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FORENSIC RADIOLOGY SPECIAL FEATURE: FULL PAPER

Walking on thin ice! Identifying methamphetamine “drug mules” on digital plain radiography

^{1,2}S N ABDUL RASHID, MD, ¹S B MOHAMAD SAINI, MD, ¹S ABDUL HAMID, MD, ³S J MUHAMMAD, MD, ¹R MAHMUD, MD, ⁴M J THALI, MD and ^{4,5}P M FLACH, MD

¹Department of Radiology, Faculty of Medicine and Health Sciences, University Putra Malaysia, Serdang, Selangor, Malaysia

²Institute of Forensic Medicine, Kuala Lumpur Hospital, Kuala Lumpur, Malaysia

³Department of Radiology, Hospital Serdang, Selangor, Malaysia

⁴Institute of Forensic Medicine, University of Zurich, Winterthurerstrasse, Zurich, Switzerland

⁵Institute of Diagnostic and Interventional Radiology, University Hospital Zurich, Zurich, Switzerland

Address correspondence to: Dr Patricia M. Flach

E-mail: patricia.flach@irm.uzh.ch

Objective: The purpose of this study was to retrospectively evaluate the sensitivity, specificity and accuracy of identifying methamphetamine (MA) internal payloads in “drug mules” by plain abdominal digital radiography (DR).

Methods: The study consisted of 35 individuals suspected of internal MA drug containers. A total of 59 supine digital radiographs were collected. An overall calculation regarding the diagnostic accuracy for all “drug mules” and a specific evaluation concerning the radiological appearance of drug packs as well as the rate of clearance and complications in correlation with the reader’s experience were performed. The gold standard was the presence of secured drug packs in the faeces.

Results: There were 16 true-positive “drug mules” identified. DR of all drug carriers for Group 1 (forensic imaging experienced readers, $n = 2$) exhibited a sensitivity of 100%, a mean specificity of 76.3%, positive predictive value (PPV) of 78.5%, negative predictive value (NPV) of 100% and

a mean accuracy 87.2%. Group 2 (inexperienced readers, $n = 3$) showed a lower sensitivity (93.7%), a mean specificity of 86%, a PPV of 86.5%, an NPV of 94.1% and a mean accuracy of 89.5%. The interrater agreement within Group 1 was 0.72 and within Group 2 averaged to 0.79, indicating a fair to very good agreement.

Conclusion: DR is a valuable screening tool in cases of MA body packers with huge internal payloads being associated with a high diagnostic insecurity. Diagnostic insecurity on plain films may be overcome by low-dose CT as a cross-sectional imaging modality and addressed by improved radiological education in reporting drug carriers on imaging.

Advances in knowledge: Diagnostic signs (double-condom and halo signs) on digital plain radiography are specific in MA “drug mules”, although DR is associated with high diagnostic insecurity and underreports the total internal payload.

For the past decade, significant worldwide manufacturing of amphetamine-type stimulants has been reported to the United Nations Office on Drugs and Crime, Vienna, Austria, with a predominance of methamphetamine (MA) and its derivatives, which are also known as “syabu” or “ice”, throughout East and South East Asia.¹ In this region, the use of this synthetic drug is more prevalent than that of cocaine or heroin, which are more common in relatively developed areas, such as Europe and the USA.² During the course of this development, an increase in the number of drug carriers being intercepted by law enforcement at the borders of Malaysia has been observed. Drug carriers or “drug mules” are generally referred to as a human harbouring internal illicit drug packet(s). Internal body concealment of illegal drugs is one of the methods used to smuggle this illicit drug across the border.^{3,4} “Drug mules”

are generally known as body packers.^{5,6} However, for correct terminology, one should differentiate between the terms body packer, body pusher and body stuffer. A body packer swallows a large amount of specially prepared drug packets to smuggle the packets in their gastrointestinal tract across a national border.^{5,6} A body pusher hides a few containers in easily accessible body cavities, such as the rectum or vagina. Body stuffers, including traffickers and users, ingest intentionally small amounts of loosely wrapped drug pellets (typically initially hidden in the mouth), usually immediately before an unexpected encounter with law enforcement.^{5–10}

