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Effects of Varying Marijuana Potency on Deposition of Tar and Δ^9-THC in the Lung During Smoking

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MATTHIAS, P., D. P. TASHKIN, J. A. MARQUES-MAGALLANES, J. N. WILKINS AND M. S. SIMMONS. *Effects of varying marijuana potency on deposition of tar and Δ^9-THC in the lung during smoking.* PHARMACOL BIOCHEM BEHAV **58**(4) 1145–1150, 1997.—To determine whether smoking more, compared to less, potent marijuana (MJ) cigarettes to a desired level of intoxication ("high") reduces pulmonary exposure to noxious smoke components, in 10 habitual smokers of MJ, we measured respiratory delivery and deposition of tar and Δ^9-tetrahydrocannabinol (THC), carboxyhemoglobin (COHb) boost, smoking topography, including cumulative puff volume (CPV) and breathholding time, change in heart rate (ΔHR) and "high" during ad lib smoking of 0, 1.77, and 3.95% MJ cigarettes on 3 separate days. At each session, subjects had access to only a single MJ cigarette. On average, smoking topography and COHb boost did not differ across the different strengths of MJ, while THC delivery, as well as HR, were significantly greater ($p < 0.01$) and tar deposition significantly less ($p < 0.03$) for 3.95% than 1.77% MJ. Although individual adaptations in smoking topography for 3.95% compared to 1.77% MJ were highly variable, three subjects with the lowest 3.95% MJ:1.77% MJ ratios for CPV also displayed the lowest 3.95% MJ:1.77% MJ ratios for tar deposition. In vitro studies using a standardized smoking technique revealed a mean 25% lower tar yield from 3.95% than 1.77% MJ ($p < 0.05$), but no difference between 1.77% and 0% marijuana. Under the conditions of this study, we conclude that tar delivery is reduced relative to THC content in a minority of subjects, and this reduction appears to be due to a reduced intake of smoke (decreased CPV) and/or a reduced tar yield from the stronger MJ preparation. © 1997 Elsevier Science Inc.

Marijuana Δ^9-tetrahydrocannabinol (THC) Smoking topography Tar yield Tar deposition Lung Carboxyhemoglobin boost "High"

WE have previously shown that compared to tobacco smoking, marijuana smoking results in an approximately fourfold greater deposition of tar in the lung and a four- to fivefold larger boost of carboxyhemoglobin (COHb) in the blood when equivalent quantities of the two substances are smoked (12,16). These differential effects appeared to be mainly due to less filtration of marijuana than tobacco cigarettes, resulting in a relatively greater tar yield from marijuana (13), and the longer breathholding time following inhalation of the smoke of marijuana than that of tobacco, resulting in a greater fractional retention in the lung of the inhaled tar and a greater absorption of carbon monoxide (13,16). These findings suggest that, at least for equivalent weights of plant material smoked, marijuana joints might have a greater potential than tobacco cigarettes for adverse health effects related to the carcinogenicity and respiratory irritant effects of components in tar (6) and the reduced myocardial oxygen delivery (1) and reduced maternal and fetal tissue oxygenation caused (8) by an elevated COHb.

It has been hypothesized that the health hazards from toxic components in marijuana smoke could be reduced if habitual marijuana users smoked higher potency marijuana (4). This hypothesis assumes the following: 1) that smokers are able to "titrate" the amount of THC absorbed during marijuana smok-

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ing in a manner that will result in decreasing their cumulative puff volume of inhaled smoke when smoking a more potent compared to a less potent preparation, to achieve a given desired level of intoxication; and 2) that the yield of tar relative to Δ^9-tetrahydrocannabinol (THC) from marijuana preparations of different potency always decreases as the THC concentration of the preparation increases. To test this hypothesis and these assumptions, we evaluated the effects of varying THC concentrations in marijuana cigarettes (0, 1.77, and 3.95%) on the deposition of tar in the lung, carboxyhemoglobin boost, and subjective and physiological measures reflecting the bioavailability of THC in ten habitual smokers of marijuana.

