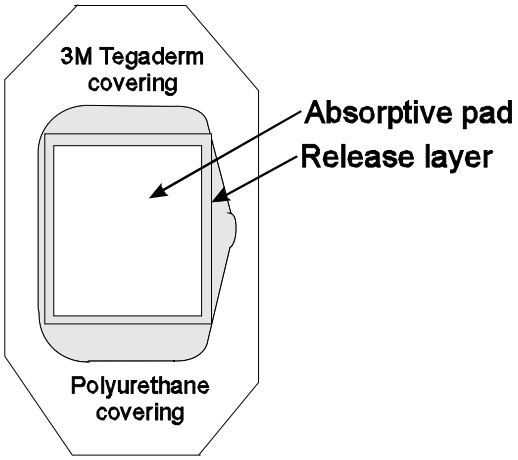
This document is a research report submitted to the U.S. Department of Justice. This report has not been published by the Department. Opinions or points of view expressed are those of the author(s) and do not necessarily reflect the official position or policies of the U.S. Department of Justice.

Introduction

Ingested drugs have long been known to appear in sweat and a number of sweat collection devices have been developed for their detection. The basic sweat collection device consists of an absorbent pad between the skin and an outer membrane that protects the sweat collection pad and provides a tamper-resistant layer. Non-occlusive membranes have been developed to allow the passage of water vapor, increasing comfort for the wearer, and allowing for longer wear.[1,2,3,4,5,6,7,8,9,10]

A sweat collection pad with a non-occlusive membrane, marketed by PharmChem, Inc. as the Pharmchek™ Drugs of Abuse patch (referred to as the patch throughout the text), is shown in Figure 1. This patch has found widespread application in the U.S. criminal justice system as a method to monitor drug use in pretrial or probationary cases due to its many perceived advantages including non-invasiveness, easily observed placement and removal, long term drug use detection of up to one week, and detectable adulteration attempts. Additionally, reports show that use of this device may either deter or cause individuals to be more forthcoming about drug use.[11] Because of its perceived advantages over other drug monitoring devices/procedures, the patch has drawn interest from the scientific community.[11,12,13,14]

Figure 1 - Bottom view of PharmCheck™ sweat patch.



Besides the advantages during use, the patch is an attractive device for several reasons. First, the skin is cleansed prior to application. Although considered by some to remove surface contamination, in reality the “cleaning” only prevents bacterial growth and removes any oils present that may interfere with the adhesion of the patch. Drugs present on the skin from prior exposure were not thought to affect results as the cleansing with 70% isopropanol swabs prior to patch application was thought to remove all drugs on the skin. Second, the patch appears to protect the skin from external contamination after application. Research has shown both of these considerations of drug removal and absolute protection not to be the case.[15,16]

Drugs from the environment bind to the skin through ionic and hydrophobic interactions, and may interact with binding sites on the surface of skin.[15] Sweat mediates the transfer of drugs from the skin to the patch by creating the wet environment needed for the transfer to occur. This transfer has been shown to be an equilibrium process. Not all of the drugs present on the

This document is a research report submitted to the U.S. Department of Justice. This report has not been published by the Department. Opinions or points of view expressed are those of the author(s) and do not necessarily reflect the official position or policies of the U.S. Department of Justice.

skin are transferred into the patch, nor does the current cleansing process remove those present on the skin. This may be because the cleansing process does not break the bonds that the drugs form with the skin, or because the drugs, given long enough time, get deep into the pores on the skin and cannot be reached by the cleansing process.[15]

Problems have arisen with its use. Offices of the U.S. Federal Public Defender have described cases in which individuals under supervised pretrial or probationary release have had their sweat patch test positive while credibly denying drug use. Urine tests on individuals have shown urine negative/patch positive results with close contact with a drug-contaminated environment. Several cases have involved individuals identified as methamphetamine positive who denied any methamphetamine use, while admittedly using other illegal drugs. The individuals involved in these cases were all in environments where profuse sweating was common and possible contamination was likely.[17] Several recent cases have been dismissed due to concerns with environmental contamination influencing the patch results.[18]

Prior research has shown that false positives using the patch could arise from both Contamination From WithOut (CFWO), where drugs from the environment diffuse across the outer, protective membrane, and Contamination From WithIn (CFWI) where drugs are present on the skin and are not removed by the cleansing process.[15,16] CFWO is thought to be a rare occurrence due to the conditions necessary for it to occur. In contrast, for CFWI to occur, only a drug source, a plausible transfer mechanism of the drugs to the skin, and binding of the drugs to the skin are needed. Because most individuals tested with the patch are previous drug users, they are more likely to be in an environment contaminated with drugs and are therefore likely to have their skin come into contact with drugs from previous use.[19] These individuals are also more likely to have labor-intensive jobs that cause profuse sweating which would assist the transfer of drugs from the skin into the patch.

Setting cut-offs to determine drug users from passively exposed individuals at arbitrary levels is unlikely to be effective because individuals may be passively exposed to any amount of drug and the removal before patch application is variable. Previous research has suggested that the skin swabs used for cleaning also be used in determining if patches are positive from drug use or from contamination. It was suggested that the results from the skin swabs must be <10% of the patch results for the patch results to be acceptable as a positive drug test.[19] In a recent report to the Administrative Office of the U.S. Courts,[20] an expert rejected this suggestion out of hand.

This paper explores the extent of CFWI, tests different methods of removing drugs from contaminated skin, tests if the 10% criteria for the last cleaning swab is sufficient to detect prior contamination, and compares various patch designs for their efficacy in absorbing and retaining drugs on the skin.

Materials and Methods

Analysis of patches

Skin swabs or patches were placed in a 15 mL plastic test tube held in place mechanically by a permeable divider at the upper third of the test tube, then spiked with a deuterated internal standard in ethanol and dried. The swabs and patches were washed with three 2 mL portions of 0.1 M hydrochloric acid, which was separated by brief centrifugation after each addition. The aqueous extracts were applied to MP1 or DAU solid phase extraction columns (Ansys, Inc.)

This document is a research report submitted to the U.S. Department of Justice. This report has not been published by the Department. Opinions or points of view expressed are those of the author(s) and do not necessarily reflect the official position or policies of the U.S. Department of Justice.

using a Zymark Rapid Trace. The columns were conditioned with methanol, 0.01 M hydrochloric acid, and 20% aqueous acetone. The columns were dried under positive pressure for one minute, and the drugs were then eluted with 40:10:1 methylene chloride/ isopropanol/ ammonium hydroxide. Patches made from Spec SCX (Ansys, Inc.) were washed with two 1mL portions of 40:10:1 methylene chloride/isopropanol/ammonium hydroxide, which was separated by brief centrifugation after each addition. For all swabs and patches, the elute was then concentrated to dryness under a stream of nitrogen and derivatized using 70 µL of 1% triethylamine in methylene chloride, 50 µL of acetic anhydride, and 20 µL of pentafluoropropanol at 70°C for 30 minutes. The excess derivatization reagents were evaporated under a stream of nitrogen. The drugs were reconstituted in 20 µL of ethyl acetate. 2 µL aliquots were injected into a Varian 4 GC/MS with the following parameters: 30 m DB-5MS column (J&W Scientific), initial temperature 100°C (20 seconds) ramped at 18°C/minute to 280°C then 5°C/minute to 300°C for 2.9 minutes for a total run time of 17.1 minutes. Samples were ionized using isobutane chemical ionization. Two mass ranges were scanned: *m/z* 90 to *m/z* 300 for the amphetamines and *m/z* 150 to *m/z* 450 for cocaine, BE, heroin, and PCP. Quantitation was performed by ratioing the peak areas of the protonated molecular ions to their respective deuterated internal standards.

Formulation of Artificial Sweat

Artificial sweat was formulated in accordance with the 3160/2 ISO standard as reported by Skoop, *et.al*.[21] Briefly, the artificial sweat contained 20 g/L NaCl, 17.5 g/L NH_4Cl, 5 g/L acetic acid, and 15 g/L *d,l*-lactic acid. The pH was adjusted to 4.7 using NaOH.

Drug Contamination on Skin Experiments

Prior to contaminating the skin of human volunteers with drugs, the skin was swabbed twice with sterile 70% isopropanol swabs for 10 seconds per swabbing while wearing new, disposable latex gloves. The swabs were saved for analysis. Then, specified quantities of drug standards in either artificial sweat or ethanol (0.05-5 µg containing 100-400 µL Rhodamine 6G dye (1 mg/mL in ethanol) for visualization under UV light) were placed on the upper arm areas. The following day, after normal activities and hygiene (including shower), the skin was swabbed twice with 70% isopropanol swabs or various acids in 70% isopropanol for 10 seconds per swab. Patches were applied to the contaminated areas, aided by the orange fluorescence from the Rhodamine 6G dye. The dye concentration was adjusted to be barely visible under UV light in a darkened room. The patches were removed for analysis according to manufacturer's instructions at designated time intervals. After patch removal, the skin was swabbed with 70% isopropanol swabs for 10 seconds per swab. All swabs and patches were then analyzed as previously described.

