

“They should be easier to use”: Expanding fentanyl test strip access through health vending machines amid policy constraints

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Abstract

Background

Fentanyl test strips (FTS) are an increasingly important overdose prevention tool, yet high acceptability has not consistently translated into sustained use. Limited access, particularly among people who use stimulants and populations experiencing structural barriers to harm reduction services, may contribute to uneven uptake. Health vending machines (HVMs) offer a low-barrier approach to expanding FTS availability, but little is known about how people engage with FTS when they are available through HVMs.

Methods

We conducted a mixed-methods study of 200 community members newly registered to an HVM program in Kern County, California. Quantitative analyses integrated cross-sectional survey data with longitudinal HVM dispensing records to examine prior FTS use, elective uptake of FTS at enrollment, and subsequent FTS dispensation. Semi-structured interviews with 17 HVM users explored experiences with fentanyl exposure, drug checking, FTS access and usability, and HVM use. Quantitative and qualitative findings were integrated to characterize patterns of engagement with FTS.

Results

Most participants (93.8%) had never previously used FTS, and only 2.8% possessed FTS at enrollment. However, 44.6% electively accepted FTS when offered by the research team. Only 5% subsequently dispensed FTS from the HVM, although these participants returned for FTS an average of 3.6 times. Previous FTS use was associated with lifetime opioid use and witnessing an overdose, while psychostimulant use was associated with subsequent HVM FTS dispensation. Qualitative findings identified a drug-checking cascade comprising awareness, access, training and practical instruction, possession, use, and re-engagement/diffusion. Participants described HVMs as expanding low-barrier access to FTS, while inadequate practical instruction and product-level usability barriers disrupted progression from access to sustained use. Among participants who continued to obtain FTS from the HVM, peer distribution of testing supplies and drug-checking knowledge extended overdose-prevention resources beyond individual HVM users to others at risk of unintended fentanyl exposure.

Conclusions

FTS engagement is better understood as a cascade than as a single measure of uptake. HVMs may provide adaptable, low-barrier infrastructure for entry and continued engagement in drug checking, including among people who use stimulants. However, access alone may be insufficient: sustained

engagement requires usable technologies, practical instruction, and policies that support continued engagement and adaptation as the illicit drug supply evolves.

1. Background

In the fourth wave of the opioid epidemic, illicitly manufactured fentanyl analogues account for the majority of opioid-related fatalities in the United States (US) [1]. While fentanyl continues to be present in heroin, prescription opioids, and counterfeit pills, it is increasingly mixed with psychostimulants such as cocaine and methamphetamine [2, 3]. Fentanyl test strips (FTS), originally developed to detect fentanyl in urine, have been adapted as a consumer-facing drug checking tool that allows people who use drugs (PWUD) to test their illicitly manufactured drugs for the presence of fentanyl before consumption [4]. FTS are now recognized as an overdose prevention tool, including by the Centers for Disease Control and Prevention [5], and are legally permitted for this purpose in 45 states and the District of Columbia [6]. As a harm reduction practice, drug checking provides PWUD with information about their drug supply that can inform decisions about how they use drugs and reduce overdose risk [7]. FTS use has been associated with risk-reduction practices such as using in the presence of others, keeping naloxone available, using drugs more slowly, and employing lower-risk routes of consumption [7].

Despite high acceptability of FTS among PWUD [8–11], engagement with drug checking remains uneven. Studies examining demographic characteristics associated with FTS use have produced conflicting findings, including differences by race/ethnicity and gender [12, 13]. Of particular concern is comparatively low engagement with drug checking among people who use stimulants, even as fentanyl has increasingly entered the stimulant drug supply. In a recent analysis of community-based drug checking samples, fentanyl was detected in approximately 13% of powder methamphetamine and 15% of powder cocaine samples [3]. People who use stimulants have reported lower uptake of drug checking [12] and lower confidence in drug checking supplies [13]. At the same time, people concerned about unintended fentanyl exposure, particularly those without opioid tolerance, have reported high levels of interest in FTS [14–16]. Personal and witnessed overdose experiences have also been associated with greater FTS use [13, 17].

Yet the availability and acceptability of FTS have not translated into widespread use. A recent review reported a median FTS utilization rate of only 19% across studies [18]. Limited access to FTS has been identified as an important barrier to uptake [16, 19], prompting calls to expand the settings in which drug checking supplies are available [12]. Expanding access may be particularly important for people who use stimulants and members of minoritized groups, who may be less likely to engage with existing drug checking services [12].

Health vending machines (HVMs) offer low-barrier, anonymous access to FTS and other harm reduction supplies and may serve as a promising intervention to reduce inequities in opioid-related overdose fatalities, particularly among structurally vulnerable people [20]. Originally launched in Western Europe in the 1980s to expand access to sterile syringes, HVMs have gained international traction, with

widespread adoption in the United States beginning in 2017, to increase naloxone access in response to the escalating opioid crisis [21]. Today, nearly 560 HVMs operate across the U.S.; however, fewer than 20% (n = 107) include FTS [22]. Evidence on FTS distribution through HVMs remains limited. In the only known study examining FTS uptake through a community-based HVM, FTS distribution exceeded that of traditional access points such as syringe service programs, and participants who detected fentanyl in their drug supply reported adopting safer use behaviors [23]. However, because FTS were bundled within safer injection and smoking kits, it was unclear whether participants intentionally sought FTS or received them incidentally while accessing other harm reduction supplies [23]. Thus, little is known about how people engage with FTS when they are independently available through HVMs, including whether this distribution model facilitates uptake among individuals with no prior experience using drug checking.

The present mixed-methods study examines FTS engagement among individuals newly registered to an HVM program, integrating participants' experiences with measures of prior drug checking, elective receipt of FTS at enrollment, and subsequent dispensing of FTS as a standalone resource from the HVM.

2. Methods

Study design, setting, and participants

This mixed-methods analysis draws on data from Project HOPE, a community-based study evaluating the accessibility and acceptability of health vending machines (HVMs) for dispensing harm reduction supplies compared with traditional harm reduction distribution approaches. Detailed study procedures are described in a separate manuscript currently under review (Herrera A, Ganesh SS, Conner B, Li M, Bluthenthal RN, Davidson P, unpublished manuscript, 2026).