METHODS

Subjects

We studied 10 male habitual marijuana smokers [mean age (± SD), 23.2 ± 2.3 years], who smoked an average of 12.7 ± 11.5 joints/week and reported a cumulative lifetime smoking history of 27.2 ± 46.5 joint-years (number of marijuana joints per day times the number of years of marijuana smoking). All were in good general health and had normal values for routine pulmonary function tests. None reported intravenous drug abuse or smoking illicit substances other than marijuana. Three were current tobacco cigarette smokers (14.0 ± 13.9 cigarettes/day) and four were ever-smokers of tobacco with a cumulative lifetime smoking history of 3.6 ± 1.1 pack-years (number of packs of cigarettes per day times the number of years of tobacco smoking). The study was approved by the UCLA Human Subject Protection Committee and the California Research Advisory Panel. All subjects signed an approved informed consent form prior to their participation in the study.

Study Protocol and Procedures

Each subject was studied on 3 separate days approximately 1 week apart after refraining from smoking tobacco for ⩾1 h and marijuana for ⩾6 h. During each study session, subjects smoked a marijuana cigarette (85 mm length × 25 mm circumference) containing either 0.000 ± 0.002% THC (mean weight 833 mg; range 808–864 mg), 1.77 ± 0.01% THC (mean weight 832 mg; range 789–924 mg) or 3.95% THC (mean weight 734 mg; range 687–774 mg), according to a crossover design. The order of assignment of the three different strengths of marijuana to each subject was randomized and subjects were masked to the assignment. All marijuana cigarettes were prepared from Mississippi-grown Mexican marijuana and were supplied by the National Institute on Drug Abuse; the 0% THC preparation was prepared by ethanol extraction. Marijuana cigarettes were stored at 4°C to minimize chemical degradation and were maintained in a humidifier at 60% humidity and 21°C for 24 h before the study to reduce harshness.

Subjects were asked to smoke each marijuana cigarette ad lib but were specifically instructed to stop smoking once they had achieved their desired level of intoxication ("high"). Peripheral venous blood was withdrawn anaerobically immediately before and 2 min after each cigarette was smoked for measurement of the percentage of COHb saturation using a CO-oximeter (Model 282, Instrument Laboratory, Lexington, MA). Immediately prior to smoking at 2, 5, 15, 30, and 45 min after smoking, heart rate was measured electrocardiographically and subjects were asked to rate their level of intoxication on a scale of 0 to 10, with 10 representing the greatest "high" they had ever achieved.

Smoking topographic measures were determined, as previously described (16). Briefly, the volume and number of puffs and the interpuff interval were measured using a 00 Fleisch pneumotachygraph (resistance 0.0068 cm H_2O; linear from 5 to 100 ml/s) connected through a differential pressure transducer (Model 282 MP54-3, Validyne, Northridge, CA) (range ± 2 cm H_2O) to a 12-channel oscilloscopic recorder with a differential integrator-computer and a rapid infrared writer attachment (Honeywell Simultrace Recorder, Model VR-12, White Plains, NY). The pneumotachygraph was connected through 1-cm diameter Tygon tubing (length 70 cm) to the distal end of a glass cylinder (diameter 5 cm; length 12 cm) that contained two 1-cm diameter ventilation ports and was sealed at its proximal end by a rubber stopper. The marijuana cigarette was held in a small plastic holder inserted through the rubber stopper. During a puff, the ventilation ports were occluded by rubber stoppers so that the entire volume of air drawn through the cigarette could be measured by the pneumotachygraph. Between puffs, the ventilation ports were uncovered to prevent extinction of the cigarette or accumulation of carbon monoxide. The volume of smoke and air inhaled into the lungs ("inhaled volume") in association with each puff was measured using inductive plethysmography (Respitrace-Plus, NonInvasive Monitoring Systems, Miami Beach, FL). During calibration maneuvers, inhaled volumes calculated from inductive plethysmography agreed with measurements obtained by spirometry within ±10%. The amount of time the inhaled smoke was retained in the lungs ("breathholding time") was calculated as the interval between the times corresponding to one-third of the maximum inhaled volume and two-thirds of the maximum volume exhaled following breathholding.

