Cannabis "Vaporization": A Promising Strategy for Smoke Harm Reduction

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SUMMARY. The primary health hazard of medical cannabis is respiratory damage from marijuana smoke. Aside from oral ingestion and other non-smoked delivery systems not yet commercially available, strategies for reducing the harm of smoking include: (1) use of higher potency cannabis and (2) smoking devices aimed at eliminating toxins from the smoke. Studies have found that waterpipes and solid filters are ineffectual at improving the THC/tar ratio in cannabis smoke. The most promising alternative appears to be "vaporization," in which cannabis is heated to a point where cannabinoids are emitted without combustion. A feasibility study by NORML and MAPS has demonstrated that an electric vaporizer can successfully generate THC at 185°C while completely suppressing benzene, toluene, and naphthalene formation. Further studies are needed to evaluate how effectively vaporizers suppress other toxins, and how their performance varies using different samples, temperatures, and device designs.

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INTRODUCTION

A leading health concern about the medical use of cannabis is respiratory sequelae due to smoking. Aside from its active cannabinoids, marijuana smoke greatly resembles tobacco smoke, containing noxious tars and gases that are a byproduct of leaf combustion. These include highly carcinogenic polycyclic aromatic hydrocarbons (PAHs) and other known carcinogens, such as benzene, at levels comparable to those in tobacco smoke. Also included are numerous other toxic inhalants, among them carbon monoxide, toluene, naphthalene, acetaldehyde, phenol, and hydrogen cyanide, again at levels comparable to tobacco (Huber 1991; Institute of Medicine 1982).

There is accordingly good reason to believe that chronic marijuana smoking poses many of the same respiratory hazards as tobacco. These hazards are offset by the fact that marijuana users typically consume a fraction as much material as tobacco smokers (1 g per day for a typical daily user, or 4 g per day for a very heavy, one-ounce per week medical patient, versus 20 g per day for a pack-a-day cigarette smoker). On the other hand, marijuana has been shown to deliver four times as much tar to the lungs per weight smoked as tobacco, possibly due to the deep breath holding of marijuana smokers (Wu et al. 1988).

On balance, the evidence indicates that marijuana smoking is not as great a public health hazard as tobacco. Epidemiological studies have yet to find evidence of lung cancer or increased mortality in frequent cannabis users (Sidney 1997a, 1997b). Unlike tobacco, cannabis lacks nicotine, a major risk factor in heart disease. Long-term studies of heavy users by Tashkin have found no evidence of a link between marijuana smoking and emphysema (Tashkin 1997, Zimmer and Morgan 1997).

Nonetheless, there is solid evidence to show a link between heavy cannabis smoking and respiratory disease. A succession of clinical studies have found that long-term, frequent marijuana smokers exhibit signs of respiratory damage, including chronic bronchitis, sore throat, inflammation, impaired immune function, and pre-cancerous cell changes (Tashkin 1993). A survey of patients at the Kaiser Permanente medical centers found that marijuana smokers suffered a significantly higher incidence of respiratory complaints (Polen et al. 1993). There have also been anecdotal reports of neck and throat cancers in heavy marijuana smokers, most of whom also smoked tobacco. Another concern in light of the widespread use of cannabis among AIDS patients is that heavy marijuana smoking might increase susceptibility to lung infections such as *Pneumocystis carinii* pneumonia, although such a risk has not been proven.

In sum, respiratory harm has been rightly called "the only well-confirmed deleterious physical effect of marijuana" in the words of Dr. Lester Grinspoon (Grinspoon 1997, p. 250). Given the growing public pressure against smoking tobacco, these concerns have loomed large as an obstacle to acceptance of medical marijuana by public health authorities. In its review of medical marijuana, the Institute of Medicine of the National Academy of Sciences found "no future" in smoked marijuana, saying, "Because marijuana is a crude delivery system that also delivers harmful substances, smoked marijuana should generally not be recommended for medical use" (Institute of Medicine 1999, pp. 10-11). However, the IOM failed to consider various harm reduction techniques that might substantially reduce the hazards associated with smoking cannabis.

