

1 **What Dose of Methamphetamine Do Regular Consumers Use**
2 **Daily? Estimating Milligrams of Oral Amphetamine Equivalent**

3 Joseph R. Friedman MD, PhD, MPH^{1*}; Adam J. Koncsol²; Caitlin A. Molina²; Ruby Romero²;
4 Jasmine Feng²; Michelle Poimboeuf²; Morgan E. Godvin²; Siddarth Puri, MD³; Carla Marienfeld
5 MD¹; Chelsea L. Shover, PhD²

6 ¹*Department of Psychiatry, University of California, San Diego*

7 ²*Department of General Internal Medicine and Health Services Research, University of*
8 *California, Los Angeles*

9 ³*Medical Director, County of San Luis Obispo, California*

10

11 *Correspondence to:

12 Joseph Friedman, MD PhD, MPH, University of California, San Diego, 200 W Arbor Dr, San Diego,
13 CA, 92103. jofriedman@health.ucsd.edu

14

15 Word Count: 1,071

16 **Abstract**

17 **Introduction**

18 The purity, accessibility, and affordability of illicit methamphetamine has increased in recent
19 decades, which has been linked to rising rates of methamphetamine-involved overdoses,
20 psychosis, cardiovascular events, and other health consequences. Nevertheless, information
21 about the quantity of methamphetamine used by regular consumers has been limited, despite
22 the potential clinical utility of exposure quantification.

23 **Methods**

24 From August 2024-April 2025, self-reported daily methamphetamine consumption was assessed
25 among n=68 individuals. Methamphetamine samples (n=112) were analyzed for purity using
26 liquid chromatography-mass spectrometry. Percent bioavailability by route of administration
27 and stimulant equivalency were obtained from literature. A simulation model leveraging
28 bootstrapping was used to estimate MOAE.

29 **Results**

30 The average reported daily methamphetamine consumption was 0.96g (median 0.36g; range
31 0.1g-4.0g). Average purity was 71.6% (median 75.5%; range 0.1%-95.0%). Given estimated
32 average bioavailability of 52.0% when smoked, 79.3% when insufflated, 67.2% orally or inserted
33 rectally, and a 2:1 amphetamine-methamphetamine equivalency, the average consumer used
34 1,549.0 MOAE daily (median 516.6; range 1.3-10,112.0).

35 **Discussion**

36 We estimate that consumers of methamphetamine in Los Angeles use an average daily
37 stimulant dose (>1,500 MOAE) that is 25-fold higher than the maximum typical recommended
38 clinical dose of mixed amphetamine salts (60mg). This may help explain the limited efficacy of
39 prescription stimulant treatment for methamphetamine use disorder, which typically employs
40 considerably lower quantities. Given this high dose, these findings shed light on the rising
41 incidence of methamphetamine-related sequelae, such as psychosis, cardiovascular
42 complications, and sudden death. Although exposure quantification is commonplace for alcohol
43 and tobacco use disorders, uncertainties in illicit drug markets has complicated this practice for
44 most illicit drugs. This study supports leveraging emerging information from drug checking
45 programs so that clinicians can approximate exposure quantification.

46 Introduction

47 The purity, accessibility, and affordability of illicit methamphetamine has increased in recent
48 decades¹. This has been linked to rising rates of methamphetamine-involved overdoses,
49 psychosis, psychiatric hospitalizations, cardiovascular events, and other health consequences²⁻⁴.
50 Nevertheless, information about the actual quantity of methamphetamine used in practice,
51 among people with methamphetamine use disorder, has been limited. This is largely due to the
52 historical difficulty in assessing the purity of illicit substances used by patients. Nevertheless,
53 there is considerable potential clinical utility of exposure quantification, such as understanding
54 how a patient's methamphetamine habit compares to potential replacement doses of
55 prescription stimulants, or assessing the health impacts of dose reductions in illicit stimulant
56 use.

57 Using recent advancements in drug checking technologies and services, we quantify the
58 purity of methamphetamine samples used by regular consumers in Los Angeles. We combine
59 this with self-reported daily consumption quantities among the same population to estimate
60 the daily Milligrams of Oral Amphetamine Equivalent (MOAE). This quantity is likely to be more
61 easily interpretable by psychiatrists and other clinicians, who are familiar with dosing of mixed
62 amphetamine salts, rather than the quantity of illicit methamphetamine, for which dosing
63 depends on drug concentration, route of administration, and bioavailability.