Using convenience sampling, we recruited community members at a community mental health access center in Kern County, California - where one of the Project HOPE HVMs was located - between September 2024 and May 2025. Participants were eligible if they were aged ≥ 18 years, spoke English or Spanish, resided in Kern County, and provided informed consent. The analytic sample included 200 community members who registered for the Project HOPE HVM program and consented to participate.

A subsample of HVM program users was recruited for qualitative interviews. Participants were eligible for the qualitative component if they were aged ≥ 18 years, spoke English or Spanish, had used the HVM at least once, and were either at risk of experiencing or witnessing an overdose.

Health vending machine and fentanyl test strip access

Project HOPE HVM #2 was an outdoor health vending machine located near a community mental health access center in Kern County, California. The HVM provided registered program users with free, 24-hour access to harm reduction and other health supplies using a unique participant identification number. FTS stocked in the HVM were obtained at no cost through the California Department of Health Care Services (DHCS) Naloxone Distribution Project (NDP), a statewide program that provides FTS and other overdose

prevention supplies to eligible organizations for community distribution [24]. Additional details regarding the development and implementation of the Project HOPE HVM are reported elsewhere [25].

Outcomes

Primary outcomes for the quantitative analyses captured FTS uptake through two distribution channels: receipt of FTS directly from the research team at enrollment and subsequent dispensing of FTS from the HVM. Additional outcomes included the number of FTS received at enrollment, the total number of FTS dispensed from the HVM, and the number of HVM vending sessions involving FTS.

Covariates

Covariates included sociodemographic characteristics, housing and justice involvement, substance use risk, and overdose-related experiences. Gender/sex was self-reported as male, female, or non-binary/third gender.

Participants could report more than one racial or ethnic identity from the following categories: Hispanic/Latine, Black/African American, White, Asian, American Indian/Alaska Native, Native Hawaiian/Pacific Islander, and other. Because of small cell sizes across individual racial and ethnic groups, race/ethnicity was dichotomized for statistical analyses as White/non-minoritized or minoritized racial/ethnic identity, with all racial and ethnic identities other than White included in the latter category.

Housing responses included institutional settings, sheltered or unsheltered homelessness, hotel/motel accommodations, rented or owned housing, and other arrangements. For analysis, participants were categorized as stably or unstably housed; those residing in institutional settings were excluded from housing comparisons because of insufficient cell sizes. Justice involvement during the past 12 months was dichotomized as justice-involved or not justice-involved.

Past 12-month opioid and psychostimulant use were assessed separately and combined to create a binary substance use risk indicator. Participants reporting opioid use, psychostimulant use, or use of both during the past 12 months were classified as high-risk, whereas participants reporting no use of either substance were classified as low-risk. Participants also reported whether they had experienced or witnessed an overdose, both ever and during the past 12 months. Typical drug use setting was categorized as using alone, in the presence of others, or varying between these settings.

Semi-structured interviews

As described in a separate manuscript currently under review (Herrera A, Ganesh SS, Conner B, Li M, Bluthenthal RN, Davidson P, unpublished manuscript, 2026), 17 HVM program participants completed semi-structured interviews between October 2024 and October 2025. Participants were purposively recruited through in-person outreach and flyers posted on the HVM. Interviews were conducted by a trained addiction researcher (ANSH), audio-recorded with participant consent, transcribed using Otter.ai, and reviewed by study staff for accuracy.

Interviews followed a flexible semi-structured guide comprising 32 core questions. The broader interview explored participants' experiences accessing and using the HVM, perceived influences of HVM access on health and harm reduction practices, and the sharing of HVM-related information and resources within social networks. The flexible format allowed interviewers to probe participants' experiences and pursue topics that arose during the interview.

Questions and probes relevant to the present analysis included:

Question

"Tell me about what you have heard about the contamination of methamphetamine with fentanyl and your concerns about accidental overdose."

Probe

"Have you shared this information with friends/family members?"

Question

"What have you heard about fentanyl test strips?"

Probe

"Have you shared this information/resource with friends/family members? Why or why not?"

Question

"Have you been dispensing fentanyl test strips from the HVM?"

Probes

"Have you been using the fentanyl test strips to test your drugs? Have your friends/family members been using the fentanyl test strips to test their drugs? Why or why not?"

Data analysis

The present analysis examined participants' experiences with FTS and factors shaping engagement with drug checking as an overdose prevention strategy.

Quantitative analysis

Brief cross-sectional survey data were collected using Qualtrics and linked with participant-level longitudinal data on FTS dispensed from the HVM. Descriptive statistics were used to characterize survey responses and longitudinal patterns of drug checking supply dispensation. Chi-square tests of independence were conducted to examine associations between participant characteristics, substance

use history, overdose history, and FTS-related outcomes, including awareness, prior use, receipt of FTS from the study team at enrollment, and subsequent dispensing of FTS from the HVM.

A general linear model was used to examine associations between participant characteristics and participants' total number of FTS vends from the HVM.

Among participants who received FTS from the study team at enrollment, negative binomial regression was used to examine associations between participant characteristics and the number of FTS received, controlling for participant characteristics. The negative binomial regression was conducted using the glmmTMB package [26].

Quantitative analyses were conducted using IBM SPSS Statistics, version 32.0, and R, version 4.6.1.

Qualitative analysis

Detailed qualitative analytic procedures are described in a separate manuscript currently under review (Herrera A, Ganesh SS, Conner B, Li M, Bluthenthal RN, Davidson P, unpublished manuscript, 2026). Interview transcripts were managed using ATLAS.ti, version 26, and collaboratively coded by two members of the research team (ANSH and SSG) using a constructivist grounded theory (CGT) approach [27]. Analysis involved iterative coding, constant comparison, and analytic memoing to refine emerging categories and relationships across participants. For the present analysis, coded interview data were examined for patterns related to participants' experiences with the changing drug supply, fentanyl and overdose risk, knowledge and perceptions of FTS, access to and use of FTS, and the role of the HVM in facilitating engagement with drug checking.