In this study, we will discuss the state of the art of marijuana smoke harm reduction, focusing particularly on smoking devices such as waterpipes and vaporizers aimed at reducing the toxins in cannabis smoke. Before doing so, however, it is worth briefly discussing other strategies for respiratory harm reduction.

SMOKE HARM REDUCTION STRATEGIES

The most obvious alternative to marijuana smoking is to ingest cannabis orally via tinctures, extracts, foodstuffs, or capsules. The limitations of oral dosages are well known and substantial (Grinspoon 1997). Oral THC is notoriously unreliable in its effects. The bioavailability of oral cannabinoids varies greatly depending on the individual patient and the state of his or her metabolism and digestive system. Unlike inhaled cannabis, the effects of which become readily apparent within seconds, allowing the patient to regulate the dose via self-titration, oral dosages require up to an hour or more to take effect. Over- or under-dosage is therefore a common problem. The delayed onset of oral cannabis also renders it unsuitable for conditions requiring prompt treatment, such as acute pain or convulsions. In addition, oral dosages are hard to keep down for patients suffering intense nausea. Finally, oral dosages do not have the same pharmacological action as inhaled marijuana, since orally ingested THC does not pass directly into the bloodstream, as with smoking, but is rather processed by the liver, where it is transformed into another, even more psychoactive metabolite, 11-hydroxy-THC (Zimmer and Morgan 1997). The medical implications of this are unknown, though they might include an increased risk of adverse "panic reactions." Historically, the declining interest in medical cannabis at the turn of the last century was attributed to the unreliability of its effects, which may be explained by its oral dosage form. The manifold drawbacks of oral preparations such as synthetic oral THC (dronabinol, Marinol) have led most of today's patients to prefer inhaled marijuana; however, a survey of medical cannabis patients found only minor differences in the subjective effects of oral and smoked herbal cannabis (Corral 2001).

Other non-smoked routes of administration have been proposed, but have not reached the stage of commercial fruition. Topical applications such as cannabis leaf poultices have been used in folk medicine, but their efficacy is dubious and unproven. A patent for a transdermal cannabinoid patch was recently filed by a California company, General Hydroponics (US Patent 6,113,940; http://www.farmacy.org/patch.html), but its efficacy has yet to be demonstrated in FDA trials. While THC is not suited for transdermal application because of its high lipophilicity (Institute of Medicine 1999), the possibility remains that other pharmacologically active cannabis derivatives can be transported through the skin.

Cannabinoid eye drops have been proposed to treat glaucoma, but have yet to be successfully tested in the USA (Grinspoon 1997; Green et al. 1976).

A rectal cannabinoid delivery system has been demonstrated by ElSohly using suppositories that deliver a pro-drug that transforms into THC. This could be a practical alternative to oral dronabinol for patients with extreme nausea. This system is currently under licensed development by Oxford Natural Products in the U.K. (ElSohly 2000).

The most appealing alternative to smoked marijuana would seem to be some form of cannabinoid inhaler. Attempts to aerosolize THC have encountered technical difficulties in the past (Tashkin 1977). However, Pertwee has recently announced the development of a cannabis spray based on a new, water-soluble cannabis-compound developed in collaboration with Razdan and Martin. Approval by the U.K. is expected within five or ten years (BBC News 2000). Meanwhile, four new delivery systems for synthetic THC (dronabinol, Marinol) are being investigated in Phase I studies by Unimed: deep lung aerosol, nasal spray, nasal gel and sublingual preparations (Institute of Medicine 1999). Similar delivery systems for natural cannabis extracts are under investigation by GW Pharmaceuticals in the U.K. (Hadorn 2001). New delivery systems are likely to be approved for marketing in the next few years, at least in certain countries. However, their usage and availability will be limited by licensing and regulatory restrictions to certain approved products. For the foreseeable future, many users will therefore continue to find them unobtainable or unaffordable.

For the immediate future, smoked marijuana is therefore likely to remain the most popular and accessible form of cannabis, both medicinally and otherwise. The question thus arises as to how to reduce its harmfulness to the respiratory system.