Cleansing of Skin with Various Acids

To evaluate the effectiveness of 70% isopropanol with various acids added in cleansing the skin, upper arm areas were cleansed as described previously then contaminated in three areas per arm with D_0 drug standards. The following day, after normal activity and a hygienic shower, the contaminated areas were cleansed with either 70% isopropanol swabs, 1% or 5% citric acid or *d,l*-lactic acid in 70% isopropanol. 1 mL of the chosen solution was placed on cotton balls that had been washed in 0.1 M hydrochloric acid, rinsed in distilled water, and dried. Each area was wiped with the chosen solution twice for 10 seconds per swab. The swabs were saved for analysis as previously described.

This document is a research report submitted to the U.S. Department of Justice. This report has not been published by the Department. Opinions or points of view expressed are those of the author(s) and do not necessarily reflect the official position or policies of the U.S. Department of Justice.

Cleansing with Hand Cleaner
Upper arm areas were cleansed, then contaminated with drug standards as previously described. These were allowed to bind for several hours before being cleansed twice with isopropanol pads as a control, or with gojo® Orange Pumice Hand Cleaner for 20 seconds, wiped off with 1 mL of water on a cotton ball, and then cleansed twice with isopropanol pads for 10 seconds per swab. Patches were then placed on the contaminated areas and worn for three days.

Use of Glycerol
Upper arm areas were contaminated with a 5 µg drug solution several hours before glycerol was used to cleanse the skin by making a 1:1 solution of glycerol/water with 10% lactic acid, or minute amounts (50 mg/10 mL) of either N-Hexadecyl-N,N-dimethyl-3-ammonio-1-propane sulfonate, or N-dodecyl-N,N-dimethylglycine. 1:1 glycerol/water without any additives was used as a control. The skin was then wiped with 1 mL of the glycerol solution on a cotton ball, 1 mL of water on a cotton ball, and then followed by two isopropanol swabs for 10 seconds per swab. All swabs were saved for quantitation of drug removed. Patches were then placed on the contaminated areas and worn for three days. Water was added to the glycerol to reduce viscosity and ease in measuring the solution, and slowly evaporated through the outer membrane of the patch.

Variation in Patch Design
Several types of patch designs were tested to evaluate the effectiveness of different anion exchange groups on the surface of the patch at retaining drugs. The Pharmchek™ Drugs of Abuse Patch was used as a reference. Ansys solid phase extraction paper (Ansys, Inc.), and Whatman P81, 3MM, and 1 chromatography papers (Whatman, Inc.) were tested. To make a patch, the papers being tested were cut to the same size as the absorbent pad in the Pharmchek™ Drugs of Abuse Patch. Since the Whatman P81 chromatography paper is small circles, 2 sheets were placed side by side for use as a patch. The papers were then placed on a piece of Whatman 1 chromatography paper (used to prevent the chosen material from adhering to the adhesive bandage). The whole assembly was placed on a 3M Tegaderm™ Transparent Dressing. For analysis, all layers were removed and tested. The patches were applied after the contaminated areas had been cleansed with various agents that had been allowed to dry to prevent interference with adhesion of the patch. Because the Pharmchek™ patches are expensive at $6 each, it was economical to find a material that worked similarly for these preliminary experiments and that would allow us to produce our own patches. Whatman 3MM proved to work similarly to the Pharmchek™ patches, and was thus used in its place for many experiments.

Addition of Glycerol to Patches
Upper arm areas were contaminated in two places per arm with 5 µg of a drug solution. Several hours later, two areas were cleansed with two isopropanol swabs, and the other two areas were cleansed with 1mL of glycerol/water, 1:1, with a small amount (50 mg/10 mL) of N-hexadecyl-N,N-dimethyl-3-ammonio-1-propane sulfonate on a cotton ball, wiped with 1 mL of water on a cotton ball, followed by two isopropanol swabs, each for 10 seconds per swab. Patches were applied to all four areas, with two patches (one per cleansing agent) having 1 mL of the glycerol solution applied to it prior to application. Water was added to the glycerol solution to reduce viscosity and ease in the measuring of the solution, and slowly evaporated through the outer membrane of the patch. The patches were worn for three days prior to being removed for analysis.

This document is a research report submitted to the U.S. Department of Justice. This report has not been published by the Department. Opinions or points of view expressed are those of the author(s) and do not necessarily reflect the official position or policies of the U.S. Department of Justice.

Addition of Glycerol to Patches in Conjunction with Orange Pumice Hand Cleaner.
Upper arm areas were cleansed once with 70% isopropanol swabs prior to being contaminated with 5 µg of a drug solution. Several hours later, the areas were cleansed with either 1 mL of water on a paper towel followed by two isopropanol swabs or Orange Pumice Hand Cleaner for 20 seconds which was then wiped off with a paper towel, then followed by 1 mL of water on a paper towel and two isopropanol swabs. The isopropanol swabs were saved for quantitation of drug removed. Once the areas were dry, patches with 1mL of a 1:1 glycerol/water solution were applied to the contaminated areas, and worn for three days prior to being removed and analyzed.

Preparation of Sulfonated Cellulose

Acetic Acid and Sulfuric Acid
To evaluate the effectiveness of acetic acid and sulfuric acid at sulfonating Whatman 1 and 3MM chromatography paper, a series was set up containing 10 mL of acetic acid with 0-5 mL of sulfuric acid. Once mixed, the solutions were cooled to room temperature, and strips of the paper were soaked for 15 to 90 minutes. The papers were then rinsed in distilled water for 10 minutes, and placed in a solution of 100 µL of 1 mg/mL methylene blue dye in 100 mL of distilled water for 10 minutes. Strips of the papers that had not undergone the sulfonation process were added at this point as a control. Upon removal from the dye solution, the papers were rinsed in distilled water, and the colors were compared. A darker blue color was indicative of more sulfone groups on the surface of the paper.

Pyridine and Chlorosulfonic Acid
Strips of Whatman 3MM chromatography paper were placed in 1 mL of pyridine. Chlorosulfonic acid was added dropwise. The papers were removed and placed in distilled water. This was then repeated for a total of four times. Papers were then exposed to 100 µL of 1 mg/mL methylene blue dye in 100 mL of distilled water for 10 minutes. The paper was tested as above for dye absorption.

Oxidation Prior to Sulfonation
Two methods of sulfonating Whatman 1 and 3MM were compared based on a procedure outlined in patent literature.[22] 1 inch X 1 inch squares of the paper were placed in 60 mM $NaIO_4$ in a 100 mM $NaHCO_3$ buffer solution in the dark for 1 to 2 hours with agitation. This procedure was also modified by placing papers in 60 mM $NaIO_4$ in distilled water. After the designated times, the papers were removed and rinsed in either distilled water for the modified procedure or 100 mM $NaHSO_3$ in water for the patent procedure for 30 minutes. Papers that had not been oxidized were added at this point as a control. The papers were then rinsed in distilled water for 10 minutes. Half were then soaked in a 100 ng/mL solution of cocaine, heroine, amphetamine, methamphetamine, and MDMA for 30 minutes with agitation. These were then spiked with an internal standard and analyzed on a Varian 4 GC/MS as previously described. The remaining papers were analyzed using methylene blue dye as previously described.

This document is a research report submitted to the U.S. Department of Justice. This report has not been published by the Department. Opinions or points of view expressed are those of the author(s) and do not necessarily reflect the official position or policies of the U.S. Department of Justice.

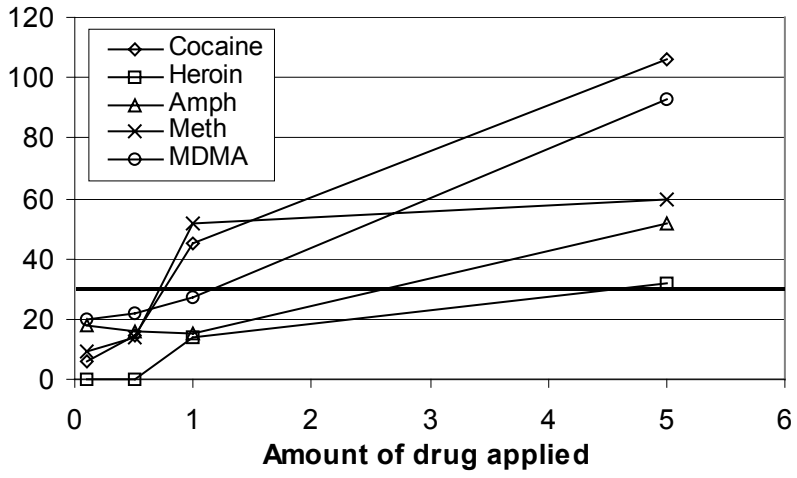
Anion Exchange Resins

Ion exchange columns were made by removing the absorbent material from a DAU solid phase extraction column and replacing it with known amounts of either DEAE cellulose (Sigma), Dowex 50wx8 (Supelco), Dowex 50wx4 (Supelco), Dowex 50wx2 (Supelco), Sulfoxyelthyl cellulose (Sigma), or Bio-Rex® 70 (Bio-Rad) that was held in the column by a frit placed on the bottom of the column. Columns were conditioned with 1 mL of methanol, methylene chloride/ isopropanol/ammonium hydroxide, 40:10:1, until color was no longer removed, 1 mL of methanol, 1 mL of distilled water, 1 mL of either 0.1 M $NaHCO_3$ or 5% sulfuric acid in distilled water, and 1mL of distilled water. After conditioning, a 0.4 µg drug solution was run through the columns followed by 1 mL each of methylene chloride/isopropanol 40:10, methylene chloride/triethylamine in either a 40:1 or 40:2 ratio, isopropanol/ triethylamine 10:2, and methylene chloride/ isopropanol/ ammonium hydroxide or triethylamine 40:10:1 or 40:10:2. Each solution was allowed to equilibrate on the columns for one minute prior to being collected for analysis.