The generally accepted radiological examination is a plain abdominal radiograph in the supine projection.^{4–6} This technique is widely available at a low cost and is a simple

method of detecting drug-filled packets within the alimentary tract. Radiation exposure to the patient is relatively moderate. In the literature, the detection rate for drug-filled packets is highly variable, and sensitivities from 58.3% to 90% have been reported.^{4,5,11} Hence, plain abdominal radiography is a flawed screening method for identifying “drug mules”. Examining the bowel for foreign bodies, such as drug containers with variable sizes and radiodensities, is problematic, even for an experienced radiologist because the drug-filled packets may have an appearance similar to that of stool and gas and may be superimposed. Specific appearances described in the literature, such as the “double-condom”, “halo” and “rosette” signs, may be diagnostic for drug packages but are not necessarily so.^{4-6,11-13} Other modalities employed worldwide for the identification of body packers include CT, ultrasound, MRI and low-dose linear slit digital radiography (LSDR or LODOX®; Lodox Systems, Johannesburg, South Africa).^{4,5,14-18}

Recent research has mainly concentrated on cocaine and heroin drug trafficking, which occurs predominantly in Western

countries.^{3,4,6,7,11,14,19} There is little research on the accuracy of plain abdominal radiography in MA drug carriers, although there has been a significant increase of MA in Asia, accompanied by draconian legal measures in cases of drug trafficking.^{1,2} The purpose of this study was to retrospectively evaluate the sensitivity, specificity and accuracy of plain abdominal digital radiography (DRL) for identifying the internal payloads of MA in “drug mules”.

METHODS AND MATERIALS

Approval was obtained from the ethics committee and the institutional review board. A retrospective evaluation of the radiology information system database of all acquired images in cases of alleged drug packing between August 2009 and October 2010 yielded 35 suspects. The inclusion criteria were adult suspected drug carriers with internal MA who were brought to the emergency department by the police. Exclusion criteria were incomplete documentation, internal illicit drugs other than MA, discharge to another centre, imaging positioning other than supine and paediatric cases.

Figure 1. Flow diagram for a comprehensive overview of the study population, regarding the obtained images. DR, digital radiography.

Study population

The study population consisted of 35 suspects [34 males and 1 female; mean age, 33.9 years; median age, 31 years, range, 22–58 years and standard deviation (SD), 10.032]. All suspects underwent digital plain abdominal radiography in the supine position. According to the clinical and/or forensic indications, 16 (all of them were read as positive) of the 35 suspects underwent multiple imaging in follow-up examinations, and a total of 59 examinations were performed (Figure 1).

Sequential abdominal radiographs were performed to assess the progress and clearance rate of the packs within the gastrointestinal tract (ordered by the district attorney, if forensic indications applied) and to rule out complications (ordered by medical personnel). The authorities deemed forensic indications for serial radiography if the single plain film was inconclusive based on the radiologist's report or if the excretion of the packs was prolonged after positive radiography. In such cases, repeat imaging was mandated until finally a negative film (after clearance of all internal packs) was obtained. No case read as negative received follow-up.

Radiological findings were compared with the written record of evidence recovered from the faeces of each detained suspect in a custody ward and confirmed by the police and laboratory studies. All suspects underwent faecal inspection, regardless of the imaging findings. Dedicated drug toilets were not available. Faeces were obtained in a simple metal bedpan and were manually searched for drug containers. For the purpose of this study, the detection of MA packs in faeces constituted a gold-standard positive result. As is common practice in South East Asia, mild laxatives were given to accelerate stool clearance. The passage of three drug-free stools was considered a negative result; this process typically required 3–5 days, depending on the number and the size of the internal drug packets and the patient's response to treatment.¹⁵ After final discharge of all the drug containers, the suspect was transferred into full police custody.

Digital radiographic imaging

Digital plain radiography was performed with a stationary system containing an X-ray generator (Polydors LX 80; Siemens Healthcare, Erlangen, Germany) and an X-ray tube (OptiTop 150/40/80 HC Systems, Siemens). DR was performed in the supine position with automated exposure control with an average exposure factor of 80 kVp and 20 mAs. The supine imaging position was used to guarantee proper visualization of the rectosigmoid region, especially in cases of body packers and pushers. Other imaging positions, such as left lateral or erect imaging, were considered to be exclusion criteria.