Mixed-methods integration

Quantitative and qualitative findings were integrated by considering survey findings and longitudinal HVM data on FTS dispensing alongside participants' qualitative accounts of fentanyl exposure, overdose prevention, drug checking, and experiences accessing and using FTS. Integrating these data allowed us to identify and contextualize patterns in participants' engagement with FTS.

Ethical considerations

All participants provided informed consent. The study was reviewed and approved by the California State University, Bakersfield Human Subjects Institutional Review Board (Protocol #24–125).

3. Results

Quantitative Findings

Almost one-quarter ($n = 47$) of participants identified that they spent time in a jail, prison, or juvenile detention center within the past 12 months. Individuals meeting the high-risk for overdose criteria comprised 43% ($n = 86$) of the sample. Of the 115 respondents who reported past 12-month substance

use, 45% reported using alone, 25% reported varying between using alone and in the presence of others, and 30% reported using in the presence of others. Additional demographic statistics for the sample are presented in Table 1.

Table 1
Demographic Statistics

<i>Variable</i>	<i>M (SD)</i>
Age	41.5 (12.6)
<i>Gender</i>	<i>n (%)</i>
Man	100 (50)
Woman	100 (50)
<i>Ethnicity/Race</i>	
American Indian/Alaskan Native	15 (8)
Asian	3 (1.5)
Black/African-American	35 (18)
Hispanic/Latine	79 (40)
Native Hawaiian/Pacific Islander	1 (0.5)
Other	8 (4)
White	59 (30)
<i>Housing Status</i>	
Hotel/Motel Room	8 (4)
Institutional Settings	18 (9)
Sheltered Homelessness	23 (12)
Owned Housing	12 (6)
Rented Housing	63 (32)
Unsheltered Homelessness	33 (17)
Figure description: Infographic depicting the FTS drug checking cascade as six sequential but potentially non-linear stages: awareness, access, training and practical instruction, possession, use, and re-engagement/diffusion. A HVM is shown as supporting access, possession, and re-engagement with FTS. The figure also illustrates how experience with the FTS cascade may prepare people who use drugs to engage with new drug checking technologies as emerging adulterants create new overdose risks, with HVMs providing adaptable infrastructure to support these future drug checking cascades. The figure was developed by the authors with support from generative artificial intelligence (AI) for visual design and layout.	

The vast majority of participants reported that they had not previously used FTS to check their drug supply ($n = 165$; 93.8%). Furthermore, only 5 participants (2.8%) reported that they possessed FTS at the time of data collection. Almost half of the participants (44.6%; $n = 87$) engaged in elective uptake of FTS from the study team after being advised of the risk of the fentanyl contamination in psychostimulants and counterfeit pills. Participants took an average of 1.28 FTS from the study team (range 0 to 8; $SD = 1.8$). During the study period, 111 drug checking kits were dispensed from the HVM; 96 were dispensed by study participants and 15 were accessed using a universal code that allowed community members who were not enrolled in the study to obtain harm reduction supplies from the HVM. While almost half of study participants elected to receive drug checking supplies at time of enrollment, only 5% of participants ($n = 10$) received drug checking supplies from the HVM over the course of the study. Participants received a mean of 0.48 FTS from the HVM (range 0 to 62; $SD = 4.5$).

Chi-square (χ^2) tests were conducted to examine associations between previous use of FTS and participant characteristics, substance use, and overdose history, respectively. Only two significant associations were found between previous use of FTS and history of witnessing an overdose ($\chi^2(1, N = 176) = 8.08, p = 0.004$) and lifetime history of opioid use ($\chi^2(1, N = 176) = 5.18, p = .023$). No other relationships were significant. Individuals who reported a history of witnessing an overdose were more likely to have previously used FTS. Similarly, individuals who reported lifetime history of opioid use were more likely to have previously used FTS.

χ^2 tests were conducted to examine the relationship between current possession of FTS and participant characteristics, substance use, and overdose history, respectively. However, no significant associations were found.

χ^2 tests were conducted to examine the relationship between elective uptake of FTS from the study team and participant characteristics, substance use, and overdose history, respectively. There was a significant association between elective uptake and lifetime history of opioid use, $\chi^2(1, N = 176) = 5.51, p = 0.02$. Individuals who denied a history of opioid use were more likely to electively take FTS. No other relationships were significant.

χ^2 tests were conducted to examine the relationship between dispensation of FTS from the HVM and participant characteristics, substance use, and overdose history, respectively. A significant association was found between dispensation of FTS from the HVM and past 12-month psychostimulant use, $\chi^2(1, N = 176) = 10.7, p = 0.001$. Individuals who reported a history of psychostimulant use were more likely to dispense FTS from the HVM. No other relationships were significant.

A negative binomial regression was conducted to determine if there was an association between the count of FTS elective uptake during the enrollment session and the participant characteristics, among those who elected to uptake FTS at the enrollment visit. Controlling for race/ethnicity, gender identity, prior incarceration, witnessing an overdose, opioid use, accidental overdose, and housing status, those

who used psychostimulants elected to take a significantly greater number of FTS during the enrollment period, IRR = 1.46, 95% CI (1.02–2.1) $p = 0.04$.

Of the 10 participants who accessed drug checking supplies from the HVM, participants averaged 3.6 drug checking supply vend sessions (range 1 to 14; SD = 4). The first time that participant dispensed drug checking supplies from the HVM, they dispensed an average of 1.7 kits (range 1 to 4; SD = 1.25). Between the first and the second session in which participants ($n = 6$) vended drug checking supplies, an average of 27 days elapsed (range 8 to 77 days, SD = 27 days). At the second vend session of drug checking supplies, participants dispensed an average of 1.2 kits (range 1 to 2; SD = 0.41). Between the second and the third session in which participants ($n = 4$) vended drug checking supplies, an average of 18 days elapsed (range 9 to 36 days, SD = 13 days). At the third vend session of drug checking supplies, participants dispensed an average of 2.5 kits (range 1 to 4; SD = 1.3). Between the third and the fourth session in which participants ($n = 4$) vended drug checking supplies, an average of 25 days elapsed (range 1 to 52 days, SD = 28 days). At the fourth vend session, participants dispensed an average of 1.25 kits (range 1 to 2; SD = 0.5). Between the fourth and the fifth session in which participants ($n = 3$) vended drug checking supplies, an average of 14 days elapsed (range 4 to 34 days, SD = 17 days). At the fifth vend session, participants dispensed an average of 2 kits (range 1 to 3; SD = 1). Only one participant obtained supplies at more than 5 vend sessions. This participant, who is unhoused and engaged in high levels of secondary distribution among social network of unhoused people at high risk for overdose, typically vended 1–2 kits at each vend session and elapsed time between vend sessions in which they dispensed drug checking supplies ranged from 1 to 45 days.