The amount of inhaled insoluble smoke particulates (tar) was measured by a previously described proportional smoke-trapping device (10) that was connected to the plastic cigarette holder at the proximal end of the puff-volume measuring apparatus (1). From the plastic cigarette holder, mainstream smoke was diverted into two parallel pathways, one containing one capillary tube and a Cambridge filter pad ("high-resistance" pathway) and the other containing seven parallel capillary tubes ("low-resistance" pathway). The filter pad trapped the smoke that passed through the high-resistance pathway. The tar (including THC) trapped by the filter was extracted with methanol. The tar content (total insoluble particulate matter) was analyzed by means of a spectrophotometer (wavelength 400 nm). THC concentrations were determined by injecting dilutions of the methanol wash into a Waters high performance liquid-chromatograph outfitted with a diode array detector according to modifications of ElSohly et al. (2). Ion pair technology was employed using a Beckman ultrasphere C18 column, a water:acetonitrile mobile phase of 15:85, and isocratic flow of 2 ml/min. Ultraviolet detection was performed at 220 nm with standards obtained from Alltech, Inc. (San Jose, CA). Because a constant fraction of the tar (approximately 12.5%) was retained in the filter over a wide range of puff volumes and flow rates, the actual quantity of inhaled tar, as well as inhaled THC, could be calculated by multiplying the amount of particulates and THC trapped in the Cambridge filter pad in the high-resistance pathway by the term ($[1 \div 0.125] - 1$), or 7 (10). At the end of the period of breathholding after each puff, subjects exhaled the smoke into a megaphone device, the distal end of which (4.5-cm diameter) was fitted with another Cambridge filter pad attached to a vacuum system (5,16) to trap the exhaled particulates. Following methanol extraction, the latter were also quantitated by spectrophotometry and the exhaled THC by HPLC (3) as detailed earlier. The amount of tar or THC retained (deposited) in the lung was calculated by subtracting the amount of exhaled from the amount of inhaled tar or THC.

The amount of tar delivered to the lung from different strengths of marijuana cigarettes is dependent not only on smoking technique but also on the actual tar yield of the cigarettes, which could vary with the potency of the preparation. We, therefore, measured the amount of tar in mainstream smoke generated from five 0%, five 1.77%, and five 3.95% marijuana cigarettes under standardized smoking conditions using a syringe with a 50-ml puff volume, 2-second duration and 30-s interpuff interval to uniform butt lengths of 25 mm. All the tar in the mainstream smoke was captured in a Cambridge filter interposed between the syringe and the cigarette and measured spectrophotometrically after methanol elution, as described above.

DATA ANALYSIS

For each subject, topographic measurements (puff volume, interpuff interval, inhaled volume, breathholding time) were averaged for each cigarette smoked. These mean values, as well as the number of puffs, cumulative puff volume (the product of the mean puff volume and the number of puffs for each cigarette), butt length, and the amounts of inhaled and retained tar and THC were averaged for all 10 subjects for each potency of marijuana smoked. COHb "boost," peak changes in heart rate from baseline and peak subjective ratings of degree of intoxication after smoking each strength of marijuana were also averaged for all subjects. In addition, for each subject, each measurement variable was expressed as a ratio of that variable determined in relation to smoking 3.95% marijuana to that determined for 1.77% marijuana; these ratios served as indicators of the relative pattern for each subject of smoking active marijuana of two different strengths. The Hotelling's T^2 test, a multivariate test for within-subject differences in repeated measures models, was used to determine the significance of differences in smoking patterns, delivery, and deposition of particulates and THC, and the "boost" in COHb and change in heart rate among the different strengths of marijuana cigarettes (9). Multiple comparisons were then performed using paired *t*-tests, where appropriate. Because the subject's levels of "high" were based on an ordinal scale, these data were analyzed for differences between the THC concentrations using Friedman's nonparametric two-way analysis of variance (7). Differences for all tests were considered significant for p values <0.05. Statistical analyses were performed using SAS (11) and BMDP (2) software.