Radiological interpretation

Single-blinded (to the results of the stool examinations, prior radiography reports and the results of the other raters) retrospective image analysis was performed by five radiologists, each with more than 5 years' clinical radiology training. Two radiologists were trained in forensic radiology (working in or affiliated to a forensic institute) and gained specific knowledge in the detection of internal drug containers in the living and the deceased, whereas the other three radiologists had no such forensic radiology training. Sensitivity, specificity, positive predictive value

(PPV), negative predictive value (NPV) and accuracy for internal drug concealment in cases of MA were calculated for DR in all "drug mules".

Cohen's κ coefficient was calculated for the interrater agreement of the two subgroups of readers, the forensically trained radiologists (Group 1) and the inexperienced radiologists (Group 2), in reading the images of "drug mules".

Radiological findings

Radiographic signs, density, shape, size, location, rate of clearance, complications and image quality

Other than sensitivity, specificity, PPV, NPV and accuracy on DR in cases of internal MA concealment, the present key findings, such as the "double-condom", "halo", "rosette", "tic-tac" and "parallelism" signs, were evaluated (see Radiographic signs for definitions).^{4–6,11–13}

The radiodensity of the MA packs was assigned a value based on a confidence scale:^{1–3} 1 = radiolucent compared with soft tissue, 2 = isodense compared with soft tissue and 3 = opaque compared with soft tissue. In addition, the reader had to state the shape, size (measurement of the largest and smallest diameters) and total internal payload of the MA drug packs on plain abdominal radiographs.

The analysis also included the determination of the location (stomach, small or large bowel) of the drug packs and the rate of clearance of the drug packets within the gastrointestinal tract, as well as medical complications, such as obstruction/ileus and pneumoperitoneum, seen on imaging. Finally, the image quality of digital radiographs was rated based on a scoring system of 1–3 (1 for poor, 2 for satisfactory and 3 for good). Assessment of the image quality included the overall quality of the radiograph in terms of exposure, coverage (diaphragm to symphysis), lateral margin covered and artefacts (motion, pixel and foreign objects other than drug packs).

RESULTS

Study population

There were 16 proven MA carriers out of the 35 investigated suspects (15 body packers, 1 body stuffer and 0 body pushers), based on the documentation of MA drug packs recovered from faeces in the study population (16 males and 0 females; mean age, 33.0 years; median age, 31.5 years, range, 22–48 years and SD, 7.703). There was one suspected female body pusher who proved to be negative, and one body packer died from intoxication. There was one positive male body stuffer (Figure 2).

19 patients were truly negative based on the gold standard (meaning the patient did not conceal internal MA or had already excreted the MA packages). Therefore, no imaging follow-up was performed.

Criteria for the definition of body packers were patient's history, the police report or the characteristics of the packs (>5 containers, minimum 2.5 cm in length, uniform shape or located throughout the gastrointestinal tract). Body stuffers were defined as having small drug pellets in their gastrointestinal tract or having

Figure 2. The only body stuffer case in this study with a single round pack presumably projecting over the large bowel (black circle). This methamphetamine pack was only detected by radiologists in Group 1 (forensic imaging experienced group); it was missed by radiologists in Group 2 (the forensic imaging inexperienced group). Evidence obtained from the faeces confirmed a single pack in this case of body stuffing.

been witnessed by law enforcement presumably swallowing MA packs. Body pushers were defined as having large MA packs in the rectosigmoid or vaginal cavity only.⁶

Table 1. Overview of the sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV) and accuracy in identifying the internal payloads of methamphetamine in “drug mules” by plain abdominal digital radiography

Diagnostic test	Group 1		Group 2			Average
	Rater 1	Rater 2	Rater 3	Rater 4	Rater 5	All raters
True positive	16.0	16.0	15.0	15.0	15.0	
False positive	6.0	3.0	0	6.0	2.0	
False negative	0	0	1.0	1.0	1.0	
True negative	13.0	16.0	19.0	13.0	17.0	
Sensitivity (%)	100.0	100.0	93.7	93.7	93.7	96.2
Specificity (%)	68.4	84.2	100.0	68.4	89.5	82.1
PPV (%)	72.7	84.2	100.0	71.4	88.2	83.3
NPV (%)	100.0	100.0	95.0	92.9	94.4	96.5
Accuracy (%)	82.9	91.4	97.1	80.0	91.4	88.6
Accuracy by group (%)	87.2		89.5			

Group 1 represented the forensic imaging experienced radiologist group, and Group 2 represented the forensic imaging inexperienced group.