Results and Discussion

As can be seen in Figure 2, the amount of drug absorbed into the patch increased as the amount of drug used to contaminate the skin increased. With 1 µg of drug applied to *ca.* 9 cm^2 of skin, the commercial positive cut-off level is reached even if a normal hygienic cleansing intervenes between contamination and patch application and two isopropanol cleanings are used. In real-life, contamination can occur at anytime prior to application of the patch and it is not assured that any decontamination other than the recommended, single isopropanol cleaning would occur. Retention of drugs on the skin appears to vary depending on drug structure (see Figure 2). Some drugs are sufficiently removed at an application of 1 µg to be below the commercial cut-off level for a positive and with some moderate human hygiene and two isopropanol cleanings. However, with higher levels of drugs (5 µg) on the skin, even these precautions do not prevent CFWI from causing a false positive sweat patch result.

Figure 2 – Amount of drug found in patches after increasing skin contamination. Varying amounts of drug were applied to *ca.* 9 cm^2 of human skin the day prior to patch application. Personal hygiene and two cleanings with isopropanol swabs occurred prior to patch application. Amounts listed are the averages of two trials. Note that the retention of drugs on the skin varies with the drug. Unknown amounts of drug are lost in personal hygiene, cleaning, and strong binding of the drug to the skin. Therefore only a fraction of the applied drugs are recovered in the patches.



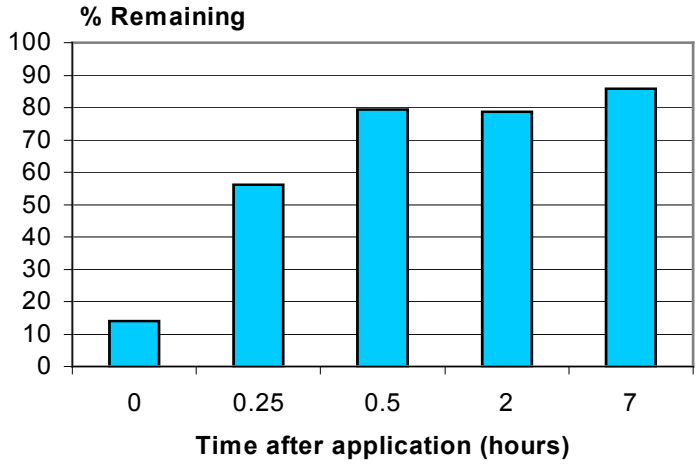
This document is a research report submitted to the U.S. Department of Justice. This report has not been published by the Department. Opinions or points of view expressed are those of the author(s) and do not necessarily reflect the official position or policies of the U.S. Department of Justice.

Rate of binding of drugs to skin

Drugs bind to the surface of the skin through ionic and hydrophobic bonds, and may interact with binding sites on the surface of the skin. Prior research has shown that drugs need to remain on the skin for several hours in order to bind efficiently. Cleansing the skin with 70% isopropanol immediately after contamination will remove nearly all of the drugs present. However, waiting for 15 minutes reduces the recovery to 50%, while after 30 minutes only about 25% of the drugs are recovered (Figure 3).[23] In real-life situations, drug contamination is likely to be unknown and a person exposed to drugs will not cleanse their skin immediately. The drugs will have time to bind, giving rise to the possibility of CFWI.

Allowing the drugs to bind to the surface for some time gives a more accurate result for a real life situation, and shows that little of the drug present on skin prior to patch application is removed by the cleansing process. Researchers reproducing the experiments discussed here must not cleanse the skin immediately after contamination, or false negatives will occur. Also, low-level contamination experiments may be deceptive if the instrumental analysis is not capable of trace level detection or if the negative result is due to the drugs being present but below an artificial cut-off level.

Figure 3 – Removal of cocaine with increasing time. *ca.* 20 ng applied to ca. 8 cm^2 of human skin and removed with isopropanol swabs at designated time intervals. Data from ref. 23.



Ethanol verses artificial sweat as a contamination medium

Some criticism of prior work concerned the skin being contaminated with ethanol solutions of drugs rather than drugs in sweat. Ethanol was chosen both for convenience, as it dried faster than sweat and to bias the data to false negatives. The keratin in skin is similar to the keratin in hair. It is known from studies on the incorporation of drugs into hair that aqueous solutions of drugs are more favorable to incorporation than are organic solutions.[24] This is because aqueous solutions both act as drug carriers and hydrate the proteins, swelling the layers, and allowing better penetration of the drugs. Also, to the extent that hydrophobic interactions of the drugs with the proteins increases binding, the less hydrophobic the media, the more these interactions can occur. Because ethanol does not readily swell proteins, it was thought that the drugs would better remain on the surface of the skin and be more easily removed. To test out this concept, drug solutions in both ethanol and artificial sweat were placed on the skin, and

This document is a research report submitted to the U.S. Department of Justice. This report has not been published by the Department. Opinions or points of view expressed are those of the author(s) and do not necessarily reflect the official position or policies of the U.S. Department of Justice.

patches were applied the following day to determine if the different mediums would affect drug absorbance into the patch. Although the patches for the two subjects absorbed differing amounts of drugs, the patches on the same subject did not vary significantly (Table 1). Since drugs are carried into the patches via sweat, the amount each subject sweated may explain the different absorbencies from subject to subject. Because the two media, upon comparison on the same subject, did not show any substantial differences, ethanol was used as the medium for contaminating the skin of the subjects for convenience. Also, the ethanol dried considerably faster than the artificial sweat, and was thus easier to apply.

Table 1 - Ethanol verses artificial sweat as a medium. Nominally 1 μg of a drug solution in either artificial sweat or ethanol was applied to *ca.* 9 cm^2 of skin the day before the patches were applied, with normal activity and a hygienic shower in between. Amounts listed are in ng/patch.

Application Media	Cocaine	Amphetamine	Methamphetamine	MDMA
Subject 1				
Ethanol	58	139	106	95
Artificial sweat	53	120	83	78
Subject 2				
Ethanol	111	172	121	140
Artificial sweat	100	168	116	167

Increasing Drug Removal by Employing Various Cleaning Agents

Cleansing the skin with 70% isopropanol swabs has been shown to leave drug residue on the skin. Considering the hypothesis that drugs bind due to ionic and hydrophobic interactions, other cleansers may work better by interrupting this binding. Unfortunately, the choices are limited by safety and convenience concerns.[25] Solutions of 1% citric acid in 70% isopropanol and 1% *d,l*-lactic acid in 70% isopropanol did not substantially increase the removal efficacy compared to 70% isopropanol swabs without additives. Increasing the citric acid and lactic acid concentrations to 5% still had no significant effect. The isopropanol swabs were far more convenient to use since they come prepackaged, whereas cotton balls for the citric and lactic acids had to first be washed then soaked in the desired solution.

Using Orange Pumice hand cleaner in the cleansing process reduced the amount of most drugs appearing in the patch (Table 2), but the drug removal was still not complete. This cleaning agent was tried because it was commercially available, contained a skin softener (to increase penetration of the cleaning agents), contained an organic base and surfactants (to disrupt hydrophobic interactions), and contained an abrasive (to remove skin cells). The abrasive level in this product was not very high and could be increased for added drug removal. Under the contamination scenario listed in Table 2, all but two drugs would be below the commercial positive cut-off levels when the skin was cleaned with Orange Pumice hand cleaner, water, and isopropanol. Whether this substantial cleaning procedure will be applicable in the field still needs to be determined. Also, contamination levels need to be measured to tell if these laboratory contamination scenarios are reasonable, as even this procedure did not completely remove all drugs.

Another method of cleaning the skin was tried by adding skin softening agents to increase the penetration of the cleaning materials. Cleansing the skin with 1:1 glycerol/water proved to be

This document is a research report submitted to the U.S. Department of Justice. This report has not been published by the Department. Opinions or points of view expressed are those of the author(s) and do not necessarily reflect the official position or policies of the U.S. Department of Justice.

beneficial (Table 3). Also, glycerol appeared to increase the amount of drugs appearing in the patch. This could be due to some of the glycerol remaining behind on the skin, creating a wet layer between the skin and the patch. This observation led to the intentional addition of glycerol to the patches (see below). As can be seen in Figure 3, the addition of surfactants to the glycerol cleaning mixture did increase the amount of drugs removed slightly, with the N-hexadecyl-N,N-dimethyl-3-ammonio-1-propane sulfonate being the most effective. These materials may increase the amount of drugs transferred to the patch by competing with the drugs for binding sites on the skin.

Though various removal methods were tested, none of the methods tried completely removed all drugs from the skin. Using Orange Pumice hand cleaner prior to 70% isopropanol was found to remove more drugs than using 70% isopropanol alone, as can be seen in Figures 4 and 5. Though the amounts of drugs removed from the skin varied between subjects, drug removal was not complete.

Table 2 - Comparison of the amount of drugs removed when using Orange Pumice hand cleaner. Nominally 5 μg of a drug solution was applied to *ca.* 9 cm^2 of skin four hours prior to cleaning and patch application. The areas were cleansed with two isopropanol swabs or with orange pumice hand cleaner followed by a wet paper towel then two isopropanol swabs. Amounts listed are in ng/swab or ng/patch.