RESULTS

Smoking topography, pulmonary deposition of tar and THC, COHb boost, and psychophysiologic responses to smoking all showed similarly wide variability across subjects for each strength of marijuana. The extent of this variability is illustrated for cumulative puff volume, breathholding time, tar deposition, and THC retention in Fig. 1, which shows the individual values for these variables for each type of marijuana preparation smoked.

Mean values (±SE) for cumulative puff volume (CPV), inhaled volume (Vol_I), breathholding time, butt length, amount of tar and THC retained in the lung, COHb boost, peak change in heart rate, and peak level of intoxication for each potency of marijuana smoked are shown in Table 1. As expected, both "active" marijuana preparations (1.77% and 3.95% THC) delivered significantly more THC, $F(2, 8) = 51.7$, $p < 0.001$; Hotelling's T^2, to the lung and resulted in a significantly greater change (increase) in heart rate, $F(2, 8) = 24.0$, $p < 0.001$; Hotelling's T^2, than the "inactive" (0% THC) preparation, although neither active preparation elicited a significantly greater "high" than "inactive" marijuana ($p = 0.12$; Freedman nonparametric two-way ANOVA). No differences in any of the measured smoking topographic variables [cumulative puff volume; average puff volume, number of puffs, or interpuff interval (data not shown); inhaled volume; breathholding time; butt length], nor in COHb boost, were noted across the different potencies of marijuana. On the other hand, despite the lack of any mean difference in smoking pattern for the different strengths of marijuana, the average amount of tar delivered to and retained in the lung from the most potent preparation (3.95% THC) was significantly lower than that from both the 0% THC and 1.77% THC preparations ($p < 0.03$). Moreover, the THC delivered to and retained in the lung from 3.95% marijuana was significantly greater than that deposited in the lung from 1.77% marijuana ($p < 0.001$); this difference is reflected in the significantly greater heart rate increase ($p < 0.01$) following the more potent "active" preparation.

The mean percent of inhaled (delivered) tar that was not exhaled and was thus deposited in the respiratory tract was comparable across the different strengths of marijuana (80.7 ± 2.1%, 86.9 ± 3.2%, and 83.6 ± 2.4% for the 0, 1.77, and 3.95% preparations, respectively). Likewise, the average percent of inhaled (delivered) THC that was retained in the lung was similar for the 0, 1.77, and 3.95% potencies (74.1 ± 5.0%, 83.6 ± 3.8%, and 76.5 ± 4.5%, respectively). Consequently, the differences between the amounts of tar (or THC) delivered to the lung between any two strengths of marijuana were similar to the differences between the amounts of tar (or THC) de-