64

65 **Methods**

66 Daily MOAE was estimated according to Equation 1, where *Consumption* is the daily milligrams
67 of illicit methamphetamine used, *Purity* is the proportion of active compound in substances sold
68 as illicit “methamphetamine”, *Bioavailability* is the route-of-administration-specific proportion
69 of total drug used that is absorbed systemically, *Methamphetamine: Amphetamine Equivalence*
70 is the ratio of physiological potency between methamphetamine and mixed amphetamine salts,
71 and *Bioavailability Oral Amphetamine Salts* is the fraction of mixed amphetamine salts that is
72 absorbed systemically when taken orally.

73

74 *Milligrams of Oral Amphetamine Equivalence (MOAE) = Consumption · Purity · Bioavailability ·*

75 *Methamphetamine: Amphetamine Equivalence · $\frac{1}{\text{Bioavailability Oral Amphetamine Salts}}$*

76 **Equation 1. Calculation of estimated mg of oral amphetamine equivalent (MOAE) self-**
77 **administered among regular consumers in Los Angeles**

77

78

79 To estimate the distribution of MOAE combining uncertainty and variation in each of the
80 aforementioned parameter inputs, we employed a bootstrapping approach leveraging 10,000
81 draws. This allows for the inclusion of uncertainty in each parameter, which is propagated
82 through to the final estimated MOAE.

83 Methamphetamine purity by weight was assessed using liquid chromatography-mass
84 spectrometry (LC-MS) among n=112 samples collected at a community-based drug checking
85 program in Los Angeles County⁵. Samples were limited to those sold as methamphetamine, and
86 for which clients expected only methamphetamine. Daily methamphetamine consumption

87 volume and route of administration was assessed by self-report using a survey among n=68
88 individuals who regularly consume methamphetamine and brought samples for testing.
89 Bioavailability by route-of-administration and stimulant equivalency factors were drawn from
90 literature review (see supplemental methods). The UCLA IRB approved this project (IRB-22-
91 0760) and additionally determined that aspects of this work constituted public health
92 surveillance and not human subjects research.

93 **Results**

94 The average reported daily methamphetamine consumption was 0.96g (Figure 1). A skewed
95 distribution was observed with a median of 0.36g. The range was 0.1g-4.0g daily. Estimated
96 mean and median purity was 71.6% and 75.5%, respectively, with a range from 0.1% to 95.0%.

97 Bioavailability was estimated from literature sources describing experimental data using
98 human subjects (see supplemental methods for a full description). Average bioavailability of
99 smoked methamphetamine was estimated at 52.0% (of the total “pipe dose”), reflecting a
100 uniform distribution with a minimum of 37% and a maximum of 67%. Bioavailability of
101 insufflated “snorted” methamphetamine was modeled using a normal distribution with a mean
102 of 79.0% and a standard deviation of 6.7%. Oral bioavailability was estimated using a normal
103 distribution with a mean of 67.2% and a standard deviation of 1.59%. Rectal bioavailability
104 was estimated using a normal distribution with a mean of 67.2% and a standard deviation of
105 20.0%. The amphetamine-methamphetamine equivalency was estimated to be 1:2.

106 Given the above factors, the estimated mean and median MOAE used daily was 1,549.0
107 and 516.6, respectively. The estimated range was 1.3 MOAE to 10,112.0 MOAE daily.

108 Discussion

109 We estimate that consumers of methamphetamine in Los Angeles use an average daily
110 stimulant dose (>1,500 MOAE) that is 25-fold higher than the maximum typical recommended
111 clinical dose of mixed amphetamine salts (60mg). This may help explain the limited efficacy of
112 prescription stimulant treatment for methamphetamine use disorder, which typically employs
113 considerably lower quantities⁶. For instance, the 60 to 110mg daily used in trials of
114 amphetamine salts for methamphetamine use disorder would represent 1/14th to 1/25th of the
115 average estimated methamphetamine usage observed in our population^{7,8}.

116 Given this high dose, these findings also shed light on the rising incidence of
117 methamphetamine-related sequelae, such as psychosis, cardiovascular complications, and
118 sudden death^{1,3}, which are much more common with illicit methamphetamine compared to the
119 prescribed use of stimulant therapies⁹.