	Orange pumice first?	Cocaine	Heroin	Amphetamine	Methamphetamine	MDMA
Subject 1						
Swab 1	No	517	565	384	310	749
Swab 2		103	94	97	83	189
Patch		55	20	63	40	71
Swab 1	Yes	38	20	38	29	57
Swab 2		24	14	19	16	31
Patch		21	3	34	24	25
Subject 2						
Swab 1	No	549	582	319	320	690
Swab 2		153	156	130	117	240
Patch		56	15	66	59	68
Swab 1	Yes	16	11	16	13	24
Swab 2		10	7	9	7	14
Patch		19	5	23	15	10

This document is a research report submitted to the U.S. Department of Justice. This report has not been published by the Department. Opinions or points of view expressed are those of the author(s) and do not necessarily reflect the official position or policies of the U.S. Department of Justice.

Table 3 - Comparison of the amount of drug removed with a glycerol/water solution containing various additives. Nominally 5 μg of a drug solution was applied to *ca.* 9 cm^2 of skin four hours prior to cleaning and patch application. The wipes listed were performed using *ca.* 50 mg of the various additives in 10 mL of the glycerol/water solution with 1 mL placed on a cotton ball. The areas were then cleansed with 1 mL of water on cotton balls, followed by two isopropanol patches. All cleaning materials were saved and analyzed for drugs. The wipes were performed using the following materials:
Solution 1: glycerol/water only, used as a control
Solution 2: N-Hexadecyl-N,N-dimethyl-3-ammonio-1-propane sulfonate as an additive
Solution 3: N-Dodecyl-N,N-dimethylglycine as an additive
Solution 4: 10% lactic acid as an additive
Amounts listed are in ng/wipe or ng/swab and are the averages of two subjects. The patches were worn for approximately 3 days.

	Cocaine	Heroin	PCP	Amphetamine	Methamphetamine	MDMA
Solution 1	1423	1499	804	370	361	1191
Water	661	1176	200	209	230	617
Isopropanol #1	295	147	204	128	146	324
Isopropanol #2	114	58	52	37	38	101
Patch	151	44	96	77	96	136
Percent Recovery	32	47	39	16	14	26
Solution 2	1903	1634	1153	511	544	1686
Water	511	413	217	272	296	625
Isopropanol #1	301	193	275	184	189	361
Isopropanol #2	149	123	127	80	85	178
Patch	227	120	148	166	206	296
Percent Recovery	37	40	55	24	21	34
Solution 3	1021	1781	450	659	528	1162
Water	473	472	240	235	263	728
Isopropanol #1	186	161	3821	99	102	239
Isopropanol #2	154	296	83	93	77	211
Patch	252	53	172	121	142	248
Percent Recovery	25	44	136	24	18	28
Solution 4	1465	1840	1752	508	583	1500
Water	713	580	548	326	399	781
Isopropanol #1	367	203	257	226	227	455
Isopropanol #2	199	114	150	106	114	211
Patch	251	130	216	169	210	309
Percent Recovery	36	46	84	27	24	36

This document is a research report submitted to the U.S. Department of Justice. This report has not been published by the Department. Opinions or points of view expressed are those of the author(s) and do not necessarily reflect the official position or policies of the U.S. Department of Justice.

Figure 4 – Comparison of effectiveness of various removal procedures – subject 1. *ca.* 5 µg drug applied to *ca.* 9 cm^2 of skin four hours prior to patch application. Patches were worn for three days. Amounts are in ng/patch. Additive used in glycerol is N-Hexadecyl-N,N-dimethyl-3-ammonio-1-propane sulfonate (*ca.* 50 mg/10 mL).

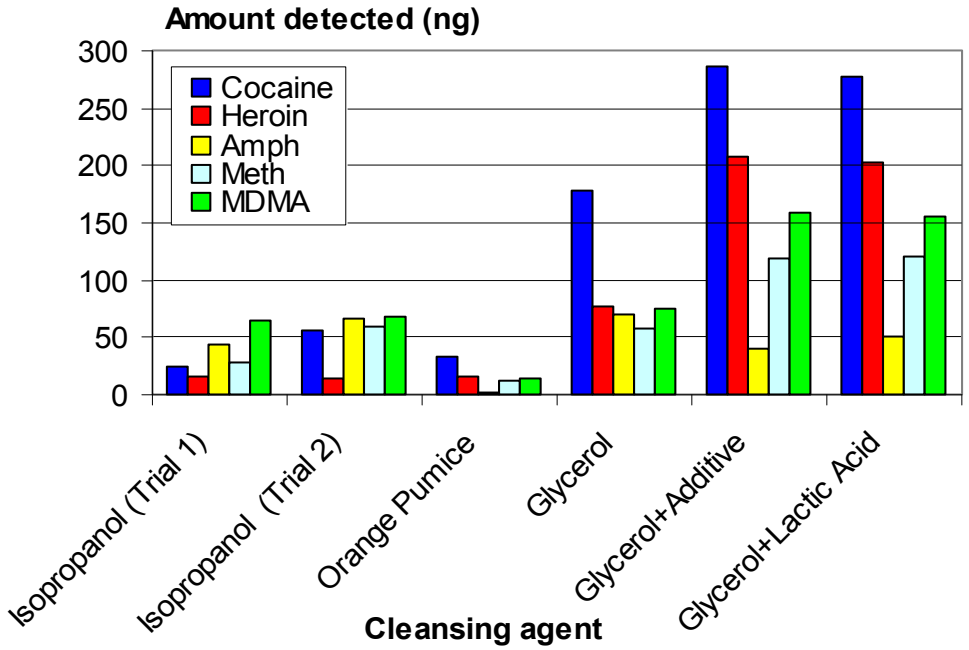
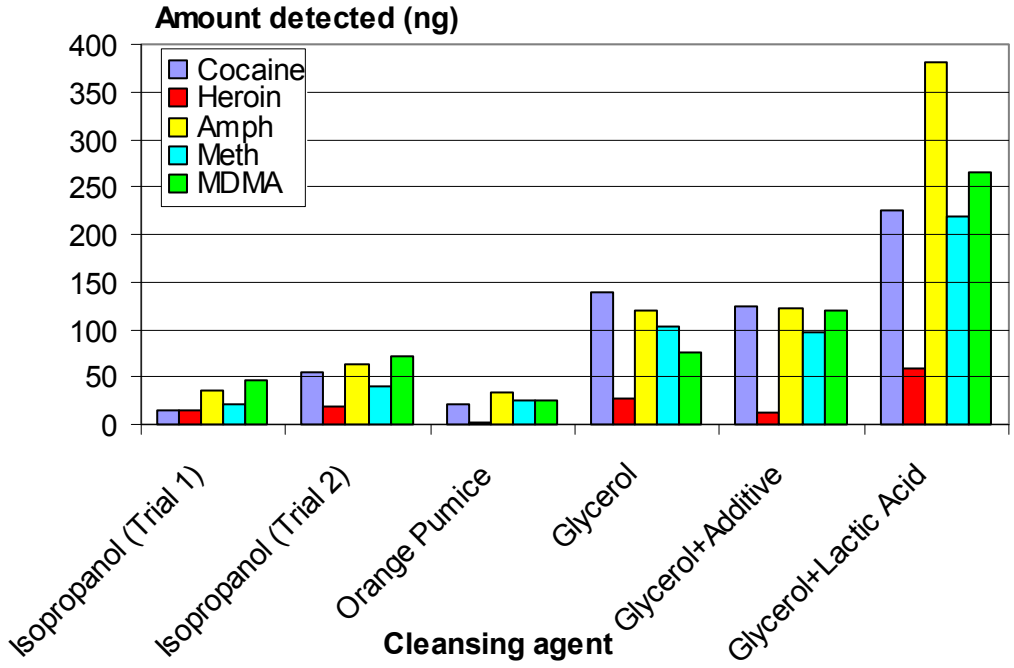


Figure 5 – Comparison of effectiveness of various removal procedures – subject 2. *ca.* 5 µg drug applied to *ca.* 9 cm^2 of skin four hours prior to patch application. Patches were worn for three days. Amounts listed are in ng/patch. Additive used in glycerol is N-Hexadecyl-N,N-dimethyl-3-ammonio-1-propane sulfonate (*ca.* 50 mg/10 mL).

.



This document is a research report submitted to the U.S. Department of Justice. This report has not been published by the Department. Opinions or points of view expressed are those of the author(s) and do not necessarily reflect the official position or policies of the U.S. Department of Justice.

Efficacy of Various Patches

Most of the one-day contamination experiments depicted in Tables 2 and 3, allowed drug recovery measurements to be made.[26] Glycerol in the cleaning solution with certain surfactants allowed nearly 50% of the drugs present on the skin to be recovered, whereas other methods removed only approximately 20% of the drugs contaminating the skin. Binding to skin must be substantial, because not all drugs are removed under any circumstances. This allows a reservoir of drugs to be present that might be released under certain conditions into the patch. To the extent that externally applied drugs mimic those excreted in the sweat of a drug user, increasing the transfer of the drugs to the patch will increase the sensitivity of the detection method. The poor recovery of drugs placed on the skin indicates that a substantial increase in sensitivity of the patch could be obtained under the proper conditions.