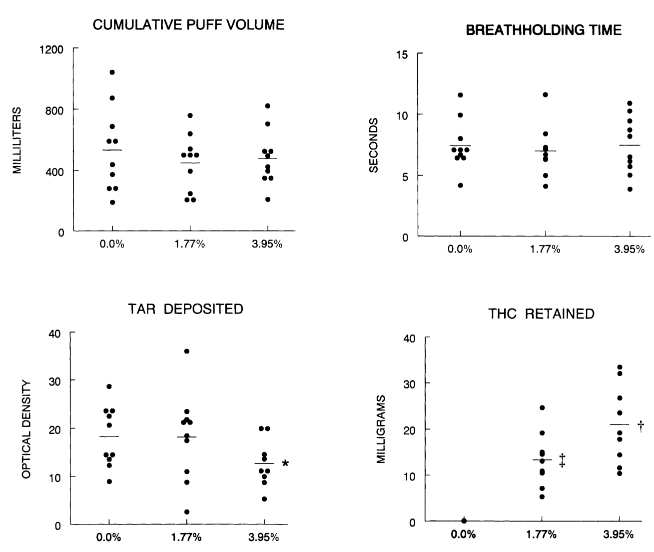

FIG. 1. Individual values for cumulative puff volume (ml) and breathholding time (s) and for amount of tar [optical density (O.D.) units] and amount of THC (mg) deposited in the respiratory tract for 0.0, 1.77, and 3.95% marijuana. Horizontal lines represent mean values. *$p < 0.03$ (compared with 1.77% and 0% THC); †$p < 0.01$ (compared with 1.77% and 0% THC); ‡$p < 0.001$ (compared with 0% THC).

TABLE 1

MEAN VALUES (±SE) FOR SMOKING TOPOGRAPHY, TAR, AND THC DEPOSITION IN THE LUNG, BLOOD CARBOXYHEMOGLOBIN BOOST, AND PSYCHOPHYSIOLOGIC RESPONSES TO THC DETERMINED DURING AND AFTER SMOKING MARIJUANA CIGARETTES OF DIFFERENT THC CONCENTRATION

	TAR O.D.	THC mg	BHT sec	CPV ml	Vol_I liters	Butt length mm	COHb %	High (0–10)	ΔHR min^{-1}
0% THC	18.9	0.1	7.5	534	2.52	16.7	2.6	3.0	6.2
	(2.1)	(0.0)	(0.6)	(87)	(0.28)	(4.3)	(0.5)	(0.7)	(1.6)
1.77% THC	19.9	13.4*	7.0	447	2.17	19.3	2.0	4.3	30.2*
	(2.6)	(2.0)	(0.6)	(5.9)	(0.33)	(4.7)	(0.4)	(0.7)	(3.8)
3.95% THC	13.6†§	21.0*‡	7.5	479	2.11	19.0	2.0	6.0	39.0*‡
	(1.5)	(2.8)	(0.7)	(57)	(0.20)	(7.2)	(0.3)	(0.6)	(4.3)

Definition of abbreviations: Tar = respiratory tar deposition; O.D. = optical density units; THC = respiratory retention of Δ^9-tetrahydrocannabinol; BHT = breathholding time; CPV = cumulative puff volume; Vol_I = inhaled volume of smoke and air; COHb = carboxyhemoglobin saturation; ΔHR = change in heart rate from pre-smoking baseline.

*Significantly different from 0% THC; $p < 0.001$.

†Significantly different from 0% THC; $p < 0.02$.

‡Significantly different from 1.77% THC; $p < 0.01$.

§Significantly different from 1.77% THC; $p < 0.03$.

posited (retained) in the lung between the same two potencies of marijuana.

The ratio of values for the variables shown in Table 1 for 3.95% marijuana to those for 1.77% marijuana were calculated for each subject and averaged across all subjects. The distributions of the individual values for most of these ratios across the 10 subjects are illustrated in Fig. 2. Deviations of these ratios from 1.0 would imply a difference between the more and less potent "active" marijuana preparation with respect to smoking technique, delivery of smoke contents to the lung or the physiological effects of such delivery. The broad range of these ratios, which straddled 1.0 for all variables except the amount of THC delivered to and retained in the lung, reflects the large degree of variability across subjects in differential smoking technique and in subjective and physiological responses to THC between the two strengths of marijuana (Fig. 2). On average, ratios of values for smoking pattern, including cumulative puff volume, breathholding time, and inhaled volume, were close to 1.0. On the other hand, ratios for THC deposition, change in heart rate and "high" were always or mostly above 1.0, while ratios for tar deposition were mostly less than 1.0.

The individual tar yields determined using a standardized, syringe-simulated smoking technique for each of the five cigarettes of each strength that were tested are shown in Fig. 3.