120 Although exposure quantification is commonplace for alcohol and tobacco use disorders,
121 uncertainties in illicit drug markets has complicated this practice for most illicit drugs. However,
122 this study suggests that by leveraging emerging information from drug checking programs, as
123 well as regularly asking their patients about consumption quantities, clinicians may be able to
124 approximate exposure quantification. This may be useful in understanding the clinical benefits
125 of treatments that result in dose reductions. This can also inform risk stratification for cardiac,
126 psychiatric and other outcomes and personalizing care, including withdrawal management. This
127 approach would also mirror efforts to quantify use and employ usage reduction as a clinical
128 endpoint in addiction-related clinical trials¹⁰.

129 This study represents an example of how emerging drug checking technologies can
130 provide consumers with information that can empower them to make safer drug use decisions,
131 despite the highly uncertain and rapidly-evolving nature of the illicit drug supply.

132 This work is limited by its use of data from a single city and may not be generalizable to
133 other contexts. Self-report consumption data is also prone to recall and desirability biases.
134 Although the LC-MS testing technology used here is generally considered the ‘gold standard’ for
135 this type of assessment, it can miss certain contaminants not explicitly tested for.

136 In sum, we provide the first quantification, to our knowledge, of the daily dose of
137 methamphetamine used by regular consumers. We defined a novel metric, MOAE, which can
138 assist psychiatrists and other clinicians to describe methamphetamine consumption in terms of
139 prescription stimulant equivalent. We find that the average regular consumer uses 25-fold the
140 recommended maximum dose of amphetamine salts, which may explain the myriad and severe
141 health harms observed among patients with long-term methamphetamine use. Further study
142 will be required to assess the degree to which these findings hold true in other populations.

143

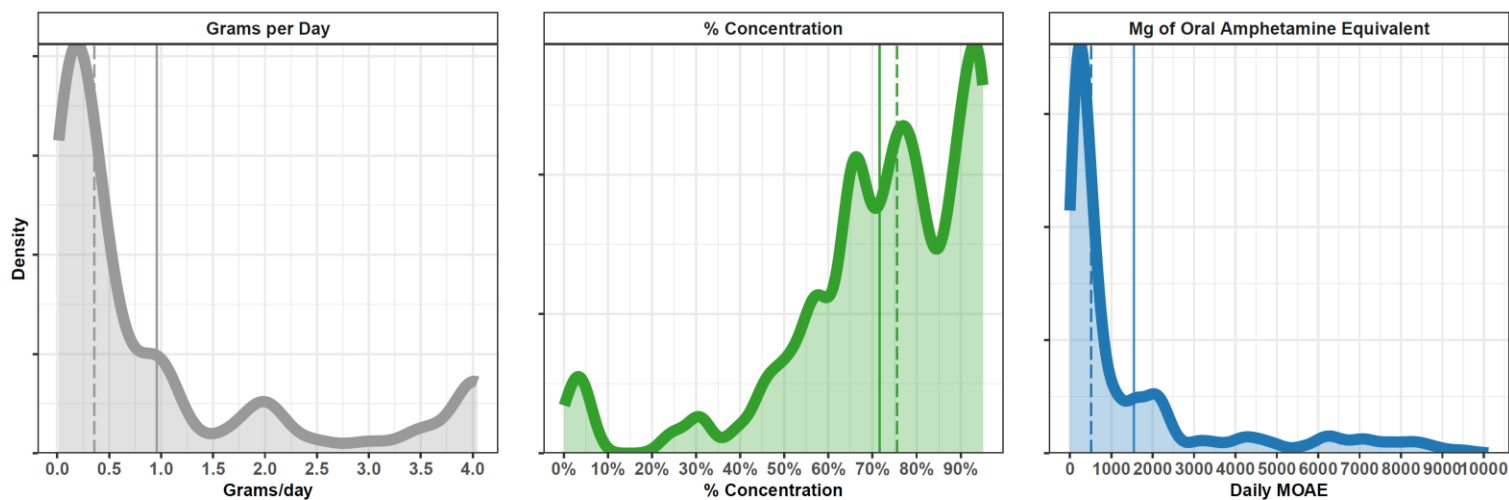


Figure. Distributions, Median, and Mean Grams per Day Consumed, Percent Concentration (Purity), and Estimated mg of Oral Amphetamine Equivalent Self-Administered Among Regular Consumers in LA

For each panel, a dashed vertical line shows the distribution mean, and a solid line shows the distribution mean. Left: The distribution of self-reported grams of methamphetamine ingested per day among regular consumers participating in drug checking services in Los Angeles. Center: Percent concentration (purity) of expected methamphetamine samples provided by clients at drug checking services in Los Angeles. Right: the estimated distribution of milligrams of oral amphetamine equivalent (MOAE) consumed among drug checking clients in Los Angeles.