One obvious answer is to use higher-potency sinsemilla (Spanish for "without seed"), or hash oil extracts so as to boost the proportion of THC in the smoke, thereby necessitating a smaller intake of smoke. Obviously, this assumes that patients can reliably adjust their smoke intake to deliver a given desired dose of cannabinoids. It also assumes that the smoke from higher-potency preparations delivers proportionately higher ratios of cannabinoids to toxins–an assumption that may not hold if their chemical consistency and combustion properties are substantially different from that of regular cannabis.

SMOKING DEVICES

Another promising strategy for smoke harm reduction is to separate or eliminate the harmful toxins from the useful cannabinoids via some sort of purification or filtration device. A profusion of smoking devices are currently available on the underground market and are in use by medical marijuana patients. Although most have no evident health benefits, a few purport to offer harm reduction attributes.

Assuming that patients aim to achieve a given dose of cannabinoids, the proper measure for smoke harm reduction should be the overall ratio of cannabinoids to toxins. The higher this ratio, the fewer the noxious smoke byproducts patients have to take into their lungs in order to achieve a given effective dose.

Three basic kinds of smoking devices are presently in use for marijuana smoke harm reduction:

- *Waterpipes:* Marijuana smoke can be inhaled through waterpipes, bongs or similar devices in the hopes of cleansing the smoke via water filtration. Many patients strongly prefer to smoke cannabis through waterpipes, feeling that they deliver smoother, cooler, less irritating smoke. Studies indicate that water filtration can be effective in reducing tars and other toxins in tobacco and marijuana smoke (Cozzi 1993). The problem is that such devices may also filter out medically active cannabinoids, degrading the actual cannabinoid/toxin ratio (Gieringer 1996).
- *Solid filters:* Smoke can also be inhaled through solid filters such as those in tobacco cigarettes. Cigarette filters are known to produce modest reductions in tobacco smoke tars, and can also be used with cannabis. Once again, the problem is that they also filter out active THC (Gieringer 1996). The essential question therefore remains as to whether solid filters can actually improve the cannabinoid/toxin ratio.
- *Vaporizers:* Observations by users and laboratory studies described below indicate that it is possible to generate psychoactive vapors from cannabis by heating it to a temperature below the point of combustion, where the bulk of carcinogens are formed. This process is popularly re-

ferred to as "vaporization" or "volatilization." (In actuality, the exact physical process is uncertain: the Merck Index lists the vaporization point of THC as 200°C *in vacuo*, but users have reported psychoactive vapors at temperatures $\leq$180°C under normal atmospheric pressure.) In theory, an ideal vaporizer would deliver a stream of medically active cannabinoids without any of the toxic byproducts of combustion. In practice, experimental vaporizers are observed to produce a light stream of apparently cannabinoid-laced vapors, without heavy smoke or ash, leaving the marijuana crisped with a toasted, green-to greenish-brown appearance. Although numerous models of vaporizers are currently available on the market, none have been subjected to FDA-style efficacy testing, and they remain technically illegal for medical cannabis use under current paraphernalia laws.

Until recently, there has been little scientific basis on which to judge the alternative marijuana smoking harm reduction strategies. However, a handful of recent studies have begun to shed light on the subject.

NORML/MAPS SMOKING DEVICE STUDY

In an effort to evaluate the feasibility of marijuana smoking harm reduction, California NORML (National Organization for the Reform of Marijuana Laws) and MAPS (Multidisciplinary Association for Psychedelic Studies) sponsored a study of seven different smoking devices: three different waterpipes, two electric vaporizers, a joint fitted with a cigarette filter, plus a regular unfiltered joint as a control (Gieringer 1996). The study was designed to assess the ratio of cannabinoids to tar for each device, on the theory that higher THC/tar ratios would correlate with reduced respiratory hazards.

Samples of government-supplied marijuana from the National Institute on Drug Abuse (NIDA) were puffed in a smoking machine in a manner designed to mimic human marijuana smoking. The smoke was collected in Cambridge glass fiber filters designed to capture particles > 0.1 microns, which are used to separate solid particulates or "tars" from gaseous smoke components such as carbon monoxide. The filtered solids also include all of the cannabinoids. The filtered residue was weighed to measure total tar content and quantitatively analyzed for three cannabinoids, THC, CBD and CBN, by means of a gas chromatograph/mass spectrometer (GC/MS).