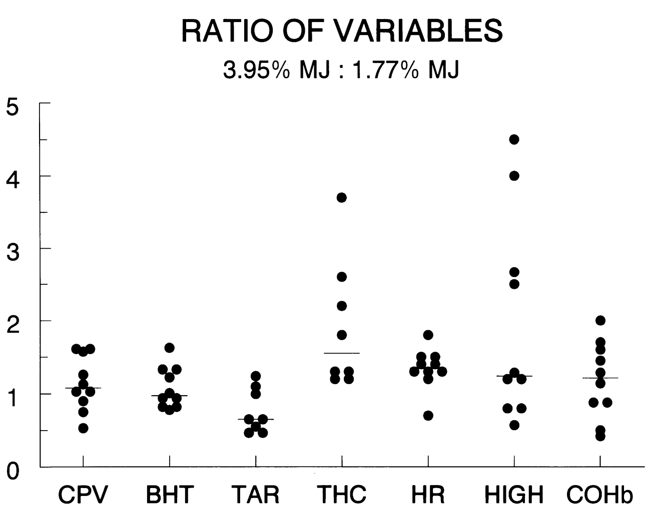

FIG. 2. Individual ratios of values for cumulative puff volume (CPV), breathholding time (BHT), respiratory tar deposition (TAR), respiratory retention of THC (THC), heart rate increase over presmoking baseline (HR), level of intoxication (HIGH) and carboxyhemoglobin boost (COHb) determined for 3.95% marijuana to those determined for 1.77% marijuana (3.95% MJ:1.77% MJ).

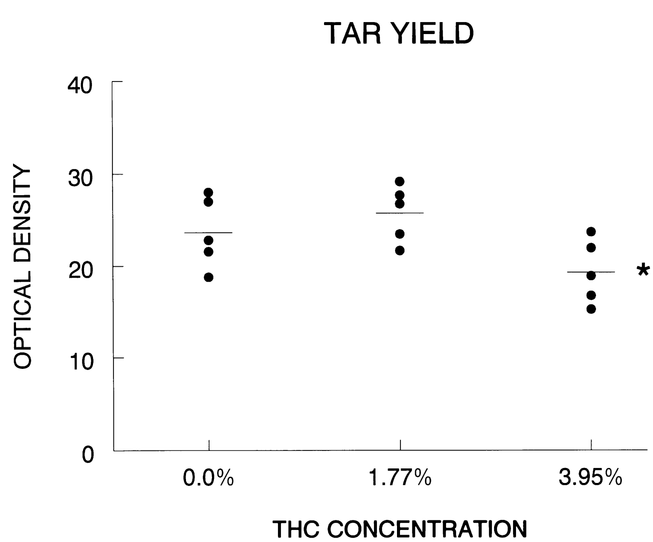

FIG. 3. Individual values for amount of tar (O.D.) in mainstream smoke generated from five 0.0%, five 1.77% and five 3.95% marijuana cigarettes using a syringe with a 50-ml puff volume, 2-s duration and 30-s interpuff interval to butt lengths of 25 mm. Horizontal lines represent mean values. *$p < 0.05$ (compared with 1.77% and 0% THC).

The average tar yield from the 3.95% marijuana cigarette was 19.3 ± 1.6 (SEM) optical density (O.D.) units, which was significantly lower ($p < 0.05$) than the tar yields from both the 1.77% preparation (25.2 ± 1.4 O.D.) and the 0% preparation (23.5 ± 1.6 O.D.).

DISCUSSION

The major findings from this study are that, in a small number of healthy, habitual marijuana smokers asked to smoke different strengths of marijuana to a desired level of intoxication, the amount of tar delivered to and deposited in the lung from the most potent marijuana preparation tested was significantly reduced compared to that of less potent preparations, despite the lack of demonstrable overall differences in smoking topography, including cumulative puff volume, across the different strengths of marijuana (Table 1). In contrast, no difference in COHb boost was observed between more and less potent marijuana cigarettes, while THC delivery and lung retention were significantly greater for 3.95% than 1.77% marijuana, as reflected in a significantly greater heart rate increase ($p < 0.01$) following the 3.95% than the 1.77% preparation (Table 1).