Qualitative Findings

Result 1: AWARENESS – Knowledge of fentanyl test strips (FTS) and their purpose

Awareness of FTS - knowing what they are and understanding their purpose as a tool to detect fentanyl in drugs before consumption - was closely tied to participants awareness' of fentanyl contamination in the illicit drug supply. Therefore, for participants to become aware of FTS and recognize them as a legitimate overdose prevention strategy that could be incorporated into drug use routines, participants first had to: a) be aware of unexpected fentanyl contamination in the drug supply and b) directly or indirectly witness the serious health risks associated with unintentional fentanyl exposure. Participants who knew that unexpected fentanyl could be present in their drug supply were more activated to identify harm reduction strategies to mitigate this risk. They recognized FTS as a tool for detecting fentanyl and informing overdose prevention decisions on themselves and their peers.

Participants generally described two pathways through which they became aware of fentanyl contamination in the local methamphetamine supply and its consequences, highlighting the potential utility of FTS for overdose prevention. First, participants like Whitney discussed personal experiences with unexpected fentanyl exposure that heightened concerns about her personal safety – specifically an instance in which she lost consciousness whilst driving, which prompted her to acquire and use FTS.

*"[FTS are important] for people to know that their stuff's not being laced. A lot of the overdoses came from their stuff being laced and [people] not knowing. I actually experienced [my drugs being contaminated with fentanyl]. [I used methamphetamine], and I thought to myself, 'this drug has fentanyl in it.' I was passing out at the wheel driving - stop in the middle of the road. **That showed me I need to start testing my drugs.** What's really bad is that the drugs out here today, you can test up to 50 drugs, and two out of the fifty doesn't have fentanyl in it. Out here in the streets, we are dealing with everything that has fentanyl and how it's happening is that we got people that are selling drugs that deal with both (methamphetamine and fentanyl)." – Whitney (White, female, unhoused, history of injecting methamphetamine)*

Second, participants became aware of fentanyl contamination through overdoses experienced by other people who used stimulants within their social networks. Sarah, for example, was part of a social network in which people primarily - and often exclusively - used methamphetamine, yet she witnessed several peers experience accidental overdoses attributed to fentanyl contamination. These experiences alerted her to the presence and overdose risk of fentanyl in the local methamphetamine supply. Learning about FTS through a local syringe service program (SSP) subsequently provided an actionable harm reduction strategy for identifying fentanyl contamination and reducing overdose risk within her social network.

"Oh, it's been bad. It's been really bad and the test strips have prevented anything like that from happening to us, because I've witnessed a few people that went out completely [overdosed] because of [fentanyl], and it wasn't their drug of choice. They don't use [fentanyl], and it was devastating." – Sarah (White, female, housed, history of injecting methamphetamine)

Beyond providing a strategy to reduce overdose risk from unexpected fentanyl exposure, participants recognized drug checking as expanding the harm reduction approaches available to them for preventing overdose. Sarah went on to describe harm reduction strategies she had used prior to integrating FTS into her routine, such as taking turns using drugs so that someone remained available to recognize and respond to an overdose. She saw FTS as an opportunity to intervene before using substances by identifying fentanyl contamination, providing an additional overdose prevention strategy particularly relevant to people using stimulants who sought to avoid unintended opioid exposure.

"You know, unless you're just gonna watch somebody [use fentanyl-contaminated drugs] and see what happens. And see [them overdose]. So [testing the supply with FTS], have been way beneficial." – Sarah

Recognition of fentanyl contamination risk in the stimulant supply, combined with an increase in opioid overdoses among people who were often seen as "non-opioid users," drove the spread of knowledge and awareness that drug checking supplies could detect the presence of adulterants and inform overdose risk-reduction strategies.

Result 2: ACCESS – Knowing where FTS are available and having obtained them

Participants identified several community sources from which they had obtained FTS, including SSPs, treatment providers, and the HVM. Knowledge and use of these access points varied. For some participants, the HVM provided an additional source of FTS. While for others who did not engage with SSPs or treatment services, the HVM was their only known source for obtaining FTS.

Participants also described how access to FTS through treatment settings could change as their engagement with those services changed. Jill had previously obtained FTS through the methadone clinic where she received MOUD. After transitioning from methadone to long-acting injectable buprenorphine, she no longer routinely returned to the clinic and therefore no longer obtained DCS through this previously established access point.

"I haven't [gotten them from the HVM], because I haven't really been using fentanyl... I have gotten them from [an narcotics treatment provider, methadone clinic]" – Jill (White, female, housed, history of injecting methamphetamine, currently using long acting injectable buprenorphine, abstaining from fentanyl)

Participants such as Perla discussed the role of the HVM in expanding access to FTS for themselves and members of their drug-using networks. Without another known source, participants emphasized that FTS were used when they were available, positioning the HVM as an access point for individuals and peer networks that might otherwise be unable to engage in drug checking as an overdose prevention strategy.

"[People in my social network are engaging in drug checking], when they have access to [fentanyl test strips]. No - [they don't know where they can get drug checking supplies beside the HVM]" – Perla (Latina, female, housed, history of smoking methamphetamine)

Together, participants' accounts demonstrated the importance of both the number and variety of access points for FTS to initiate and sustain drug checking practices.

Result 3: TRAINING AND PRACTICAL INSTRUCTION – Receiving the instruction and developing the skills needed to use FTS correctly

Obtaining FTS alone did not prepare participants to effectively use them as an overdose prevention strategy; participants also emphasized the need for practical instruction on preparing samples, conducting tests, and interpreting results. Participants identified a need for additional practical instruction on how to use DoseTest, the FTS product available through the HVM, local SSPs, and treatment programs at no cost through California's NDP. Although DoseTest included written directions, participants emphasized that written instructions alone appear to not be enough for people to confidentially use FTS properly.