As expected, all of the devices produced a reduction in tars relative to the control: 33% for the filter, 89%-98% for the waterpipes, and 56%-97% for the vaporizers (Table 1). However, only the vaporizers achieved an improvement in the ratio of tars to cannabinoids. The cigarette filter performed worse than

TABLE 1. Tar and Cannabinoid Delivery–7 Smoking Devices

	Nonfilter Cigarette	Filter Cigarette	Waterpipe #1	Waterpipe #2	Waterpipe #3	Vaporizer #1	Vaporizer #2
Total Tars (mg/puff)	309.8	140.5	24.5	9.2	78.3	4.76	11.3
Total Cannabinoids (% Tar)	7.82	5.32	5.46	4.48	2.50	7.89	9.82
Total THC (%Tar)	5.99	4.12	4.31	2.14	3.36	6.27	5.24

Adapted from Gieringer, D. "Marijuana Waterpipe and Vaporizer Study," 1996

the unfiltered joint, producing 30% more tar per cannabinoids. Worse yet were the waterpipes, which produced from 30% to 180% more tars per cannabinoids. Ironically, the worst waterpipes were those designed to maximize the vapor's exposure to water. The disappointing implication is that waterpipes may actually be counterproductive in reducing tars from cannabis smoking.

A likely explanation for the poor performance of physical filtration systems is that THC molecules are especially sticky and apt to adhere to other smoke particles. Any attempt to screen out the latter is therefore apt to pick up the former as well. Indeed, to the extent that cannabinoids are relatively stickier than other compounds, particles containing them may be more likely to be trapped by filters.

The vaporizers were the only devices to outperform the unfiltered joint, though only by a modest margin. The first vaporizer, a commercial model consisting of a battery-powered metal hot plate inside a jar to trap the vapor, achieved a 26% improvement in the cannabinoid/tar ratio. The second model, a homemade, hybrid device, consisting of a hot air gun blowing through a beaker of water, combined vaporization with water filtration. It achieved a statistically insignificant 0.25% improvement. However, its performance may well have been degraded by the water filtration component, the inclusion of which seemed in retrospect to be a design flaw in the experiment.

Evaluation of the vaporizers was further complicated by the fact that the "hot plate" model produced anomalously high amounts of CBN and 30% less THC. The origins of the CBN are not certain, but might well be due to partial pyrolysis of THC (Fehr and Kalant 1972). Since CBN has negligible pharmacological activity compared to THC, it seemed appropriate to recompute the device performances in terms of the ratio of THC to tars. When this was done, the hotplate turned out to be 13% worse than the unfiltered joint, while the hot air device was 4.6% better.

The most disappointing finding of the smoking device study was the apparent counter-productivity of waterpipes and cigarette filters. However, this conclusion must be qualified by several important caveats due to limitations in the study design:

- The gaseous component of the smoke was not analyzed in the study. Cannabis smoke contains numerous noxious gases, including hydrogen cyanide, which incapacitates the lung's defensive cilia, volatile phenols, which contribute to the harshness of the taste, aldehydes, which promote cancer, and carbon monoxide, a known risk factor in heart disease (Huber 1991). There is evidence that water filtration may be quite effective in absorbing some of these gases, especially those that are water-soluble (Cozzi 1993). If so, waterpipes could still turn out to have some health benefits.
- The study did not attempt to quantify the specific chemical components of the tars except for the cannabinoids. It is conceivable that the tars from the waterpipe or cigarette filter contained relatively less harmful toxins and carcinogens, and more inert ingredients, than the unfiltered ones.
- In conformity with cigarette smoking conventions, a 30-cm butt length was left unsmoked on the unfiltered joint. Thus, the study did not test the last part of the joint, the "roach," which is commonly savored to complete exhaustion by marijuana connoisseurs. The roach is known to accumulate higher concentrations of tars and THC from the rest of the cigarette (Tashkin et al. 1991a). It is possible that the cannabinoid/tar ratio for the unfiltered joint would have been considerably different if the roach had been included. It is also possible that there are other ways in which the smoking machine did not accurately replicate the inhalation pattern of human smokers.