The amount of drug detected in the patch increased as the amount of exercise, and thus the amount of sweat produced, increased. Since drugs are carried into the patch by sweat, increased activity is expected to increase the amount of drug detected. The addition of 1:1 glycerol/water with a small amount of a surfactant to the patch significantly increased the amount of drug transferred into the patch (Table 4). Adding the glycerol to the patch creates a permanent wet layer between the skin and the patch. Because the skin must be wet to transfer drugs into the patch, glycerol allowed drugs to be transferred into the patch even when the subject was not actively sweating. Also, the glycerol improved the comfort in wearing the patch.

Since the addition of glycerol to the patches significantly increased the amount of drugs transferred into the patch, its use was combined with what was found to be the best cleansing agent. As can be seen in Figure 6 and Table 5, the use of Orange Pumice hand cleaner reduced the amount of drugs seen in patches when compared to isopropanol use. While this cleaner worked the best of all the agents tried, substantial amounts of drugs still remained on the skin. The addition of glycerol to the patch enhanced the transfer of drugs such that even patches with the best cleaning procedure would be considered positive if based on the commercial cut-off level.

This document is a research report submitted to the U.S. Department of Justice. This report has not been published by the Department. Opinions or points of view expressed are those of the author(s) and do not necessarily reflect the official position or policies of the U.S. Department of Justice.

Table 4 - Amount of drug transferred into patches with the addition of glycerol to the patch. 0.5 µg of drugs were applied to human skin *ca.* 4 hours prior to patch application. Contaminated areas were cleansed with either two isopropanol pads (Method 1) or with the glycerol/water (1:1, containing *ca.* 50 mg/10 mL of N-hexadecyl-N,N-dimethyl-3-ammonio-1-propane sulfonate), water, then two isopropanol pads (Method 2). Patches were worn for three days, removed and analyzed. Amounts of drugs are listed in ng/patch.

Cleansing procedure	Glycerol in patch?	Cocaine	Heroin	PCP	Amphetamine	Methamphetamine	MDMA
Subject 1							
Method 1	No	10	2	12	4	2	5
Method 1	Yes	376	151	123	126	165	198
Method 2	No	138	27	120	102	76	124
Method 2	Yes	462	204	121	133	138	271
Subject 2							
Method 1	No	16	18	9	4	5	18
Method 1	Yes	256	119	60	86	98	191
Method 2	No	33	16	2	13	14	42
Method 2**	Yes	19	14	2	10	11	32

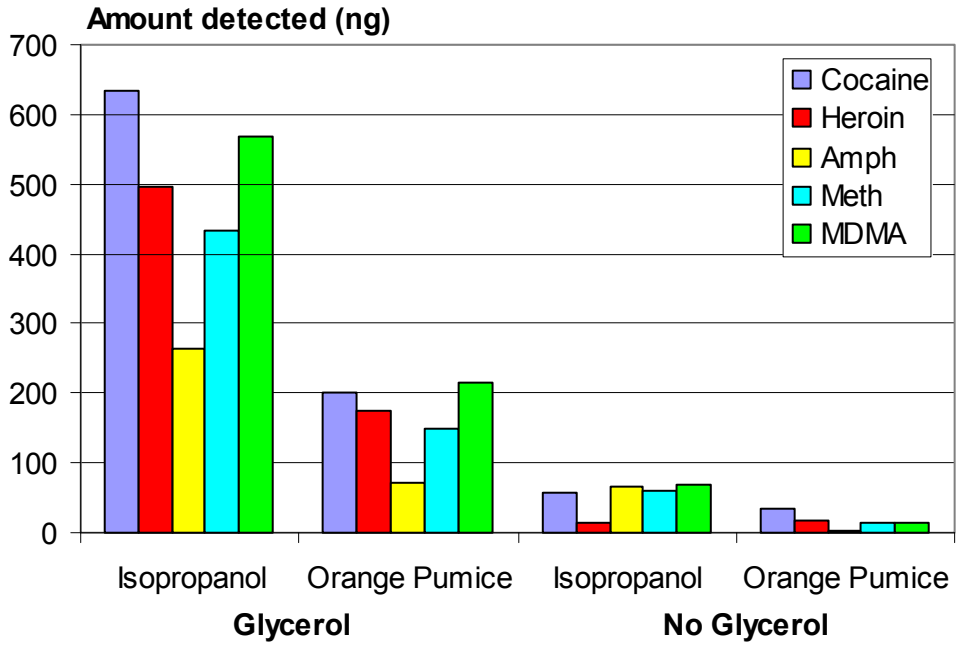
**Membrane of patch was compromised during wear.

Table 5 - Comparison of the amounts of drugs seen in patches wet with glycerol after cleansing with isopropanol or Orange Pumice hand cleaner. 5 µg of drugs were applied to *ca.* 9 cm^2 skin *ca.* 4 hours prior to patch application. Contaminated areas were cleansed with either water then two isopropanol swabs (method 1) or Orange Pumice Hand Cleaner, water, then two isopropanol swabs (method 2). 1 mL of 1:1 glycerol/water was added to the patches, which were then worn for 3 days, removed, and analyzed. Amounts of drugs are listed in ng/swab or ng/patch.

Cleansing Procedure	Cocaine	Heroin	Amphetamine	Methamphetamine	MDMA
Subject 1					
Method 1					
Swab 1	637	943	332	392	754
Swab 2	317	413	175	207	426
Patch	336	218	125	184	291
Method 2					
Swab 1	180	206	112	133	274
Swab 2	119	174	80	90	156
Patch	46	29	5	8	28
Subject 2					
Method 1					
Swab 1	707	1198	490	506	1138
Swab 2	254	385	194	230	354
Patch	633	496	264	434	567
Method 2					
Swab 1	89	120	57	78	98
Swab 2	77	110	46	59	81
Patch	202	174	73	150	214

This document is a research report submitted to the U.S. Department of Justice. This report has not been published by the Department. Opinions or points of view expressed are those of the author(s) and do not necessarily reflect the official position or policies of the U.S. Department of Justice.

Figure 6 – Comparison of the amount of drug detected in patches when using glycerol on the patch. *ca.* 5 µg drug solution applied to *ca.* 9 cm^2 of skin four hours prior to patch application. Skin was cleansed with two 70% isopropanol swabs or with Orange Pumice hand cleaner, water, and two 70% isopropanol swabs. Patches were worn for three days.



Increasing drug retention in the patch

Throughout the experiments, cleansing with 70% isopropanol removed some, but not all, of the drugs present on the subject's skin if the drugs were allowed to bind for several hours. After patch removal, cleansing the skin once again with 70% isopropanol and analyzing the swabs showed that drugs could still be removed in these post-patch swabs. This demonstrated that not all of the drugs used to contaminate the skin and that were readily removable were absorbed into the skin or the patch. Note that this is a distinct concept from the recovery experiments discussed above.

Pharmchek™ patches have an absorbent cellulose pad as the main drug storage system. Cellulose does not have many functional groups present that would be expected to bind and retain cationic drugs. Thus, if the patch was wet with sweat, drugs would be in equilibrium with the skin and poor transfer to the cellulose pad would be expected. Equilibrium was shown to occur in previous experiments, where about half of the drugs applied to the cellulose pad of a patch before placing it on the skin were lost on wearing the patch.[19]

Attaching stronger anion exchangers to the cellulose should make the drugs bind tighter to the patch and prevent equilibration with the skin. Sulfate groups were considered first because of their strong cation exchange ability. Though various methods of adding sulfate groups to the cellulose were tried, none were very successful. High concentrations of sulfate groups increased the solubility of the paper and allowed it to disintegrate upon washing, while cellulose derivatized with lower parentages did not appear to retain drugs any better than underivatized cellulose. Other anion exchangers such as Whatman P81 (phosphate groups) and Ansys solid phase extraction paper (sulfonic acid and hydrophobic groups) showed no substantial increase in the amount of drug retained when these materials were used as the absorbent material in

This document is a research report submitted to the U.S. Department of Justice. This report has not been published by the Department. Opinions or points of view expressed are those of the author(s) and do not necessarily reflect the official position or policies of the U.S. Department of Justice.

patches. Likewise, sulfoxyethyl cellulose, DEAE cellulose, and Bio-Rex® 70 did not retain drugs adequately.