Whitney, who had experience using DoseTest FTS to test her methamphetamine for the presence of fentanyl, reflected on the limited training available to PWUD to develop the practical skills needed to effectively use the available drug checking supplies as an overdose prevention strategy.

“The fentanyl test strips - they suck. They literally suck. Some of the tests [fentanyl test strips] need a little bit of instructions [on how to use the FTS to check drugs for fentanyl], but [the current instructions are] not what [they] need to be. It needs to be a little bit more effective. A little bit easier to read. Half the people out there can't read, and they need to have pictures or something on it.” – Whitney (White, female, unhoused, history of injecting methamphetamine)

Whitney further explained that written instructions alone did not provide the practical guidance participants needed to confidently use DoseTest. She identified uncertainty around fundamental testing procedures - including the amount of drug and water required, where samples should be placed, and which testing components to use - as sources of frustration that could discourage drug checking. Drawing on her lived experience, Whitney suggested that instructions use familiar and measurable references, such as syringe units, to make testing procedures more understandable and usable for PWUD.

“Number one, [instructions on] opening the package. Number two, you know how much [drugs] to put in a spoon, or what area that you put the drugs in or the water [in the testing packet]. You got the big blue package [DoseTest], and everybody's so intimidated by that big blue package, because they don't know if they're supposed to use a little strip, a big strip. It just needs to be identified. Exactly where to put the drugs, exactly how much water to put. [They could describe it as] a syringe, because people can get a syringe now and know that they got to drop 2 or 10 units in there. They know that; they understand that part, but they don't understand the drop [of drugs], how the water needs to be administrated, and they're not understanding that. So a lot of people aren't testing their drugs because they're tired and frustrated and everything else.” – Whitney

Together, participants' accounts challenged the assumption that written packaging instructions are sufficient to prepare PWUD to use DCS effectively. When instructions were difficult to understand or translate into practical testing procedures, participants described feeling frustrated and discouraged from testing their drugs. In this way, participants identified insufficient practical training and instruction as barriers to continued engagement with drug checking as an overdose prevention strategy.

Result 4: POSSESSION – Keeping FTS on hand for use when needed

Some participants maintained FTS “on hand” so they were readily available to incorporate into their drug-use routines. Participants discussed keeping FTS available to assess their drug supply and inform decisions intended to reduce the risk of unexpected fentanyl exposure and opioid-related overdose.

Participants who used methamphetamine and recognized the risk of fentanyl contamination discussed keeping FTS readily available to test their drugs and reduce the risk of an unintended opioid-related overdose. After learning about fentanyl contamination and accessing FTS through the study, Kohlman maintained possession of both FTS and naloxone, incorporating these harm reduction resources into his efforts to protect himself and members of his social network from overdose.

“And then we also have those drug testing strips on our table. We use that [fentanyl test strips] too” – Kohlman (Black, housed, male, history of smoking methamphetamine)

By keeping FTS laid out and readily accessible where he used drugs, Kohlman incorporated possession of these supplies into his routine, ensuring they were available when drug checking was needed.

Result 5: USE – Using FTS to check drugs and experiencing barriers to usability

Participants who used FTS discussed testing their drug supply to identify potential adulterants and inform decisions intended to reduce overdose risk. However, participants also identified product usability as an important factor shaping whether available FTS were actually used. DoseTest - the no-cost FTS product available through community distribution points including the HVM, SSPs, and treatment programs - presented practical barriers to testing, particularly for structurally vulnerable PWUD with limited resources to purchase alternative drug checking products.

Despite consistently endorsing drug checking as an important overdose prevention strategy, participants described DoseTest as cumbersome and difficult to integrate into their drug-use practices. Beyond the instructional barriers identified earlier, participants described product-level usability challenges that discouraged testing even when FTS were available and participants intended to use them. In particular, participants like Whitney identified the multistep preparation required to use DoseTest as a barrier, including the need to measure the requisite number of scoops of their drug sample before conducting the test. This requirement introduced additional preparation and precision into the testing process that participants found difficult to navigate in practice.

“It needs to be easier for someone just to drop a stick [into their drugs] instead of having to measure out a little piece [of their drugs]. I think they're so hard to use [FTS]. I think it's so important [to use FTS], but they're so hard.” – Whitney (White, unhoused, female, history of injection methamphetamine)

Whitney went on to explain attempting to share FTS within her drug-using network. She provided DoseTest to a peer who served as a drug-market connection in an area experiencing high levels of overdose; however, the immediate feedback she received focused on the difficulty in using the FTS product available through the HVM:

“The first time I got [FTS] from the [health vending] machine, I used them right immediately, testing some stuff [methamphetamine] I had on me. The second time I got them, I took them to my ex's house. He was testing his drugs, and I gave him some. I actually took about 10 of them. About four or five to [neighborhood] and I gave them to a connection. I said, ‘please use these’ and explained to him how to use them. And he said, ‘they should be easier to use.’ And I go, ‘I know.’” – Whitney

Participants also highlighted that the amount of drugs required to perform the DoseTest as a barrier to use. Jill explained that the recommended sample – between five and ten scoops of drugs – did not align with material scarcity needs of participants, who could not afford to allocate that amount of their drug supply to testing. For participants with limited resources, the quantity of the drug required for testing

could therefore discourage use of FTS despite interest in drug checking as an overdose prevention strategy.

"[DoseTest – fentanyl testing] takes too much of the drug [methamphetamine] to test it to want to use [DoseTest to check for fentanyl contamination]. I feel like, if there was a different kind of test, because nobody wants to use that much to freaking test their shit [their drugs]. Not nobody that's buying off the street, because just testing, it's like you're wasting [drugs]. Honestly, it was awkward, because at first it didn't work because we didn't put enough [drugs] in there, and then then we noticed we had to put a lot to do it. And I was like fuck this. We're not wasting the shit. I feel like it takes a lot [of drugs] to get it to work. A lot of my friends don't check it. They don't care. They don't care when they're in there that up in their addiction. They don't give a shit... But it takes too much product to test it or the people don't know." – Jill (White, female, housed, history of injecting methamphetamine, using LAIB and abstaining from fentanyl)

Despite possessing FTS, product-level usability barriers discouraged some participants from continued drug checking and limited their willingness to promote FTS use within their drug-using networks.