A total of 59 supine DR examinations were reviewed, of which 35 (59.3%) were performed immediately upon the delivery of the suspects to the emergency department and 24 (40.7%) were examinations for progress assessment throughout drug container excretion. A total of 16 patients (45.7%) had multiple examinations, whereas 19 (54.3%) patients had only a single examination. Investigating only the true-positive cases of internal MA drugs (16 patients), a significant increase in the number of sequential examinations was noted; no patient had a single examination, 9 patients (56.25%) had 2 examinations, 6 (37.50%) had 3 examinations and 1 (1.7%) patient had 4 sequential examinations. For the true-negative cases, 18 subjects had a single examination and only 1 had 2 examinations because of motion artefacts on the initial DR, resulting in 20 negative examinations (Figure 1).

Radiological interpretation

The overall rater agreement by Group 1 (experienced radiologists, $n = 2$) identified 16 images each as true positives and 13 and 16 as true negatives, respectively; and that by Group 2 (inexperienced radiologists, $n = 3$) identified 15 images each as true positives and 19, 13 and 17, respectively, as true negatives out of all 35 suspect examinations (Figure 1). The overall (averaged to all five readers) sensitivity (mean, 96.2%) and specificity (mean, 82.1%) were high compared with the values reported in the recent literature. The average PPV was calculated to be 83.3%, the average NPV was 96.5% and the average accuracy was 88.6% (Table 1).

The evaluation of the radiologist subgroups revealed the highest sensitivity and an NPV of 100% in the forensic imaging experienced group of radiologists (“Group 1”, $n = 2$) because no false negative results were found by this group. However, specificity was lower in this group, ranging from 68.4% to 84.2% (mean, 76.3%), the PPV ranged from 72.7% to 84.2% (mean, 78.5%) and the accuracy ranged from 82.9% to 91.4% (mean, 87.2%) because

Table 2. The interrater agreement between Group 1 (experienced group) and Group 2 (inexperienced group)

Interrater	Raters	κ	SE
Group 1 (mean, 0.72)	1–2	0.7191	0.1163
Group 2 (mean, 0.79)	3–4	0.6645	0.1247
	3–5	0.8298	0.0783
	4–5	0.8860	0.0939

SE, standard error.

of the higher number of false-positive results found by the experienced forensic radiologists compared with the inexperienced forensic group.

The radiologists without forensic training (“Group 2”, $n = 3$) showed a sensitivity of 93.7%, with an NPV ranging from 92.9% to 95.0% (mean, 94.1%), a specificity of 68.4% to 100% (mean, 85.9%) and a PPV of 71.4% to 100% (mean, 86.5%). Accuracy was between 80% and 97.1% (mean, 89.5%)

The interrater agreement of Group 1 was 0.72 [standard error (SE) 0.1163], indicating good agreement, compared with Group 2, which had a varying κ of 0.6645 (SE, 0.1247) up to 0.8860 (SE, 0.0939), indicating fair to good agreement (Table 2).

Radiological findings

An overview of the specific imaging findings is presented in Table 3.

Radiographic signs

In all confirmed drug carriers, the “double-condom” and “halo” signs (100%) were detected by each radiologist. These radiological signs occur as a result of inevitable air inclusion during manufacturing of drug packets, which creates the specific double-condom sign if the pack is projected longitudinally or the halo sign if it is imaged transversely (Figure 3a,b). However, the “rosette” sign (due to trapped air at the twisted end of a pack) is not easily detectable on plain radiographs and was

only reported in a single (6.25%) case by one radiologist in the experienced group. Other signs, such as the “tic-tac” sign and the “parallelism” sign, which are created by the parallel arrangement of longitudinal packs within the large bowel, could be seen in 3 (18.8%) cases and were congruently reported by all radiologists. Suspicious gas formation in the rectum was reported in two cases by one radiologist in the inexperienced group, but these cases were confirmed to be negative (Figure 4). Suspicious geometrical-shaped gas formation may be an indicator for internal drug containers but cannot be used as a reliable sign.