Differences in THC delivery and the related physiological responses to smoking marijuana of different strengths were found despite instructions to the subjects to smoke only to their desired level of intoxication. Possible reasons for the observed differences in THC delivery are 1) that subjects were generally unable to "titrate" THC delivery to achieve a uniform "high" from the 1.77 and 3.95% marijuana cigarettes; or 2) that their desired level of intoxication was greater than that which could be achieved with the weaker of the two active marijuana preparations under the conditions of the experiment, in which they were constrained to smoking only a single marijuana cigarette. In favor of the former possibility is that maximum levels of intoxication were not attained in the majority of subjects (7 of 10) until at least 5 min, and in some subjects (4 of 10) as long as 15 min, after completion of smoking, thus compromising their ability to self-titrate intake of smoke (and thus THC) based on levels of "high" perceived during active smoking. On the other hand, it is still possible that adjustments could be made during smoking with the expectation of delayed peak "highs" based on previous experience. The alternative possibility, namely that the single 1.77% preparation was insufficient, even if consumed to the maximum extent tolerable, to produce the desired level of intoxication, appears inconsistent with the finding that mean butt lengths of the smoked 1.77% and 3.95% marijuana cigarettes were nearly identical (19.3 mm and 19.0 mm, respectively). On the other hand, in 3 of the 10 subjects, butt lengths of the 1.77% marijuana cigarette were substantially shorter than those of the 3.95% preparation and, in 2 additional subjects, both preparations were nearly completely consumed (butt lengths 2–4 mm). Therefore, the possibility remains that in this subset of subjects the weaker of the two active preparations was insufficient to yield the desired level of intoxication, even when smoked to a relatively short butt length, in the absence of access to more than one marijuana cigarette.

The observation that the amount of tar deposited in the lung tended to be reduced for 3.95% marijuana compared to 1.77% marijuana (Table 1 and Fig. 1) is difficult to explain solely on the basis of differences in smoking topography, because smoking topography, including the variables that have been found to correlate best with the amount of tar delivered to and retained in the lung (cumulative puff volume and breathholding time) (13) were, on average, nearly identical for both the higher and lower strengths of active marijuana. Smoking marijuana down to a longer butt length would be expected to decrease tar delivery partly due to the increased filtration through the longer shaft of the cigarette (14); because average butt lengths were similar for the two active strengths of marijuana that were studied, however, this factor could not have accounted for the generally lower tar delivery from the more potent cigarette. On the other hand, considerable interindividual variability was observed in the 3.75:1.77% marijuana ratios both for tar delivery and deposition and for cumulative puff volume and breathholding time (Fig. 2). For the most part, those subjects who exhibited lower cumulative puff volumes when they smoked 3.95% marijuana than 1.77% marijuana also deposited lower amounts of tar in their lungs when they smoked the more potent preparation. A similar relationship between breathholding time and respiratory tar delivery for the two active strengths of marijuana was not observed. These observations suggest that, at least in some subjects, the reduced tar delivery to the lung from the higher potency marijuana preparation might be accounted for, at least in part, by adjustments in smoking technique that result in a lower cumulative puff volume.

Reduced tar delivery from more potent marijuana cigarettes could also occur if the actual tar yield from stronger preparations were reduced relative to that from the same quantity of weaker preparations, when smoking technique was standardized. To evaluate this possibility, we measured the amount of tar in mainstream smoke generated from the different strengths of marijuana cigarettes using a standardized in vitro smoking technique. As shown in Fig. 3, the average tar yield from the 3.95% marijuana cigarette was significantly lower ($p < 0.05$) than the tar yields from both the 1.77% and the 0% preparations. Consequently, a reduced tar yield from stronger preparations of marijuana might contribute, at least partly, to less delivery of tar to the lung. On the other hand, no difference was noted between the tar yields of the 0 and 1.77% preparations, so that a linear relationship between the potency of a marijuana cigarette and its tar yield was not apparent over the entire range of potencies (0.00–3.95% THC) of the preparations that we tested. Data from a recent preliminary Australian study on the relative yields of condensed particulate matter (tar) and THC from different samples of seized marijuana ranging in potency from 0.57 to 13.0 % (mean 3.42%; median 1.8%) (Hall, W., National Drug and Alcohol Research Centre, Kensington, Australia; Personal Communication) show a weak relationship between THC content and tar yield for preparations with THC concentrations ≤2.5% and inconsistently lower tar yields for the few preparations tested with THC concentrations >5%. Consequently, had we been able to evaluate the influence of smoking marijuana cigarettes with THC concentrations >5%, we might have found greater reductions in respiratory tar delivery than we demonstrated in the present study for 3.95% compared to 1.77% marijuana.