Result 6: RE-ENGAGEMENT AND DIFFUSION – Sustaining the sharing of FTS and drug checking knowledge within social networks

Participants described the HVM as an important source for continued access to FTS, enabling them to obtain additional supplies for themselves and members of their drug-using networks. Participants shared both FTS and knowledge about drug checking with peers they perceived to be at risk of overdose, extending this overdose prevention strategy beyond individuals who directly accessed the HVM. As participants used and distributed their supplies, the ability to return to the HVM for additional FTS supported re-engagement and continued peer-driven distribution and diffusion of drug checking practices.

Participants who were already aware of fentanyl contamination risk in the stimulant supply expressed a strong commitment to re-engaging with FTS by obtaining additional supplies to maintain possession for themselves and members of their drug-using networks. Sarah emphasized the importance of refilling FTS because the presence of fentanyl could not be reliably known without testing, making continued access to FTS an important component of overdose prevention for herself and others in her network.

"Knowing about that the test [for fentanyl contamination]... I hand [fentanyl test strips] out to everybody, like I we keep a bunch [of fentanyl test strips], as much as we can on hand to give to anybody that uses [methamphetamine] because if you don't test it, how do you know" – Sarah (White, housed, history of injecting methamphetamine)

For some participants, learning about the risk of fentanyl contamination in the stimulant supply from the research team prompted them to share both drug checking knowledge and supplies within their social networks. Drawing on his lived experience and knowledge of local drug-use environments, Jimmy developed a novel peer-led distribution strategy, placing FTS on a fence where they would be accessible

to other unhoused people who use stimulants and could support overdose prevention efforts within his community.

"I got some of the [fentanyl] test strips on the fence. I didn't know if one of the fatty heads [people who use fentanyl] came by and used that or not. What I thought was that you test the drug make sure there's no fentanyl in the drug. I don't know if it [distributing the fentanyl test strips by placing them on the fence] was working or not. I don't know if [the fentanyl test strips] got used them, or somebody took it to their house to use, or if it got used somewhere else. But I had to tell them what the test strips are for. One day, I put a little sign on it, this is for testing drugs, not for people, not for testing people. This is like a chain link fenced that has those wooden slats there, so I just slipped them in right there [on the fence]." – Jimmy (White, male, unhoused, history of smoking methamphetamine)

However, Jimmy's account also highlighted the limitations to FTS uptake across peer networks. Although supplies were made available through peer-led distribution, some individuals were unfamiliar with their purpose and initially interpreted them as tools for urinalysis rather than testing the drug supply for contaminants. Jimmy's experience demonstrated that making FTS physically available within peer networks did not necessarily translate into awareness of their purpose or subsequent uptake.

Similarly, Whitney distributed FTS in communities with limited access to harm reduction resources, including transporting test strips to a community more than 300 miles away without an SSP. Alongside secondary distribution, she diffused information about drug checking and encouraged others to test their supply before using, sharing, or selling it. Whitney also described a broader sense of responsibility within her drug-using network to reduce others' risk of unintended fentanyl exposure, particularly among older members who viewed themselves as looking out for younger people in their community.

"I know a lot of people [who] share their thoughts [about] how they wish they could just test their drugs. I always bring in test strips, and tons of test strips, and I go and I take them to [a community over 300 miles away with no SSP] with me, and I get them out there, because they don't have them there. I just explain how important it is. And the first thing I do, if you know somebody just picked up a bag or something, I said, 'just test it... just test it.' Because I explained to them, 'the first thing you don't want to do, and I understand that you might be using this too, but you don't want to sell it to people that knowing there's fentanyl in it.' To me, it's just like actually being the person who is administering the fentanyl to the community. I don't get down like that. A lot of people that I hang out with are not supportive of that, like the older people like me and the crowd. There's not very many of us out here, but we do take care of the younger crowd as much as we can, or look out for [them]." – Whitney (White, female, unhoused, history of injecting methamphetamine)

Whitney's account illustrates how diffusion of drug checking extended beyond sharing supplies and information to reinforce a peer-generated ethic of care and responsibility for overdose prevention within drug-using communities.

Result 7: ADAPTATION - Readiness to adopt new drug checking tools responsive to emerging adulterants

Beyond their use of FTS, participants were sensitive to the evolving risks posed by an unpredictable illicit drug supply. Participants described lived experiences encountering new or suspected contaminants and, already familiar with drug checking as a harm reduction strategy, perceived a need to extend drug checking to emerging threats in the drug supply. Awareness of a new adulterant therefore represented a potential entry point into a new drug checking cascade responsive to the contaminant of concern.

While most participants emphasized the need to test their stimulants for fentanyl contamination, Jill also shared increasing awareness of the potential for xylazine contamination and the need to check the local drug supply using drug checking supplies.

“How do you know you're not doing xylazine? I went over [to rural community] for two weeks running amok, and there's so many people over there, and they're struggling [with withdrawal symptoms]. And this one person was not getting well, and not getting off anything. [You're] looking sick, yellow, pale. And [as] soon as you take [opioid supply contaminated with xylazine], life's back in you. It's when I seen these kids, and then the life was coming back being in them, I'm like, “Who the fuck is giving him something else?” It must be xylazine. I feel like that's what scares me is that some of these people know what they're dealing xylazine, and they don't want to test this. We test them because they're either too sick to test or whatnot. And I think they're getting, they're getting messed up with that [xylazine contamination].” – Jill (White, female, housed, history of injecting methamphetamine, using LAIB and abstaining from fentanyl)

Jill's account illustrates how participants familiar with drug checking were positioned to engage with a new DCS cascade when confronted with an emerging drug threat.

4. Discussion

Our mixed-methods findings support conceptualizing engagement with FTS as a drug checking cascade comprising awareness, access, training and practical instruction, possession, use, and re-engagement/diffusion (see Fig. 1). Participants moved unevenly through the cascade, and characteristics associated with initial engagement differed from those associated with subsequent re-engagement. This distinction may help explain why high interest in and acceptability of FTS have not consistently translated into sustained utilization [11, 16, 18, 28, 29]. Our findings further position HVMs as low-barrier infrastructure for entry and re-entry into drug checking practices.