146 References

- 147 1. Han B, Compton WM, Jones CM, Einstein EB, Volkow ND. Methamphetamine Use,
148 Methamphetamine Use Disorder, and Associated Overdose Deaths Among US Adults. *JAMA*
149 *Psychiatry*. 2021;78(12):1329. doi:10.1001/jamapsychiatry.2021.2588
- 150 2. Rognli EB, Heiberg IH, Jacobsen BK, Høy A, Bramness JG. Transition From Substance-Induced
151 Psychosis to Schizophrenia Spectrum Disorder or Bipolar Disorder. *AJP*. 2023;180(6):437-444.
152 doi:10.1176/appi.ajp.22010076
- 153 3. Calcaterra SL, Yamkovoy K, Swathi PA, et al. U.S. trends in methamphetamine-involved
154 psychiatric hospitalizations in the United States, 2015-2019. *Drug Alcohol Depend*.
155 2024;262:111409. doi:10.1016/j.drugalcdep.2024.111409
- 156 4. Friedman J, Shover CL. Charting the fourth wave: Geographic, temporal, race/ethnicity and
157 demographic trends in polysubstance fentanyl overdose deaths in the United States, 2010–
158 2021. *Addiction*. 2023;118(12):2477-2485. doi:10.1111/add.16318
- 159 5. Koncsol AJ, Molina CA, Romero R, et al. Purity of consumer-level methamphetamine samples
160 and methamphetamine-adulteration of other drugs: Los Angeles, 2023-2024. Published
161 online March 20, 2025:2025.03.18.25323868. doi:10.1101/2025.03.18.25323868
- 162 6. Prescription psychostimulants for the treatment of stimulant use disorder: a systematic
163 review and meta-analysis | Psychopharmacology. Accessed April 26, 2025.
164 <https://link.springer.com/article/10.1007/s00213-020-05563-3>
- 165 7. Galloway GP, Buscemi R, Coyle JR, et al. A Randomized, Placebo-Controlled Trial of Sustained-
166 Release Dextroamphetamine for Treatment of Methamphetamine Addiction. *Clin Pharmacol*
167 *Ther*. 2011;89(2):276-282. doi:10.1038/clpt.2010.307
- 168 8. Longo M, Wickes W, Smout M, Harrison S, Cahill S, White JM. Randomized controlled trial of
169 dexamphetamine maintenance for the treatment of methamphetamine dependence.
170 *Addiction*. 2010;105(1):146-154. doi:10.1111/j.1360-0443.2009.02717.x
- 171 9. Moran LV, Skinner JP, Shinn AK, et al. Risk of Incident Psychosis and Mania With Prescription
172 Amphetamines. *AJP*. 2024;181(10):901-909. doi:10.1176/appi.ajp.20230329
- 173 10. Amin-Esmaeili M, Farokhnia M, Susukida R, et al. Reduced drug use as an alternative
174 valid outcome in individuals with stimulant use disorders: Findings from 13 multisite
175 randomized clinical trials. *Addiction*. 2024;119(5):833-843. doi:10.1111/add.16409

176

177 Acknowledgements

178 The authors report no conflicts of interest. JRF received funding from the National Institute on
179 Drug Abuse (DA049644) and the National Institute of Mental Health (MH101072). AJK received
180 educational support through the NIH/National Center for Advancing Translational Science
181 (NCATS) UCLA CTSI (TL1TR001883). CLS received support from the National Institute on Drug
182 Abuse (K01DA050771). This work was supported by the Centers for Disease Control and
183 Prevention as part of Overdose Data to Action: LOCAL (CDC-RFA-CE-23-0003), and made
184 possible through an equipment grant from the James B. Pendleton Charitable Trust to the UCLA
185 AIDS Institute and UCLA Center for AIDS Research. The funders played no role in the design and
186 conduct of the study; collection, management, analysis, and interpretation of the data;
187 preparation, review, or approval of the manuscript; and decision to submit the manuscript for
188 publication. CLS and JF had full access to all the data in the study and take responsibility for the
189 integrity of the data and the accuracy of the data analysis.