Mainstream smoke from marijuana or tobacco is a highly concentrated aerosol of liquid particles that is formed by complex chemical reactions, including hydrogenation, pyrolysis, oxidation, decarboxylation, dehydration, chemical condensation, distillation, and sublimation (15). The smoke aerosol is composed of a large variety of organic and inorganic chemicals dispersed in a gaseous medium of nitrogen, oxygen, hydrogen, carbon dioxide, carbon monoxide, and a number of volatile and semivolatile organic chemicals. The tar phase consists of total particulate matter minus water and contains a number of constituents, including tumor initiators, carcinogens, and cocarcinogens that contribute to the health hazards of smoking. Several factors influence the tar yields of tobacco cigarettes (15) that might also be relevant to marijuana. These include plant genetics and growth conditions that affect chemical composition and physical properties of the leaf, moisture content, the curing and fermentation process, burning temperature, the quality of the cigarette paper (e.g., porosity), and the presence or absence of a filter. Which of these factors may be responsible for the apparently lower tar yield from more potent preparations of marijuana is unclear.

The mean percentage of inhaled tar deposited in the lung in the present study from marijuana cigarettes of different potency (80.7–86.9%) is similar to that previously reported from our laboratory from 0.00 and 1.24% marijuana cigarettes (84.4–86.1%) and higher than that deposited from tobacco cigarettes (64.0%) (16). The greater percentage deposition of inhaled tar from marijuana than tobacco cigarettes is attributable to the longer breathholding time characteristic of marijuana smoking compared to tobacco smoking (13,16). The similarity in mean breathholding times observed in the present study during the smoking of marijuana cigarettes of different strengths (Table 1) is consistent with the comparability in mean percentage of delivered tar that was deposited in the lung across the different potencies of marijuana.

In summary, in a small number of habitual marijuana users studied during the smoking of single marijuana cigarettes of varying potency up to a maximum THC concentration of 3.95%, adjustments of smoking topography to the different strengths of marijuana were highly variable between subjects. Under the conditions of the experiment (limited maximum potency of marijuana and a limit of a single cigarette), smokers generally appeared unable to titrate THC delivery to achieve a uniform "high," so that the level of intoxication and heart rate were often more increased after smoking cigarettes of higher than lower potency. Tar delivery from 3.95% marijuana was reduced relative to that from 1.77% marijuana in 3 of 10 subjects, and the reduction in tar delivery appeared to be related to reduced intake of smoke (lower cumulative puff volume) in these few subjects, as well as to the reduced tar yield during combustion of the stronger marijuana preparation. COHb boost was not affected by the potency of the marijuana smoked. We conclude that, compared to lower potency marijuana cigarettes, stronger preparations appear to lead to a modest reduction in exposure of the lung to tar in some smokers but not to carbon monoxide. We did not assess the influence of varying THC content on the respiratory delivery of volatile constituents other than carbon monoxide in the gas phase of marijuana smoke, some of which are known to be biologically hazardous. Although it is possible that relatively reduced exposure to carcinogenic components in the tar phase of marijuana from smoking cigarettes with a higher THC content might reduce the carcinogenic risk of marijuana smoking, the true health implications of these findings are as yet unclear.

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