Patterns of FTS engagement both aligned with and differed from previous research. Consistent with prior studies, lifetime opioid use and witnessing an overdose were associated with previous FTS use [12, 13, 17]. Minoritized status was not significantly associated with FTS engagement, in contrast to previous findings [12], while gender was associated with previous FTS use [13] but not subsequent HVM dispensation. These findings add to an inconsistent literature on demographic correlates of FTS engagement and point to the importance of examining factors beyond individual characteristics.

Most notably, recent psychostimulant use was positively associated with FTS dispensation from the HVM. This finding contrasts with previous reports of lower drug checking uptake among people who use

stimulants [12] and is particularly salient given the increasing presence of fentanyl in the stimulant supply [3]. Qualitative accounts reinforced this finding, with participants describing FTS as a means of identifying unexpected fentanyl exposure and navigating uncertainty in the methamphetamine drug supply. HVMs may therefore provide an important access point for people who use stimulants, consistent with prior research demonstrating interest in drug checking among this population and recommendations to expand FTS distribution beyond traditional settings [12, 16, 19].

Providing access to FTS, however, may be insufficient to support continued progression through the drug checking cascade. Participants described difficulty interpreting instructions and completing testing procedures and expressed less confidence using and distributing FTS. These findings suggest that practical training and instruction and the usability of the FTS product itself are critical to sustaining engagement once access has been achieved. This is consistent with Childerhose et al. [30], who identified substantial differences in ease of use across FTS products. Difficult testing procedures or inadequate instruction may interrupt continued engagement, reducing the likelihood that PWUD return for additional supplies or feel confident sharing FTS and drug checking knowledge with others. Low-barrier access must therefore be paired with usable products and practical instruction to support sustained re-engagement and diffusion.

The importance of re-engagement is illustrated by the small subset of participants who continued accessing FTS: although only 5% obtained FTS from the HVM, those participants returned an average of 3.6 times. The reach of this engagement also extended beyond individual HVM users. Qualitative findings described participants sharing FTS and drug checking knowledge through their social networks, including substantial secondary distribution among unhoused people at high risk for overdose. These findings position PWUD as active participants in the diffusion of harm reduction resources and suggest that HVM transaction data may underestimate intervention reach when supplies obtained by one person are distributed to others.

Finally, HVM infrastructure may support continued engagement with drug checking as technologies and drug-supply risks change [31]. Familiarity with drug checking and an established source of supplies may facilitate uptake of new drug checking supplies, as HVMs can remain in place as their contents are adapted to emerging threats such as xylazine, nitazenes, medetomidine, and other adulterants. The value of HVMs may therefore extend beyond distributing FTS to providing adaptable infrastructure through which PWUD and harm reduction systems can respond to an evolving illicit drug supply.

Policy implications

Policy can shape engagement across the drug checking cascade by influencing both access to drug checking supplies and the capacity of harm reduction systems to adapt to changes in the illicit drug supply. SAMHSA's April 2026 Dear Colleague Letter marked a reversal in federal support for drug checking supplies, including FTS [32]. Although FTS had previously been an allowable use of federal harm reduction funding - and remained permitted despite prior restrictions on other harm reduction expenditures in 2025 [33] - the 2026 guidance explicitly prohibited the use of SAMHSA funds to purchase

drug checking supplies [32]. Because this policy is recent, its effects on drug checking availability and use have yet to be established. However, restricting federal funding may constrain opportunities for entry and re-engagement in the FTS cascade, particularly in communities without sufficient state or local resources. It may also limit the capacity of harm reduction programs to introduce new drug checking technologies as the illicit drug supply evolves, potentially weakening their ability to respond rapidly to emerging drug threats.

California's NDP illustrates a different policy challenge: expanding access does not ensure sustained engagement if the technology provided is difficult to use. The NDP provides FTS at no cost to eligible organizations, reducing financial and organizational barriers to distribution [24]. However, participants described difficulties with DoseTest, the FTS product distributed through the NDP, including its instructions and the amount of drug required for testing. These experiences are consistent with comparative usability testing in which DoseTest received the lowest ease-of-use ratings among evaluated FTS products [30]. Differences among FTS products that may appear minor during procurement can become consequential under actual conditions of use: requiring a larger sample may mean sacrificing a meaningful portion of a limited or costly drug supply, while complicated preparation or instructions may impede routine testing. Although our findings cannot establish that DoseTest usability caused lower FTS re-engagement through the HVM, they demonstrate how product characteristics can create friction that may undermine continued engagement and peer diffusion. Meaningfully incorporating the expertise of PWUD into procurement decisions may help ensure that publicly funded technologies are feasible under the conditions in which they will actually be used.

Together, the federal and California examples demonstrate how policy can act at different points in the cascade: funding decisions shape access and the capacity to sustain adaptable drug checking infrastructure, while procurement decisions shape whether available technologies can be feasibly used in practice. HVMs provide one mechanism for maintaining adaptable, low-barrier infrastructure through which drug checking resources can change in response to an evolving illicit drug supply. Considering both access and usability in drug checking policy may therefore be important for supporting continued engagement across the cascade.

Limitations

Several limitations should be considered when interpreting these findings. First, the study was conducted within a single community-based HVM program in Kern County, California, and participants self-selected into the program and study. Findings may therefore not generalize to HVM programs operating in different geographic, policy, or service environments. The program also distributed a specific FTS product (DoseTest), and participants identified barriers related to its instructions and practical use. Programs distributing FTS with different testing procedures or usability characteristics may observe different patterns of use, re-engagement, and peer diffusion. The qualitative findings are similarly context-specific and were intended to provide an in-depth understanding of participants'

experiences rather than statistical generalizability; however, they provide important context for interpreting patterns observed in the quantitative and HVM dispensing data.

Second, only a small proportion of the quantitative sample dispensed FTS from the HVM. Although repeated vending among these participants provided evidence of re-engagement, the small number of HVM FTS users limits statistical power and the precision with which factors associated with subsequent dispensation can be estimated. Findings regarding re-engagement should therefore be interpreted cautiously and examined in larger samples and across multiple HVM programs.