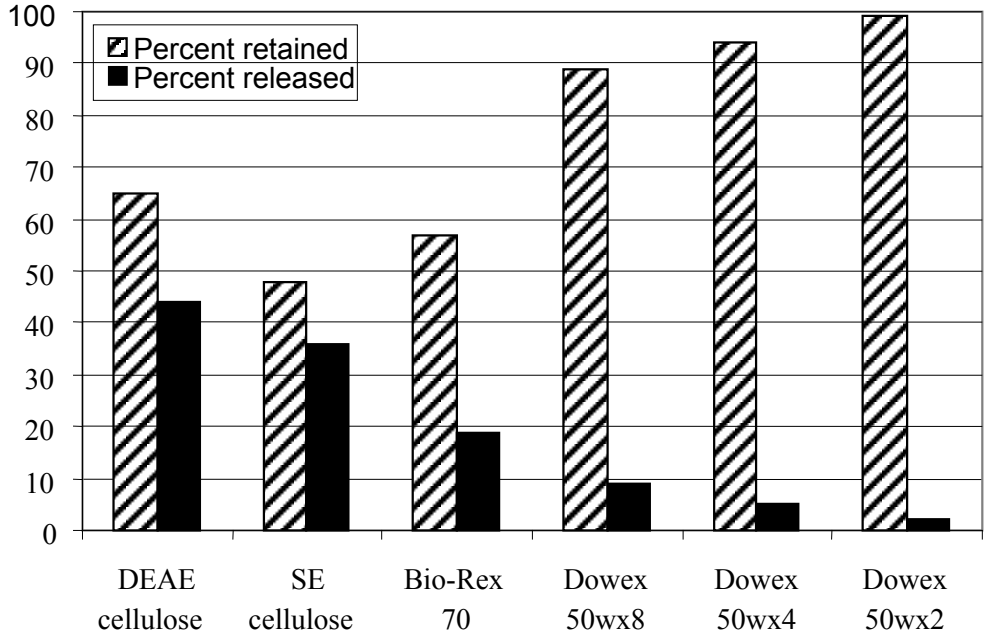
Besides ion exchange functionalities, cellulose lacks a hydrophobic character, which in conjunction with the ionic groups helps retain drugs. The patent literature suggests using a hydrophobic ion exchange resin to retain drugs.[5] Dowex resins did retain drugs, probably because of both the hydrophobic character of the resin and the ion exchange sites present, with the less crosslinked resins retaining the most. Unfortunately, the drugs are difficult to extract from the resins. The best solvent combination was methylene chloride/isopropanol/ triethylamine pulled more drugs off of the resin with higher concentrations of triethylamine working best, though a significant amount of drugs were still retained. As can be seen in Table 6 and Figure 7, a majority of the drugs are not eluted from the columns with organic solvents. Converting the resins into various cationic forms did not seem to affect the amount of drugs that were retained by the column. Converting the columns into the acid form did allow slightly more cocaine and heroin to be released compared to the sodium form though a significant amount remained on the column. Development of a less hydrophobic material than polystyrene would allows drugs to be eluted more readily.

Table 6 – Comparison of drug retention and recovery of various resins. Nominally 0.4µg of a drug solution was applied to each column. The percent retained is the amount taken-up by the resin from the drug solution. The percent released is the percent of drugs taken-up that was recovered in some eluent. Amounts listed are in percent of that applied.

Resin	Form	Cocaine	Heroin	Amphetamine	Methamphetamine	MDMA
Percent retained						
DEAE cellulose	Sodium	65	62	48	47	59
SE cellulose	Sodium	48	42	25	24	43
Bio-Rex® 70	Sodium	57	58	39	36	56
Dowex 50wx8	Sodium	89	83	87	85	93
Dowex 50wx4	Sodium	94	87	82	81	93
Dowex 50wx4	Acid	92	88	96	91	91
Dowex 50wx2	Sodium	99	96	96	97	96
Dowex 50wx2	Acid	97	97	98	97	97
Percent released						
DEAE cellulose	Sodium	44	50	54	65	37
SE cellulose	Sodium	36	45	100	100	34
Bio-Rex® 70	Sodium	19	14	18	22	22
Dowex 50wx8	Sodium	9	8	16	16	13
Dowex 50wx4	Sodium	5	4	6	7	7
Dowex 50wx4	Acid	18	52	1	1	1
Dowex 50wx2	Sodium	2	2	1	4	2
Dowex 50wx2	Acid	14	45	3	3	1

This document is a research report submitted to the U.S. Department of Justice. This report has not been published by the Department. Opinions or points of view expressed are those of the author(s) and do not necessarily reflect the official position or policies of the U.S. Department of Justice.

Figure 7 – Amount of drugs retained by various anion exchange resins. *ca.* 0.4 µg of cocaine applied to 250 mg of resin in a column. Percent retained is the amount absorbed from that applied. Percent released is the total amount released of that absorbed using all solvent systems.



Criteria for detecting CFWI

The results shown above indicate that cleaning the skin will never be 100% effective. A substantial amount of drugs can appear in patches due to prior skin contamination and this contamination confused with drug use. Previous research has suggested that the skin swabs used for cleaning be saved and used in determining if patches are positive from drug use or from contamination. It was suggested that the results from the skin swabs must be <10% of the patch results for the patch results to be acceptable as a positive drug test.[19] As shown in Table 7, based on these criteria, the patches for both subjects listed in Table 7 would indicate contamination, even though the drug levels found in the patches would be otherwise positive. This research has shown that a high amount of drugs in the skin swabs will precede drugs appearing in the patch in amounts large enough to result in a positive patch test. This should be taken into consideration when using this device for drug testing. If the results are questioned, a positive patch result should be checked by testing the skin swabs. If drugs are present in the swabs, then the patch results should not be used for punitive results. If the individuals are frequently positive in the swabs either due to environmental contamination (for example living in a drug infested area or in a house where drugs had previously been used) or intentional contamination, then these individuals are not candidates for use of the patch. Such individuals should be place in a frequent urine testing program.[27]

Because this 10% criteria is arbitrary, it needs to be checked under a number of different scenarios. The longer the drugs remain on the skin and the more frequent the personal hygeine that acts as a removal mechanism, the more likely that this 10% criteria would fail to detect prior contamination. Several scenarios are shown in Figures 8-11. In most cases, but not all (see

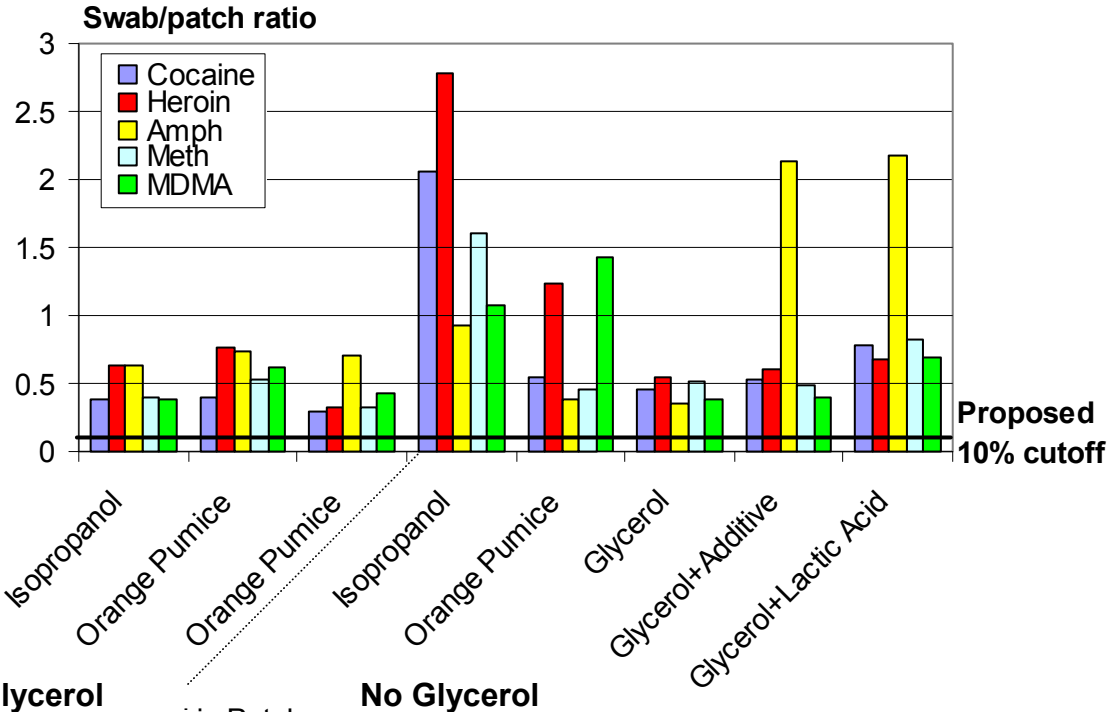
This document is a research report submitted to the U.S. Department of Justice. This report has not been published by the Department. Opinions or points of view expressed are those of the author(s) and do not necessarily reflect the official position or policies of the U.S. Department of Justice.

Figures 10 and 11) the previously suggested criteria of the swabs containing less than 10% of the patch results for a test to be positive for drug use were used, these results would clearly indicate contamination. Comparing Figures 8 and 9 to Figures 10 and 11, shows that an intervening shower reduces the contamination on the skin such that the 10% criteria sometimes fail, especially when the amount applied is small. However, these patches do not meet the commercial cut-off criteria for being positive. Thus a combination of judicious choice of positive cut-off level and the use of swabs having low amounts of drugs will identify CFWI.

Table 1 - Amount of drug recovered when cleansing with 70% isopropanol swabs. Nominally 5 µg of a drug solution was applied to *ca.* 9 cm^2 of skin the day prior to two isopropanol swabs being taken with normal activity and a hygienic shower in between. Patches were applied after the swabs were taken. Subject 1 wore patch for 3 days, while subject 2 wore patch for 6 days. Amounts are listed in ng/wipe or ng/patch.

	Cocaine	Heroin	Amphetamine	Methamphetamine	MDMA
Subject 1					
Swab 1	38	30	32	22	63
Swab 2	15	29	19	13	45
Patch	40	6	16	16	34
Ratio Swab 2:Patch	38%	483%	119%	81%	132%
Subject 2					
Swab 1	29	43	21	106	103
Swab 2	18	38	6	16	43
Patch	12	0	55	28	52
Ratio Swab 2:Patch	150%	NA	11%	57%	83%

Figure 8 – Swab/patch ratio quantitations – subject 1. *ca.* 5 µg of a drug solution was applied to subject 1 several hours prior to cleansing with the various agents listed before patch application. Patches were worn for three days prior to removal and analysis. The additive used in the glycerol solution is N-Hexadecyl-N,N-dimethyl-3-ammonio-1-propane sulfonate.