Although the vaporizers showed at best marginal effectiveness in the study, substantial improvements might have been realized with more careful research and development. Neither vaporizer was carefully designed, adjusted, or optimized for laboratory testing. Furthermore, unlike waterpipes and filtration devices, vaporizers are at least based on a physical principle that offers a theoretical hope for further development. For this reason, NORML and MAPS decided to undertake a second study devoted specifically to vaporizers, preliminary results of which are presented below.

SOUTH AUSTRALIAN GOVERNMENT STUDY

A study sponsored by the South Australian Drug and Alcohol Services Council confirmed the apparent inefficacy of waterpipes, while raising confusing new issues about marijuana smoke harm reduction (Gowing et al. 2000).

The study tested 12 different varieties of cannabis, ranging from low-grade leaf to high-potency sinsemilla. All samples were dried, trimmed, shredded and homogenized in a blender. The samples were smoked in standard joints, in waterpipes, and in combination with tobacco using a Filtrona smoking machine under standard cigarette smoking conditions. Particulate matter was trapped in Cambridge type glass fiber filters. The smoke was analyzed for THC yield, tar, water, and carbon monoxide.

The study found that the waterpipes consistently generated more tars and carbon monoxide than the unfiltered cigarettes. Tar yields were on the order of 3 to 7 times higher per given sample, while carbon monoxide was 2 to 4 times higher. Unfortunately, no comparative data on THC yield were produced, making it impossible to assess the overall THC/tar and CO ratios. Nonetheless, the researchers concluded that the risks of cannabis smoking were less likely to be reduced by a waterpipe as opposed to a cigarette.

A significant part of the difference between waterpipes and cigarettes could be explained by differences in smoking conditions. Whereas the cigarettes had been puffed at 60-second intervals, the waterpipes had to be puffed at 6-second intervals in order to keep them lit. When the cigarettes were re-tested at 6-second intervals, it was found that two-thirds of the increase in tar content and one-third of the increase in CO were accounted for. (Again, there were no THC data to assess what change may have occurred in the relative THC/tar and CO ratios.) Another factor that could have explained the higher tar from the waterpipe was that the cigarettes were smoked to a butt length of 23 mm, while the waterpipe smoke was drawn directly into the smoking machine. Hence, the butt may have filtered out more tars and CO from the cigarette smoke.

A startling finding of the study was that the composition of the smoke varied widely depending on the specific samples and smoking conditions. In particular, THC yields varied radically for different samples and devices. In the case of cigarettes, no clear correlation was observed between the potency of cannabis smoked and the amount of THC actually delivered in the smoke. One cigarette of 0.69% THC leaf delivered smoke of 0.62% THC content, while another cigarette of 12.97% flowering "heads" yielded only 0.54% THC in smoke, a remarkable 25-fold difference in efficiency of THC delivery. In the case of waterpipes, smoke and sample potency were better correlated, although not in full proportion. For example, high-grade samples of 9-13% potency yielded no more than 2.4% THC in waterpipe smoke, while low-grade samples of 2% yielded amounts ranging from 0.08% to 1.1%. These results are strikingly at variance with the observations of many experienced users, who report that one or two tokes (inhalations) of good, high-grade sinsemilla can be equivalent to a whole cigarette of regular cannabis. Such discrepancies may be explained by peculiarities in the particular samples tested or by systematic differences between human smoking and the laboratory smoking machine used in the Australian study. In any event, the Australian study implies that higher cannabis potency does not necessarily translate to more available THC.

The investigators inferred that actual THC delivery is highly dependent on the particular sample and smoking conditions, including puff length, temperature, and other factors. In particular, tests showed a significant, positive correlation between THC delivery and water content of the smoke for both cigarettes and waterpipes. It is unknown how the water content of the smoke was related to the original water content of the samples as opposed to other factors, such as temperature of combustion. For example, it is possible that excessively moist samples could have produced *less* water and THC in the smoke if they burned less efficiently. The most that can be concluded is that THC yield is related to factors that are also related to water yield. It has been proposed that THC is normally released not via pyrolysis or volatilization, but by a process of co-distillation with steam, in which cannabinoids are expelled along with water vapor in the 2 mm high temperature gradient zone before the burning front (Fehr and Kalant 1972). This hypothesis seems bolstered by the finding that THC and water yield are correlated.