Finally, HVM dispensing records capture supplies obtained directly from the machine but not whether each FTS was ultimately used, how test results influenced subsequent behavior, or the extent to which supplies were redistributed to others. Our qualitative findings suggest that secondary distribution occurred, meaning HVM transaction data may simultaneously overestimate individual use while underestimate the broader reach of FTS through participants' social networks.

5. Conclusions

This study advances drug checking as a cascade of engagement rather than a single measure of FTS uptake, highlighting opportunities for HVMs to reach people who may be newly engaging with drug checking and to support continued engagement and peer diffusion. Importantly, PWUD demonstrated a willingness to use drug checking to protect themselves and extend harm reduction resources and knowledge throughout their social networks. Their ability to do so, however, depends on access to practical, usable technologies and is shaped by upstream policy decisions that can either support their agency or constrain their ability to engage in harm reduction. At a time of rapidly evolving drug supplies and high overdose risk, drug checking technologies and the policies governing their funding, procurement, and distribution must keep pace so that PWUD have the tools they need to prevent overdose and protect themselves and their communities.

Declarations

Author Contribution

ANSH conceptualized the study, acquired funding, collected data, conducted quantitative and qualitative analyses, wrote the original manuscript, contributed to manuscript review and editing, and developed Figure 1. SSG contributed to manuscript writing, conducted qualitative analysis and validation with ANSH, and reviewed and edited the manuscript. BTC contributed to manuscript writing, conducted quantitative analysis and validation with ANSH and MIH, prepared Table 1, and reviewed and edited the manuscript. MIH conducted quantitative analysis with ANSH and BTC and contributed to validation of the quantitative findings. RNB contributed to study conceptualization and manuscript review and editing. PJD contributed to study conceptualization, supervision, and manuscript review and editing. All authors reviewed and approved the final manuscript.

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Data Availability

De-identified quantitative data generated and analyzed during the current study are available from the corresponding author upon reasonable request. Qualitative interview transcripts are not publicly available and will not be shared due to the sensitive nature of the data and the potential risk of participant re-identification.

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Figures

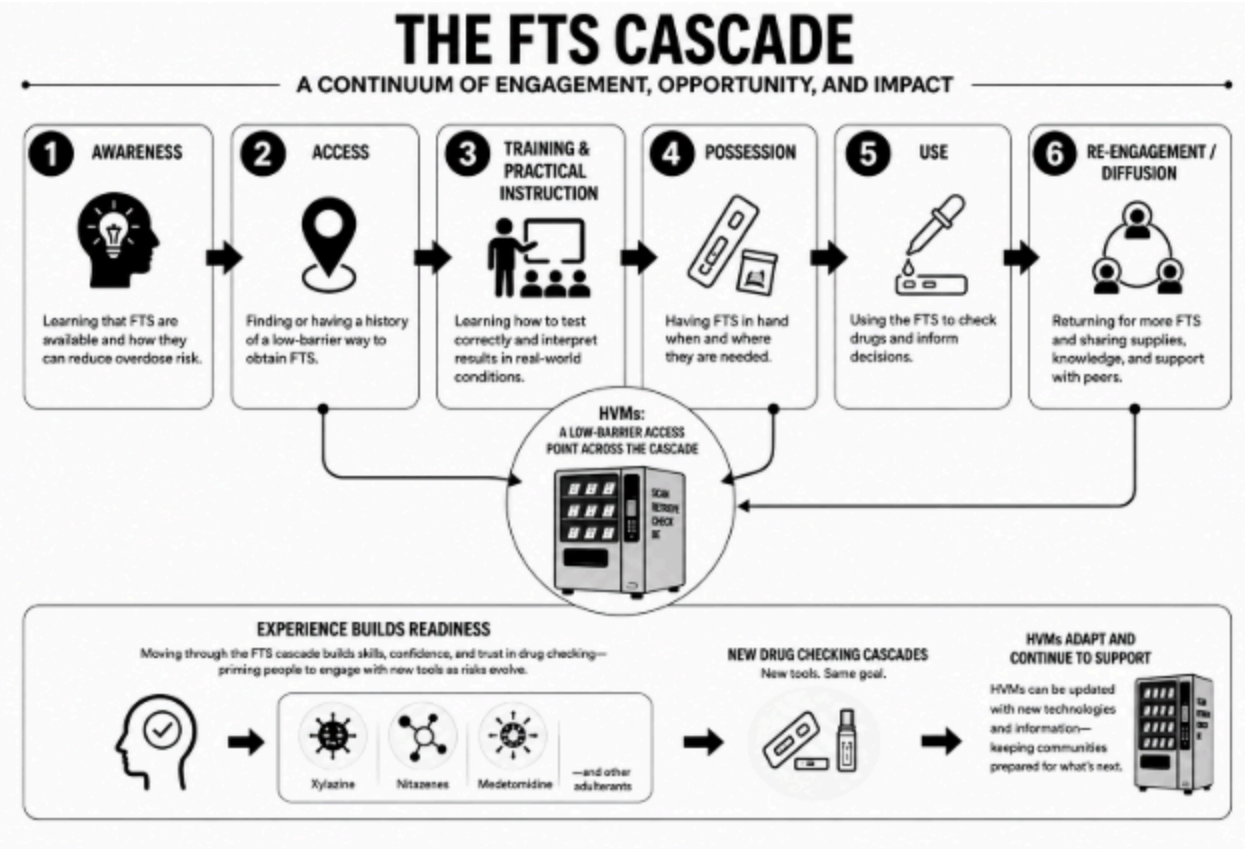


Figure 1

The Fentanyl Test Strip Cascade.

Figure description: Infographic depicting the FTS drug checking cascade as six sequential but potentially non-linear stages: awareness, access, training and practical instruction, possession, use, and re-engagement/diffusion. A HVM is shown as supporting access, possession, and re-engagement with FTS. The figure also illustrates how experience with the FTS cascade may prepare people who use drugs to engage with new drug checking technologies as emerging adulterants create new overdose risks, with HVMs providing adaptable infrastructure to support these future drug checking cascades. The figure was developed by the authors with support from generative artificial intelligence (AI) for visual design and layout.