This document is a research report submitted to the U.S. Department of Justice. This report has not been published by the Department. Opinions or points of view expressed are those of the author(s) and do not necessarily reflect the official position or policies of the U.S. Department of Justice.

Figure 9 – Swab/patch ratio quantitations – subject 2 *ca.* 5 µg of a drug solution was applied to subject 2 several hours prior to cleansing with the various agents listed before patch application. Patches were worn for three days prior to removal and analysis. The additive used in the glycerol solution is N-Hexadecyl-N,N-dimethyl-3-ammonio-1-propane sulfonate.

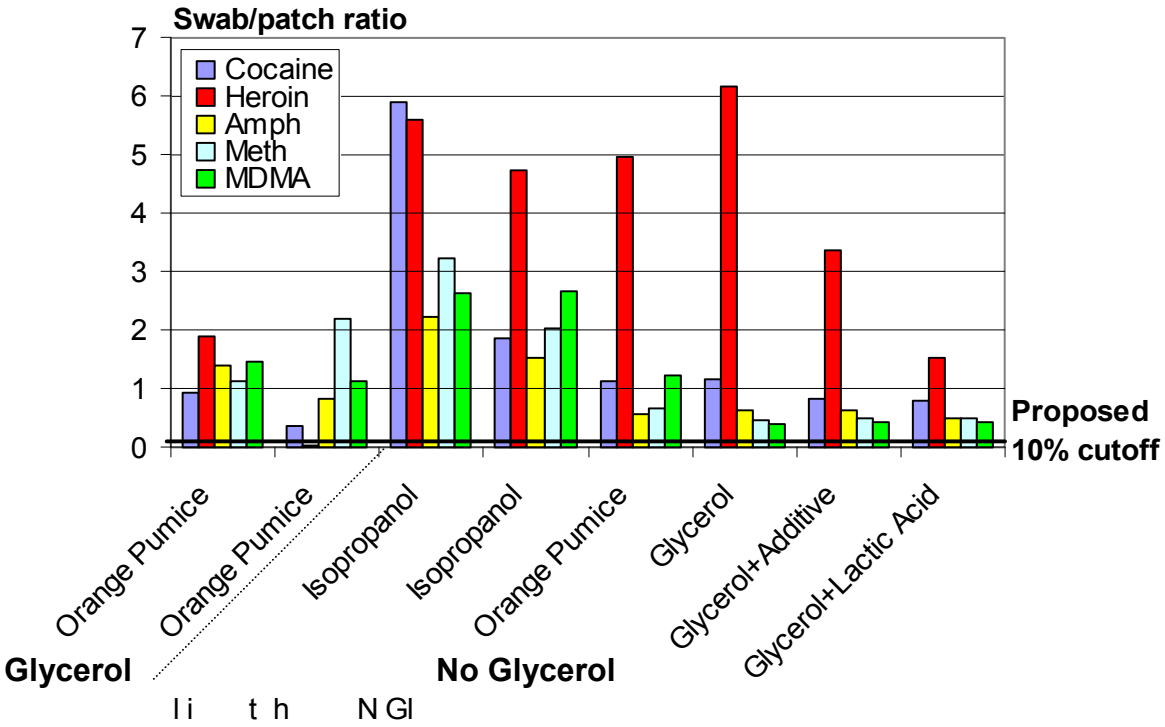
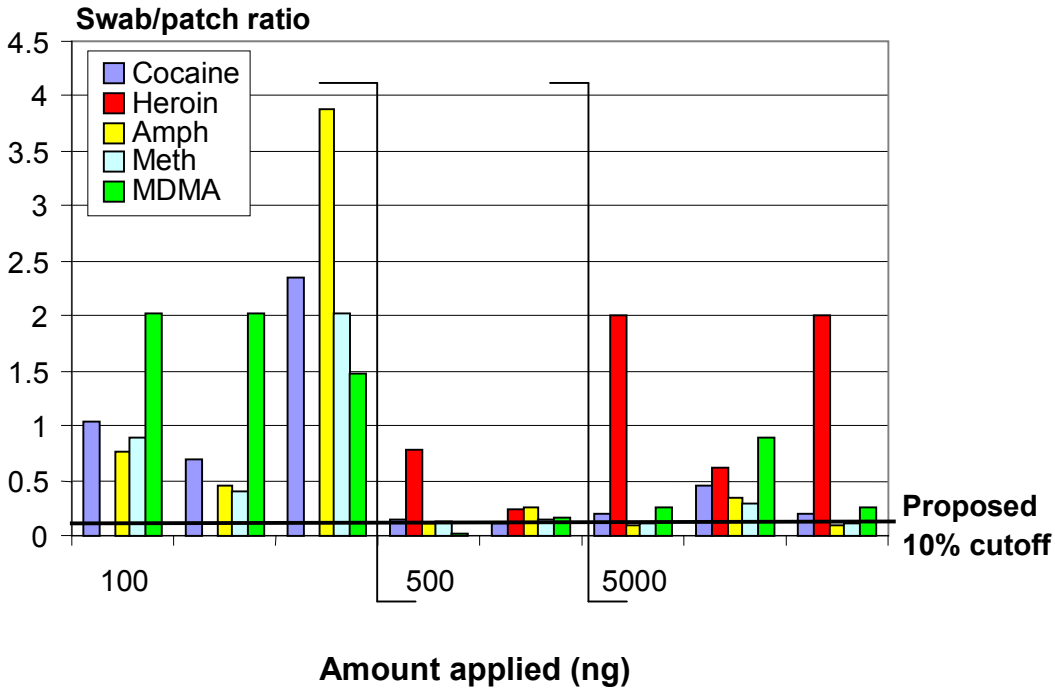
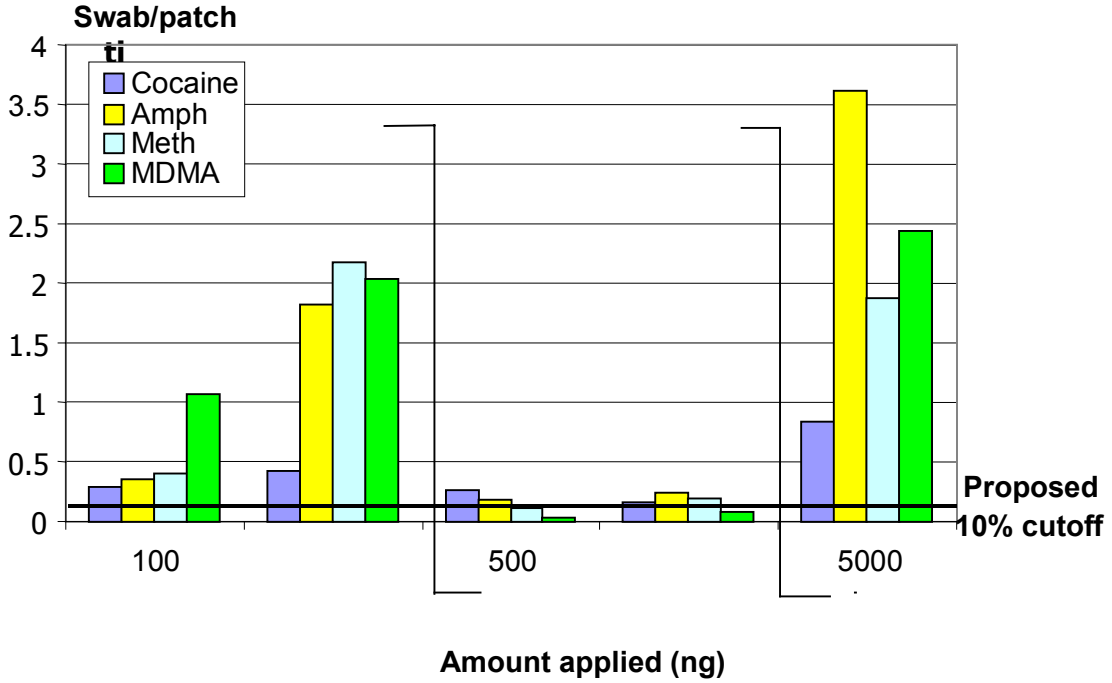


Figure 10 – Swab/patch ratio quantitations – subject 1. Varying amounts of a drug solution were applied to subject 1 the day prior to patch application with a hygienic shower in between. Contaminated areas were cleansed with isopropanol prior to patch application. Patches were worn for three days before removal and analysis. Ratios are taken from data shown in Figure 2. The patches from both the 100 and 500 ng application would not meet the cut-off criteria for a positive result.



This document is a research report submitted to the U.S. Department of Justice. This report has not been published by the Department. Opinions or points of view expressed are those of the author(s) and do not necessarily reflect the official position or policies of the U.S. Department of Justice.

Figure 11 – Swab/Patch Ratio Quantitations – Subject 2
Varying amounts of a drug solution were applied to subject 2 the day prior to patch application with a hygienic shower in between. Contaminated areas were cleansed with isopropanol prior to patch application. Patches were worn for three days before removal and analysis. Heroin was applied, but not detected. Ratios are taken from data shown in Figure 2. The patches from both the 100 and 500 ng application would not meet the cut-off criteria for a positive result.