Further evidence for the importance of smoking conditions with respect to THC yield was seen when tobacco was added to the cannabis. When mixed with 50% tobacco and 50% cannabis, the cigarettes yielded between 93% less and 81% *more* THC. The waterpipes performed more consistently with expectations, yielding 30-55% less THC in most cases. Tar levels increased when tobacco was added to cigarettes but generally held steady for waterpipes, while carbon monoxide increased for both, though more so in waterpipes. The samples that had the worst THC delivery in cigarettes showed the most marked improvement when combined with tobacco. This suggested that the tobacco had made the samples burn better, perhaps by raising the temperature so as to release more THC.

VAPORIZER STUDIES

The theory supporting vaporization has been known for sometime. A vaporizer known as the Tilt was commercially marketed in the early 1980's before passage of the anti-paraphernalia laws. Its performance was investigated in an unpublished study for the manufacturer by a graduate research assistant at MIT (Herms 1978). Although the Tilt is no longer available, the study report provides good evidence for the feasibility of vaporization.

The Tilt consisted of a wire sample screen mounted 5 mm above an adjustable 80-watt radiant heater, all encased in a plastic chamber with an exit port near the top (Diagram 1). In the study, samples of unpowdered cannabis buds and fragments were placed on the screen and held at constant temperatures

DIAGRAM 1. Tilt Advertisement

while the vapors were drawn off by suction. The lab reported that the Tilt achieved efficient vaporization at sample temperatures around 185-95°C. This is similar to the temperature range used by patients today. The sample exuded a thin stream of vapors, but kept its green color. Spontaneous combustion was reported at sample temperatures above 200°C.

Vapors from the Tilt were compared to smoke produced by similar samples combusted in a common clay pipe. THC and CBD were measured by capturing the smoke in a cold trap, dissolving the residues in acetone and methanol, and analyzing them via GC/MS. Tars were measured by capturing them in a Cambridge glass filter and weighing them. Carbon monoxide was detected by passing the smoke through a solution of palladium chloride, which precipitates palladium in the presence of CO.

The Tilt performed impressively, producing 79% less tar than the pipe while producing 80% more THC and 60% more CBD (Table 2). Unlike the pipe, the Tilt produced no detectable CO. The overall THC/tar ratio was improved by a factor of 8.5. The sizeable reduction in tars was evidently due to the absence of combustion, which forms hazardous quantities of PAHs at temperatures above 560-600°C (Wynder and Hoffmann 1967). Insofar as PAHs are thought to constitute the major carcinogenic hazard of smoking, the Tilt would seem to have offered substantial harm reduction benefits. Another remarkable feat of the Tilt was to generate more available cannabinoids than the pipe. The report speculated that this was because cannabinoids undergo degradative reactions such as polymerization, cyclization, etc., at combustion temperatures of 600° or more. However, a more likely explanation may be differences in combustion conditions, as observed in the Australian study.

NORML/MAPS VAPORIZATION STUDY

In order to further explore the potential of vaporization, California NORML and MAPS have undertaken a second, new vaporizer research project. The project is focusing on two models of vaporizers that are currently available and

TABLE 2. Pipe Smoke Compared to Vapor from Tilt Vaporizer

	Smoke from clay pipe	Vapor from Tilt
Delta-9-THC	0.044%	0.079%
Cannabidiol	0.015%	0.024%
"Tar"	16.5%	3.4%
Carbon Monoxide	Present	Absent

Adapted from Herms 1978

in use by medical marijuana patients: an electric radiator similar to the Tilt, and a hot air gun. The first phase of the project, a preliminary "proof of concept" study of the first device, is now complete. The results confirm that cannabinoid vapors can be generated around 185°C with substantial reductions in certain smoke toxins. Further studies are currently in progress.

The preliminary study tested a device called the M1 Volatizer (Figure 1), an aromatherapy device developed by Alternative Delivery Systems, Inc., consisting of an electric heating element arranged to radiate heat over a sample placed on a wire screen in a standard glass bong bowl. The sample consisted of sifted, cured sinsemilla cannabis (Figure 2). Temperature was regulated by a rheostat and measured via a themocoupled electronic thermometer on the sample. Vapors were drawn off with a vacuum pump and analyzed in three separate tests for: (1) carbon monoxide, (2) particulate matter, and (3) six target analyses: three cannabinoids (THC, CBD and CBN), and three toxic aromatic hydrocarbons, benzene, a known carcinogen, plus toluene and naphthalene.