Density

2 (12.5%) of the 16 positively identified drug carriers were graded with an opacification of 3 (Figure 3a), meaning that the packs were more opaque than the surrounding soft tissue. The remaining 14 (87.5%) cases were classified as 1 or 2 in equal numbers (Figure 3b). The average density (Grades 1–3) was radiolucent to isodense with respect to the soft tissue, with a mean grading of 1.8 (median, 2; SD, 0.468).

Shape

Nearly all of the drug mules ($n = 15$, 93.75%) ingested typically shaped longitudinal or tubular body packs wrapped in plastic (Figure 5a) or condoms (Figure 5b). Most did not ingest atypically shaped (conus-like, small pellets or pouch-like) drug containers. The only reported body stuffer ($n = 1$) swallowed round drug packs with latex wrapping (Figure 5c) that appeared not to have been made professionally and did not correspond to the common plastic-wrapped small pellets.^{5,9,17}

The longitudinal or tubular shape was observed in each case (100%) on imaging, whereas the round shape was observed in 1 (6.25%) case by all radiologists.

Size

The size of the drug packs varied widely. The average length of the longitudinal packs was 4.93 cm (range, 2.5–6.8 cm; median, 5.0 cm; SD, 0.82 cm) and the width was 2.12 cm (range, 1.4–3.1 cm; median, 2.1 cm; SD, 0.31 cm). The round drug packs measured 2.0–5.6 cm in diameter, with an average diameter of 3.18 cm (median, 2.5 cm; SD,

Table 3. Summary of imaging characteristics of methamphetamine (MA) drug packs compared with the results of radiographic findings on digital radiography (DR)

Imaging characteristics of the drug containers	Results of MA findings on DR
Radiographic signs	Halo and double-condom signs (100%), tic-tac and parallelism signs (18.8%) and rosette sign (6.25%)
Average density	Similar or less opaque than soft tissue (87.5%), rarely opaque (12.5%)
Shape	Longitudinal tubular packs are more frequent than other shapes
Width and length	Longitudinal packs: 2.1 cm in width and 4.9 cm in length; round packs: diameter of 3.2 cm
Internal payload	Average: 39 ± 19.5 packs (range, 0–75 packs; median, 41 packs)
Location	Large bowel, 100%; small intestines, 62.5%; stomach, 25%
Rate of clearance	Average: 2.7 days
Image quality	Mean: 2.2 (median, 2; range, 1–3)

Figure 3. (a) This body packer exhibited opaque packs throughout the alimentary tract on digital radiography. Note the typical “double-condom” sign (black arrow) and the “halo” sign (white arrow). The longitudinal shape indicating the double-condom sign on imaging occurs as a result of the parallel position of the drug packs within the bowel, whereas the round appearance of the halo sign is due to transverse imaging. (b) In a different suspect from that in Figure 2a, the intestinal packs are more difficult to detect because of their radiolucent appearance. The grading from opaque to radiolucent revealed that the majority of the methamphetamine drug containers (87.5%) were classified by their density as radiolucent compared with soft tissues, as displayed in this image.

1.26 cm). The shapes and size measurements on DR were correct according to the measured packs in the faeces.

Internal payload

Assessment of the total number of internal drug containers was clearly difficult on DR as a result of the overlapping of the packs within the gastrointestinal tract and concomitant summation, especially in cases with huge payloads (Figure 6). The average payload was 39 packs on DR (range, 0–75; median, 41; SD, 19.5; SE, 2.2). The assessment of Group 1 was better, with 79.0% accuracy in counting the internal payload, compared with Group

2, with 59.0%; these results were verified by the gold standard (Table 4).

The mean number of packs secured from the faeces was 65 packs (range, 12–111; median, 70; SD, 25). However, in DR, there was a noted tendency to underreport in 13 (81.3%) of the 16 cases compared with the number of secured packs; overreporting was only observed in 3 (18.7%) cases. Based on imaging and the gold standard (Table 5), no correlation was found between the age of the drug carriers and the number of packs constituting the internal payload.

Figure 4. (a, b) Both images show suspicious gas formation (black arrow) projecting over the rectum or small pelvis. Contrary to the radiological image interpretation by a radiologist in Group 2, these patients were truly negative based on the gold standard.