190

191 Supplemental Methods

192

193

Purity

- 194 1. Data describing methamphetamine purity and daily quantity ingested among
195 regular consumers were assessed via data generated from anonymous participants
196 accessing a community-based drug checking program, *Drug Checking Los Angeles*.
197 Participants voluntarily provide samples of illicit drug products for testing at four
198 different sites in Los Angeles County, California from August 2024 to April 2025.
- 199 2. Samples were analyzed initially in the field with Fourier-transform infrared (FTIR)
200 spectroscopy and immunoassay test strips. Samples were then sent to the National
201 Institute of Standards and Technology (NIST) for secondary laboratory-based
202 qualitative and quantitative testing using direct analysis in real time mass
203 spectrometry (DART-MS) and liquid-chromatography mass spectrometry (LC-MS).
204 Both FTIR and DART-MS assess samples against libraries of over 1,300 substances,
205 including pharmaceutical and illicit drugs, adulterants, cutting and bulking agents,
206 precursor chemicals, and other substances (e.g., adhesives, food products, etc.).
207 The LC-MS quantification panel included twelve substances: fentanyl and
208 fluorofentanyl, fentanyl precursor chemicals (4-ANPP, phenethyl 4-ANPP), heroin,
209 methamphetamine, cocaine, α 2-agonists (xylazine and medetomidine), and three
210 common fentanyl adulterants (tetracaine, lidocaine, and Bis(2,2,6,6-tetramethyl-4-
211 piperidyl) sebacate (BTMPS)).

- 212 3. Of 1,644 total available samples, this study included n=112 that were sold as
213 methamphetamine, expected to contain only methamphetamine, per client self-
214 report, and had quantified results available based on LC-MS.
- 215 4. Methamphetamine purity was initially reported as the freebase form which does not
216 account for the additional weight of the hydrochloride salt form. In order to convert
217 this to methamphetamine HCL values (the form that all samples in our dataset were
218 sold as, and the form that medication forms of stimulants typically consist of)
219 concentration values were multiplied by 1.24 to reflect the ratio of the molecular
220 weights between the HCL and freebase forms of methamphetamine.
- 221 5. As a result of measurement limitations, concentration at or above 95% was imputed
222 to be 95%. Additionally, samples with methamphetamine concentration below the
223 limit of quantitation were imputed to be 0.1%.
- 224 6. The 112 available methamphetamine purity values were resampled to create 10,000
225 draws representing the distribution of purity using the sample() function in R. A seed
226 was set to ensure the reproducibility of results between code iterations.

227

228 **Drug Quantity Consumed**

- 229 1. Information on drug quantity consumed for methamphetamine (and other drugs)
230 were collected through an anonymous, optional survey conducted by trained drug
231 checking staff.
- 232 2. Of n=68 participants who regularly consume methamphetamine and brought
233 methamphetamine for testing, n= 46 reported the quantity of methamphetamine
234 they consume in grams and had the option to report the quantity per day, week, or
235 month. Weekly values were converted to days by dividing by 7. Monthly values were
236 converted to daily by dividing by 30. N=22 participants reported quantities in dollars
237 spent on methamphetamine per day or week. Dollar values were converted to
238 grams using a standardized price of \$20 per gram, which was known to the drug
239 checking team as a typical 'going rate' for a gram of methamphetamine. This may
240 slightly underestimate the consumption of individuals who spent larger quantities
241 per day and therefore achieve a lower price per gram.
- 242 3. The 68 available methamphetamine quantity values (alongside associated route of
243 administration information) were resampled to create 10,000 draws representing
244 the distribution of purity using the sample() function in R.