Results showed that the vaporizer produced qualitative reduction in CO and particulates and complete elimination of the three toxic hydrocarbons (Table 3).

- Carbon monoxide was tested semi-quantitatively by drawing the sample for 20 seconds through a Drager tube. The M1 was operated at the comparatively low sample temperature of 170°C, where it produced a light gray vapor. Unlike the Tilt, the M1 produced detectable carbon monoxide (although the sensitivity of the Tilt CO test is unknown). When combusted with a match, the sample produced a thick, dark gray smoke. Unfortunately, the combustion test saturated the Drager tube, making it impossible to quantify the change in CO. The most that could be determined was that the M1 reduced CO by ≥33% compared to combustion.
- Particulate matter was measured by passing the smoke through a Balston Microfibre Disposable Filter Unit. The M1 was maintained at 185°C for 3 min and 45 secs and the vacuum pump run simultaneously for 5 min. A second sample was combusted with a match and the vacuum pump run for 5 min. The filter from the M1 showed slight discoloration at the top, while the filter from the combusted sample was saturated with yellow discoloration. The net particulate weight in the filter was at least 56% less using the vaporizer. Once again, however, it was impossible to measure the full extent of the reduction, since the combusted smoke appeared to have completely saturated the second filter.
- The three cannabinoids and three toxic hydrocarbons were measured by passing the vapors through a methanol-filled collection flask. The M1 was held at 185°C for three minutes and the vacuum pump run for 5 minutes. The control sample was combusted with a match with the vacuum pump running for three minutes. The contents of the flask were removed

> and assayed using a High Performance Liquid Chromatograph-Diode Array Detector-Mass Spectrometer. The three toxic hydrocarbons (benzene, toluene and naphthalene) were all detected in the combusted smoke, but not in the vaporized output. Unlike the Tilt, the M1 produced 85% less THC than combustion. There were indications that THC production could have been improved by refinements in laboratory technique. In any event, there was a 100% reduction in the toxin/THC ratio.

Data were insufficient to evaluate changes in CBD and CBN. (Users of the M1 have reported that they obtain different psychoactive effects at different temperatures, suggesting possible variations in the proportions of different cannabinoids.)

IMPLICATIONS FOR RESPIRATORY HARM REDUCTION

Results so far are tentative and incomplete, but promising. Clearly, much work needs to be done to explore the effects of different adjustments and smoking conditions. NORML and MAPS are currently sponsoring more research to determine how temperature affects the production of THC and other cannabinoids relative to other toxins. Tests indicate that small amounts of THC may be released at temperatures as low as 140°C. Significant amounts of

FIGURE 1. M1 Volatizer

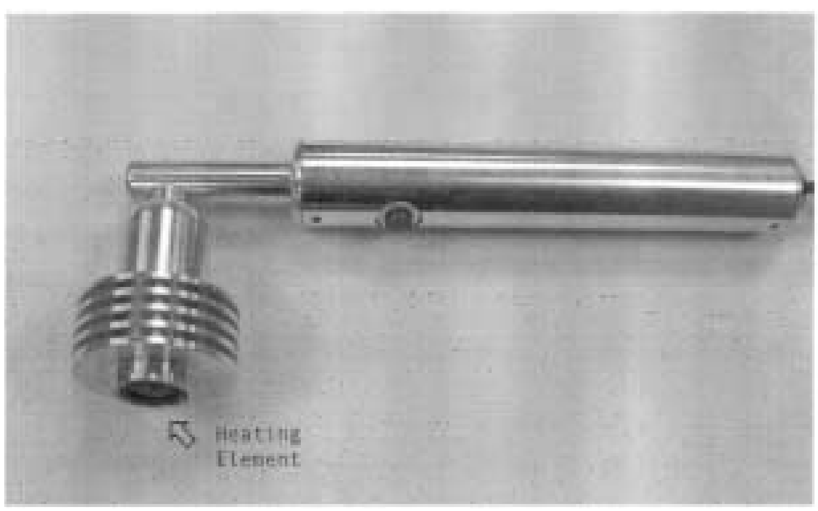
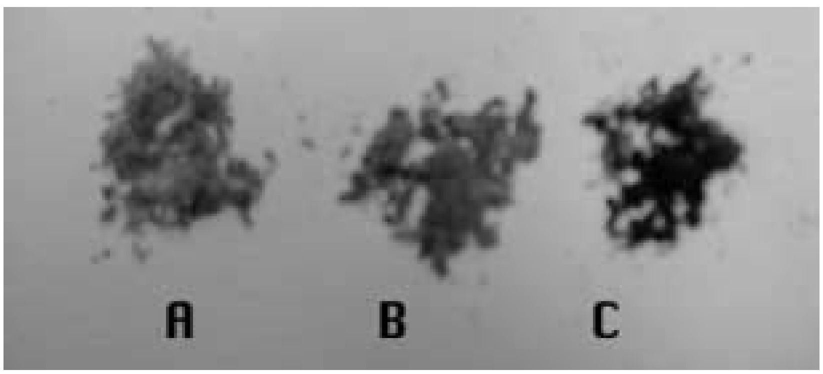