Figure 5. (a) Methamphetamine (MA) drug container manufactured with a condom wrapping and covered with a rubber coating. (b) MA drug container with plastic wrapping and taping. (c) Unprofessional knotted latex wrapping of round MA drug containers in the case of lethal MA body packing (Figure 7a).

Conventional imaging did not allow for an estimation of weight. However, the weight of the secured illicit drug determines the punishment for the drug carrier. The average total weight of the secured packs was 545 g (range, 62–998 g; median, 549 g; SD, 235.7), whereas the mean weight per drug pack was 8.2 g (range, 5.2–10.8 g; median, 8.4 g; SD, 1.5). There was only one body stuffer in our study, who excreted a drug pack weighing 9.5 g (Table 4).

Location

Evaluation of the localization of drug packs in the 16 confirmed drug mules produced the following distribution: 100% ($n = 16$) in the large bowel (predominantly in the descending colon and the rectosigmoid), 62.5% ($n = 10$) in the small intestines and 25% ($n = 4$) in the stomach. The actual locations of the packs could not be verified by the gold standard but was assessed indirectly by the time interval to final clearance of all packs.

Rate of clearance

The average duration of total bowel clearance on plain abdominal radiographs was 2.7 days (median, 2 days; SD, 2.9 days). The

majority of patients (43.8%, $n = 7$) showed total clearance on imaging after 2 days, 31.3% ($n = 5$) showed total clearance by Day 3 and a quarter (25%, $n = 4$) by Day 4. Only 1 (6.25%) case took 5 days to discharge all packs on DR, as the patient suffered from intoxication symptoms. The remaining case ($n = 1$, 6.25%) died of complications from obstruction and leakage of the drug containers in the stomach after 5 days, which was confirmed by autopsy. Clearance rates were concordant with police reports.

Complications

Complications, such as direct evidence of drug package rupture or leakage, are less likely to be displayed by plain radiography than by CT. There are assessable indirect signs on DR, such as bowel dilatation/obstruction due to ileus or pneumoperitoneum in cases of perforation. There was 100% accordance of all radiologists in identifying ileus in the fatal case (Figure 7a). In four cases, multiple, tiny, opaque particles were noted that were scattered along the large bowel (Figure 7b); four investigators suggested that this observation was attributable to leakage or imaging artefacts. These body packers were clinically asymptomatic and had swallowed sand or other metallic foreign bodies, which is a common practice to potentially disguise swallowed drug packs on plain abdominal radiographs.⁴ No case showed pneumoperitoneum.

Figure 6. This case showed the highest internal payload within the alimentary tract in this study. The gold standard revealed a total of 111 methamphetamine drug containers. All radiologists underestimated the total number of drug packs because of the overlapping effects. The double-condom sign is easily detectable in this body packer case.

Table 4. Drug containers estimated on imaging [digital radiography (DR)] and the actual gold standard (faeces) with the collected drug containers

Case no.	Estimated drug containers on DR					Actual number of packs excreted
	Group 1		Group 2			
	Rater 1	Rater 2	Rater 3	Rater 4	Rater 5	
1	50	50	34	25	44	64
2	65	60	72	60	63	64
3	65	60	45	51	53	45
4	60	60	31	36	50	64
5	43	40	32	28	50	76
6	62	60	33	41	53	71
7	14	12	9	30	12	18
8	49	45	39	35	47	66
9	49	45	25	25	36	70
10	16	15	5	12	5	12
11	40	40	27	30	34	82
12	75	70	41	35	53	111
13	56	55	49	45	44	58
14	66	65	46	45	56	84
15	34	35	9	18	24	77
16	1	1	0	0	0	1
Total	745	713	497	516	624	963

Group 1 represents the experienced group of radiologists and Group 2 the inexperienced radiologists in forensic imaging.

Image quality

For the 59 total radiographs, the mean image quality was 2.2 (median, 2; SD, 0.68); 49.1% had a satisfactory image quality ($n = 29$), 37.3% ($n = 22$) had good image quality and 13.6% ($n = 8$) had poor image quality. 21 radiographs displayed incomplete coverage, meaning that either the diaphragm or the symphysis was not completely covered. In four radiographs, the lateral margin was out of view and parts of the large bowel were not displayed. Over- or underexposure occurred on five images as a result of imaging by a mobile X-ray station on the ward. Pixel artefacts were observed on three images, and foreign objects, such as swallowed sand, were identified on four images (Figure 7b). No motion artefacts resulting from incontinent patients were detected on DR.