Conclusions

The current method of cleansing the skin prior to patch application does not completely remove all drugs present from environmental contamination. Although a commercial hand cleaner appeared to be more effective at removing applied drugs, even with this method, the patches were still positive. Thus, if an individual were living in a drug-contaminated environment, CFWI could occur producing misleading or ambiguous results for drug use.

The amount of drugs remaining on the skin after hygiene appears to be linearly related to that applied. In real-life testing situations, the amount of exposure and thus contamination for an individual is unknown. The microgram amounts of drugs used for contamination in these experiments parallel the concentrations found on the skin of children living with drug users.[19] Higher levels could be expected, so complete removal by cleansing is essential. In fact, to provide a margin of error, future experiments should be preformed with greatly increased amounts of drugs applied to the skin. Also, experiments testing the patch should be reevaluated because prior skin contamination was not examined. Some or all the “use” indicated by the patches may be because drug users contaminate themselves.

The cellulose pad in the patch does not retain the drugs completely and allows equilibration with the skin to occur. A stronger anionic exchange group on the surface of the absorptive pad should allow the drugs to bind, and thus accumulate them in the patch better. Because active sweating is not constantly occurring, the skin is not always hydrated which reduces the transfer

This document is a research report submitted to the U.S. Department of Justice. This report has not been published by the Department. Opinions or points of view expressed are those of the author(s) and do not necessarily reflect the official position or policies of the U.S. Department of Justice.

of drugs from the skin into the patch. The addition of glycerol to the patch helps transfer drugs by providing a better transfer medium and eliminating the dependence on active sweating. Glycerol as an additive should be tested in a wider population of individuals. As used in these experiments, the glycerol does not appear to cause skin irritation. In fact, it seemed to enhance wear comfort of the patch.

If used without other supporting data, positive test results should be interpreted carefully until a better skin cleansing method is found. However, saving the wipes after "cleaning" the skin and testing them if questions arise about the results of the patch will likely detect CFWI and therefore can be the supporting data necessary to support a positive result. Nevertheless, until more experiments are performed under various cleaning procedures and personal hygiene, it is not known if the criteria outline above will detect all CFWI. Alternatively, if test results are questioned by an individual who denies drug use, frequent urine tests could be used to determine if CFWI is occurring and other information about drug use should be present before disciplinary action is taken. A combination of better skin procedures with saving the cleaning materials for further examination should allow the patch to be used under almost any contamination scenario.

Acknowledgements

This work was partially supported by the National Institutes of Justice through the DoD Counterdrug Technology Development Program at the Naval Surface Warfare Center. The opinions expressed in this paper are those of the authors and do not necessarily reflect the views of the Department of the Navy or the U.S. Government.

References

[1] D.A. Kidwell, J.C. Holland, and S. Anathanaselsis, "Testing for drugs of abuse in saliva and sweat," *J Chromatog B*, ***713***(1998)111-135.
[2] D.E.C. Cole and M.J Boucher, "Use of a new sample-collection device (Macroduct™) in anion analysis of human sweat," *Clin Chem,* **32**(1986)1375-1378.
[3] M. Phillips, R.E. Bandervoort and C.E. Becker, "Long-term sweat collection using salt-impregnated pads," *J Invest Dermatol*, **68**(1977)221-224.
[4] Phillips, "An improved adhesive patch for long-term collection of sweat," *Biomater Med Dev Artif Org,* **8**(1980)13-21.
[5] C.C. Peck, "Dermal substance collection device," US Patent 4,706,676, November 17, 1987.
[6] C.C. Peck, "Dermal substance collection device," US Patent 4,906,467, October 2, 1990.
[7] C.C. Peck, "Dermal substance collection method," US Patent 4,819,645, April 11, 1989.
[8] J.B. Eckenhoff and F. Theeuwes, "Sweat collection patch," US Patent 4,756,314, July 12, 1988.
[9] M. Phillips and M.H. McAloon, "A sweat-patch test for alcohol consumption: Evaluation in continuous and episodic drinkers," *Alcohol Clin Exp Res,* **4**(1980)391-395.
[10] Product package insert part # P00020 Revision: A. PharmChek™ Drugs of Abuse Patch for Collection of Cocaine and Cocaine Metabolites, Amphetamines, Opiates, Cannabinoid, and Cannabinoid Metabolites, and Phencyclidine (PCP) Through the Skin. Pharmchem Laboratories, Inc., Menlo Park, CA 1999.
[11] P. Kintz, "Drug testing in addicts: A comparison between urine, sweat and hair." *Therapeutic Drug Monitoring*, **18**(1996)450-455.
[12] *E.J. Cone, M.J. Hillsgrove, A.J. Jenkins, R.M. Keenan, and W.D. Darwin. "Sweat testing for heroin, cocaine and metabolites," J Anal Tox, **18**(1994)298-305.*
[13] M. Burns and R.C. Baselt, "Monitoring drug use with a sweat patch: An experiment with cocaine," *J Anal Tox,* **19**(Jan/Feb)(1994)41-48.

This document is a research report submitted to the U.S. Department of Justice. This report has not been published by the Department. Opinions or points of view expressed are those of the author(s) and do not necessarily reflect the official position or policies of the U.S. Department of Justice.

[14] V. Spiehler, J. Fay, R. Fogerson, D. Schoendorfer, and R.S. Niedbala, "Enzyme immunoassay validation for qualitative detection of cocaine in sweat," *Clin Chem*, **42**(1)(1996)34-38.
[15] D.A. Kidwell and F.P. Smith, "Susceptibility of PharmChek™ drugs of abuse patch to environmental contamination", *Forensic Sci Int*, **116** (2001)89-106.
[16] D.A. Kidwell and F.P. Smith, "Susceptibility of PharmChek™ Drugs of Abuse Patch to environment contamination," Naval Research Laboratory Memorandum #NRL/MR/6170-99-8414, November 3, 1999.
[17] F. Forsman and L. Fatowe, "Emerging issues in supervised release/probation revocation hearings," Presentation to the National Seminar for Federal Defenders, Minneapolis, MN, May 26-28, 1999.
[18] November 2000, US v. McLemore, Las Vegas, Federal District Judge Lloyd George, defense attorney - Franny Forsman, Federal Public Defender (US Attorney dropped the case right after PharmChem testified about the in-house research). McLemore had every-other-day negative urines and positive patches, lived in a contaminated apartment with young child, played with child on the carpet, testimony of owner that previous tenants left behind 3 garbage bags full of cocaine paraphernalia. Jan 2000 US v. Self, Kansas City. Federal District Judge Rob Larson. Attorney Ms. Laine Cardarella, assistant Federal Public Defender. (Judge ruled not to revoke) Self had extensive contamination and sweated on the job, worked with users, used lotion for scabies. March 2000 US v. Gillette, Kansas City. Federal District Judge Rob Larson, attorney Ms. Laine Cardarella, assistant Federal Public Defender. (Judge ruled not to revoke)
[19] F.P. Smith and D.A. Kidwell, "Cocaine in hair, saliva, skin swabs, and urine of cocaine users' children", *Forensic Sci Int*, **83** 179-189(1996).
[20] Leo J. Kadehjian and R.E. Willette, "Sweat Patch Testing for Cocaine: A Review of Issues and Studies Prepared for The Administrative Office of the U.S. Courts," February 26, 2001.
[21] G. Skoop, L. Potsch, and M.R. Moeller, "On cosmetically treated hair-aspects and pitfalls of interpretation," *Forensic Sci Int*, **84**(1997)43-52.
[22] R.T. Shet, "Sulfonated cellulose and method preparation", U.S. patent 5,522,967, June 4, 1996.
[23] D.A. Kidwell, M.A. Blanco, and F.P. Smith, "Cocaine detection in a university population by hair analysis and skin swab testing," *Forensic Sci Int*, **84**(1997)75-86.
[24] D.L. Blank and D.A. Kidwell, "Environmental Exposure - The Stumbling Block of Hair Testing", in *Drug Testing in Hair*, Pascal Kintz, Ed., CRC Press, Boca Raton, FL, 1996, pp. 17-68.
[25] Strong acids or bases and organic solvents such as dimethyformamide should disrupt drug binding better than the weak acids tried. However, their toxicity would prevent their use by the general public. Likewise, cleaning agents in conjunction with abrasives could remove the top layers of contaminated skin. However, this severe process is unlikely to gain acceptability both because of the discomfort as well as the time required for an adequate preparation.
[26] An example of a recovery experiments is: The skin is contaminated with 5 μg of drugs in a given area. Summing all the concentrations in the swabs and patch may produce a total of 2.5 μg (which varies for a given drug). This results in a drug recovery of 50%. By carrying out the experiment WITHOUT normal hygiene, recovery calculations can be made. If normal hygiene occurred, as in prior experiments, the amount of drugs removed would be unknown.
[27] A frequent urine testing program is suggested to make it inconvenient for the individuals being tested and dissuade intentional skin contamination. The frequency of urine testing could be decreased after a set number of negative urine samples. Alternatively, charging the subject for testing the swabs if they are positive may offer a financial disincentive to become contaminated.

This document is a research report submitted to the U.S. Department of Justice. This report has not been published by the Department. Opinions or points of view expressed are those of the author(s) and do not necessarily reflect the official position or policies of the U.S. Department of Justice.