245

246

247 Bioavailability and Equivalence

- 248 1. Literature values were used to estimate credible intervals for all other model
249 parameters, including bioavailability and equivalence factors.
- 250 2. Bioavailability of orally consumed methamphetamine was estimated using
251 experimental data from: Cook, C. E., Jeffcoat, A. R., Sadler, B. M., Hill, J. M.,
252 Voyksner, R. D., Pugh, D. E., White, W. R., & Perez-Reyes, M. (1992).
253 *Pharmacokinetics of oral methamphetamine and effects of repeated daily dosing in*
254 *humans. Drug metabolism and disposition: the biological fate of chemicals*, 20(6),
255 856–862 and Cook CE, Jeffcoat AR, Hill JM, et al. *Pharmacokinetics of*
256 *methamphetamine self-administered to human subjects by smoking S-(+)-*
257 *methamphetamine hydrochloride. Drug Metab Dispos.* 1993;21(4):717-723. The
258 authors estimated the oral bioavailability of methamphetamine to be 67.2% +/-
259 3.1%. This quantity was used directly as no other studies were found. Draws were
260 estimated using a normal distribution with a mean of 67.2 and a standard deviation
261 of 1.59.
- 262 3. Bioavailability of smoked methamphetamine was estimated from three studies:
- 263 a. Cook CE, Jeffcoat AR, Hill JM, et al. *Pharmacokinetics of methamphetamine*
264 *self-administered to human subjects by smoking S-(+)-methamphetamine*
265 *hydrochloride. Drug Metab Dispos.* 1993;21(4):717-723. The quantity of
266 interest is the percent of the “total pipe dose” that is ultimately absorbed.
267 This study estimated that a bioavailability of 66% (90% absorption of 73.1%
268 of drug smoked, 26.9% left in pipe).
- 269 b. Harris DS, Boxenbaum H, Everhart ET, Sequeira G, Mendelson JE, Jones RT.
270 *The bioavailability of intranasal and smoked methamphetamine. Clin*
271 *Pharmacol Ther.* 2003;74(5):475-486. doi:[10.1016/j.clpt.2003.08.002](https://doi.org/10.1016/j.clpt.2003.08.002). This
272 study estimated a bioavailability of 37.4% (67% absorption of 55% of drug
273 smoked, 45% left in pipe). Nevertheless, the authors used a method that was
274 not designed to maximize the methamphetamine extracted from the pipe, as
275 each participant took only 2 inhalations of each dose. The authors of this
276 study estimate, in their discussion section, that true absorption of an
277 effective pipe dose is likely to be 37% to 67% based on user smoking skill.
- 278 c. Perez-Reyes, M., White, R., McDonald, S., Hill, J., Jeffcoat, R., & Cook, C. E.
279 (1990). *Pharmacologic effects of methamphetamine vapor inhalation*
280 *(smoking) in man. NIDA research monograph*, 105, 575–577. This study
281 estimated the bioavailability of “vaporized” (i.e., smoked) methamphetamine
282 to be approximately 50%. This was largely a result of analyzing subjective and

283 cardiovascular effects under experimental conditions between IV and
284 smoked methamphetamine.

285 Given the above, the bioavailability of smoked methamphetamine was
286 estimated using a uniform distribution with a minimum of 37% and a maximum
287 of 67%.

- 288 4. The bioavailability of insufflated (“snorted”) methamphetamine was estimated
289 using the following study: *Harris DS, Boxenbaum H, Everhart ET, Sequeira G,*
290 *Mendelson JE, Jones RT. The bioavailability of intranasal and smoked*
291 *methamphetamine. Clin Pharmacol Ther. 2003;74(5):475-486.*
292 *doi:10.1016/j.clpt.2003.08.002.* This study estimated a bioavailability of 79% +/-
293 13.1%. Bioavailability was estimated using a normal distribution with a mean of 79.0
294 and a standard deviation of 6.72%.
- 295 5. No literature sources were found describing the bioavailability of “boofed” or
296 rectally administered methamphetamine. Given that per rectum absorption is often
297 similar or greater than oral absorption, the distribution was estimated using a
298 normal distribution with a mean of 67.2% (the same as for PO bioavailability), yet
299 with a significantly larger standard deviation of 20%, given the lack of data on this
300 topic.
- 301 6. The bioavailability of injected methamphetamine was, by definition, set at 100%.
- 302 7. Among the n=68 individuals providing route of administration information alongside
303 quantity of consumption information (resampled to create 10,000 draws)
304 bioavailability was calculated for each draw. If an individual reported multiple
305 routes of administration, then the average of the bioavailability coefficients was
306 used for that draw. In effect, this assumes that individuals evenly split their
307 consumption between the different methods they reported. This could
308 underestimate or overestimate their total absorption depending on their true route
309 of administration habits and the relative frequencies of each method of
310 consumption.
- 311 8. The methamphetamine to amphetamine potency ratio was assessed using
312 equivalency tables (<https://www.adhdmedcalc.com/>), which tend to assign a 2:1
313 ratio, and based on clinical trials data
314 (https://www.accessdata.fda.gov/cdrh_docs/reviews/K040133.pdf) . This value of
315 2.0 was used for calculations.
- 316 9. The bioavailability of oral mixed amphetamine salts was assessed using literature
317 sources. Although no specific experimental data were identified, review sources
318 generally reported a high-level of absorption, with values ranging from 75%-95%.

319 Bioavailability was therefore estimated using a uniform distribution ranging from
320 75% to 95%.

321

322 **Calculations**

323 1. Calculations were performed according to the equation listed in the main text for
324 the 10,000 draws of each parameter, derived as defined above. The distribution of
325 quantity consumed, purity, and MOAE was graphed directly across the draws, and
326 summary statistics were calculated.