However, those evaluated imaging trade-offs did not affect diagnostic accuracy.

DISCUSSION

Although governments in South East Asia enact the harshest drug laws and impose draconian measures, including the death sentence, for drug offences, an increasing number of drug carriers have inundated the market with illegal drugs, especially smuggling MA, as contraband. These carriers are frequently admitted to hospital emergency departments for either legal or medical assistance. Because of the potential for harsh punishment, there is a need for immediate, highly sensitive and specific tests to eliminate the suspicion of internal drug conveyance and to accurately detect concealed packs in a suspected perpetrator.

Table 5. Summary of the gold standard (secured evidence in the faecal inspection) of the internal methamphetamine (MA) drug packs

Gold standard	Results on MA drug carriers
Age of drug carrier	Average, 33 ± 7.7 years; median, 31.5 years; range, 22–48 years
Internal payload	Mean, 65 ± 25 packs; median, 70 packs; range, 12–111 packs
Total weight of the MA packs	Average, 545 ± 235.7 g; median, 549 g; range, 62–998 g
Weight of each MA pack	Average, 8.2 ± 1.5 g; median, 8.4 g; range, 5.2–10.8 g

Figure 7. (a) The only fatal case exhibited a dilated stomach containing clearly discernible multiple round packs (black circles). The radiological findings were validated by subsequent autopsy (Figure 5c). (b) In a different patient from that in Figure 7a, note the scattered sand particles within the ascending large bowel (white arrows). Sand particles are commonly swallowed by body packers to disguise the swallowed drug packs on plain abdominal radiographs.

This study showed several aspects of diagnostic insecurity in reporting DR of this patient collective. Radiologists should be proficient at interpreting radiographs of potential body packers, stuffers and pushers and be aware of how such packages appear on radiographs.^{5,11–14,20}

This study on MA drug carriers showed an overall rater agreement with a high sensitivity (96.2%) and NPV (96.5%) with slightly poorer specificity (82.1%), PPV (83.3%) and accuracy (88.6%) in all MA drug carriers. This result yielded a higher diagnostic accuracy than has been reported in most of the recent literature.^{4,5,11,13} The higher accuracy of this study can be explained by the limitation of the small sample size and, foremost, by the almost homogeneous study population. This population comprised 93.75% body packers ($n = 15$) who had huge internal payloads (mostly consisting of typically longitudinal shapes), a mean of 65 packs with a mean length of 5 cm; these payload characteristics facilitated the radiological interpretation tremendously, simply because of the amount of internal drugs. This study included only MA drug carriers; thus, the presumably slightly different appearance on DR of different substances within the packs was not a limiting factor in this study, whereas other studies evaluated internalized cocaine or heroin. In addition, 100% of the patients had drug containers within the large bowel and rectosigmoid region; containers in these areas are easier to assess on DR than those in the small intestine or stomach because there is less summation and a greater accumulation of packs within the lumen. There was only 1 (6.25%) body stuffer included in the study population who exhibited one obvious drug container weighing 9.5 g, which was located in the large bowel. Another limitation to this study was the potential for manipulation of the internal payload by the perpetrator because the patients were not continuously monitored and no dedicated holding cell or drug toilet was available. Therefore, false positives on imaging may not have been truly false positives, and the suspect may have

managed to discharge the drug container and dispose of it (e.g., dissolved in supplied drink or food or hidden in small gaps in the wall) (Figure 8).