TABLE 3. M1 Vaporizer Performance: Reduction in Presence of Compounds Under Vaporization at 185°C Relative to Combustion

	Particulate "Tar"	Benzene	Toluene	Naphthalene	Carbon Monoxide*	THC
Reduction	> 56%	100%	100%	100%	> 33%	85%

*CO vaporization temperature 170°

FIGURE 2. Effect of Vaporization



A = Crude sinsemilla (olive green)
B = Similar specimen after vaporization by hot air gun at 180°C for ~5 min (brownish green)
C = Similar specimen after combustion (black)

benzene, toluene and naphthalene were observed above 200°C, and combustion occurred at temperatures of 230°C or higher. Further work is necessary to ascertain how these temperatures vary for samples of different humidity, potency, composition, and consistency. It is reasonable to assume that the vaporizer can completely avoid production of the highly carcinogenic PAHs, since these require pyrolysis to form. There is accordingly good reason to think that vaporizers can substantially reduce the presence of carcinogens in marijuana smoke. The question of carbon monoxide and other toxins is more uncertain. NORML and MAPS are seeking to explore these issues in future research. From the Australian work, it also seems likely that the performance of vaporizers and other smoking devices is critically dependent on the particular cannabis sample, its preparation and curing, variations in smoking technique, and other factors. These issues remain to be researched. In the meantime, vaporizers are becoming increasingly popular with medical cannabis patients, who report they are far less irritating than other methods of smoking.

Aside from vaporization, the one remaining strategy for cannabis smoke harm reduction is to use stronger THC preparations. Studies to date have found little evidence that users self-titrate dosage according to the potency of cannabis being smoked (Chait 1989; Zimmer and Morgan 1997). However, research has been restricted to a limited, low potency range (typically 0%-3%), using standard NIDA-issued leaf cigarettes. To date, no studies have been done with the kind of high-grade sinsemilla now widely available to patients through medical cannabis clubs, the potency of which may range from 8% to 20% or greater (Gieringer 1996). Lack of research in this area remains a grievous deficiency. The usefulness of high-grade sinsemilla for smoke harm reduction may be questioned in light of the Australian study, insofar as it indicates that differences in sample consistency and smoking conditions can be more important than the THC content of marijuana cigarettes. Nonetheless, patients widely report that they can effectively reduce smoke inhalation using high-quality sinsemilla.

The hazards of marijuana smoke may also be affected by the breathing pattern of the user. Some studies have suggested that prolonged breath holding does nothing to enhance the subjective effects of cannabis, but does increase absorption of carbon monoxide and other toxins (Azorlosa et al. 1995; Zacny and Chait 1991; Zimmer and Morgan 1997). However, other evidence indicates that breath holding does increase absorption of THC (Tashkin et al. 1991b). No clear-cut conclusions appear warranted at this point.

There is an evident need for further research on cannabis vaporization and marijuana smoke harm reduction. Sadly, due to the political fallout of the war on drugs, the government or leading private health research foundations are not supporting such research.

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