The read-outs were performed by two groups of radiologists: Group 1 radiologists were experienced in reading images of drug carriers, and those of Group 2 had no knowledge of forensic imaging in “drug mule” cases. The evaluation by those in Group 1 showed no false-negative results, so no drug carriers escaped detection. There were more false positives in the read-outs of the forensic experienced group than in those of Group 2, which consisted of forensic imaging inexperienced radiologists. All investigators underestimated the internal payload in 81.3% of cases, although Group 1 was more accurate. Recent studies on drug carriers also stated diagnostic insecurity; however, they did not document the problem of underreporting on DR.⁶ This finding substantiates the need for image reading training in drug carrier cases, awareness of the typical radiological findings in such cases and may favour cross-sectional imaging rather than conventional X-ray in drug carriers. On DR, the mean density of the MA packs was radiolucent to isodense compared with the soft tissue, which further aggravated easy detection. Diagnostic signs, such as the double-condom and halo signs, had a detection rate of 100% and were specific. The determined shapes and size measurements on DR were correct according to the gold standard. Conventional imaging allowed for no weight estimation, but CT imaging would allow for segmentation of the internal drug containers and may also allow for weight estimation. This hypothesis should be substantiated by further studies.

Based on the present data, there is a high probability of complications with a prolonged clearance rate requiring more than 5 days. The study population was too small to substantiate this hypothesis, but the longer the drug stays within the alimentary

Figure 8. (a) This case was read as a false positive because of typical suspicious gas formation with two subtle double-condom signs projecting over the rectum (black circle) and the coincidence of swallowed sand particles projecting over the ascending colon (bold white arrow). The sand particles, in addition to the findings projecting over the rectum, led to the identification of a potential case of body packing on imaging. The gold standard was negative, potentially because of apprehension of the suspect after excretion of the possible ingested packs. (b) Magnified view of the scattered sand particles (bold white arrow) within the large bowel. (c) Magnified detail of the small pelvis with two presumed methamphetamine drug containers (outlined by black and white arrows).

tract, the higher the risk of complications becomes.¹⁵ In a case of suspected complications, CT is the recommended imaging modality.¹¹ Subsequent immediate surgery is indicated in cases of intoxication due to rupture, leakage or the removal of an intestinal obstruction.⁵

Image quality did not impair the read-out or diagnostic accuracy. Lateral margins and the complete coverage from diaphragm to symphysis should be included. Foreign materials (other than drug containers), such as sand swallowed by drug carriers to obscure image quality, did not affect the read-out of drug containers in this study, in accordance with the study by Algra *et al.*⁴

Because of medicolegal issues, the results of the read-outs may have critical effects on further management of patients in South East Asia. Inexperienced readers may not detect internal MA, and a false-negative radiograph diagnosis may lead to complications, such as intestinal obstruction by overlooked drug containers and/or drug toxicity in cases of rupture or leakage of such packs. Overlooked drug containers on imaging may also allow for the successful introduction of illicit drugs into the market and community. False-positive results may detain the suspect for days or may even result in criminal charges against innocent suspects.

Other modalities used for the detection of body packers worldwide include CT, which has a higher radiation dose and initial higher costs and may not be readily available.^{19,21,22} Sonography, MRI and LSDR are of negligible benefit in the cases described here.^{6,14,16}

This critical patient collective may benefit from cross-sectional imaging by a single low-dose CT rather than multiple DR, determining the location, size and shape of packs and accurately allowing true drug carriers to be distinguished from innocent suspects.⁶ Although CT may initially seem to have a higher cost, in the long term, a negative result will allow the patient to be discharged quickly and complications may be detected earlier, resulting in lower associated costs.²¹ The total payload can be counted precisely on CT because of its three-dimensional imaging capability and will therefore allow for a precise statement when all counted drug packs (on CT imaging) are cleared after faecal inspection (receiving a concordant count after excretion on the internal payload) and obviate multiple DR examinations. The suspect may even be exposed to less radiation by a single low-dose CT compared with multiple DR examinations, as already compared in the recently published work of Flach *et al.*⁶ and stated by Mandava *et al.*,²³ Ziegeler *et al.*²⁴ and Rousset *et al.*²⁵

CONCLUSION

Digital plain radiography is a valuable screening tool in cases of MA body packers with huge internal payloads of classical longitudinal drug containers, but this method is still associated with a high diagnostic insecurity. Regarding medicolegal issues, especially in countries with draconian drug laws, based on the diagnostic insecurity of plain films in this study and on recent research, low-dose CT may offer a more reliable alternative to DR to increase diagnostic security.^{6,17–19,21–25} Training radiologists in reading drug carrier images should be obligatory to increase the specificity of detection on imaging and to overcome literally walking on “thin ice”.

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