Medical Marijuana: Review of the Science and Implications for Developmental-Behavioral Pediatric Practice

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ABSTRACT: Marijuana policy is rapidly evolving in the United States and elsewhere, with cannabis sales fully legalized and regulated in some jurisdictions and use of the drug for medicinal purposes permitted in many others. Amidst this political change, patients and families are increasingly asking whether cannabis and its derivatives may have therapeutic utility for a number of conditions, including developmental and behavioral disorders in children and adolescents. This review examines the epidemiology of cannabis use among children and adolescents, including those with developmental and behavioral diagnoses. It then outlines the increasingly well-recognized neurocognitive changes shown to occur in adolescents who use cannabis regularly, highlighting the unique susceptibility of the developing adolescent brain and describing the role of the endocannabinoid system in normal neurodevelopment. The review then discusses some of the proposed uses of cannabis in developmental and behavioral conditions, including attention-deficit hyperactivity disorder and autism spectrum disorder. Throughout, the review outlines gaps in current knowledge and highlights directions for future research, especially in light of a dearth of studies specifically examining neurocognitive and psychiatric outcomes among children and adolescents with developmental and behavioral concerns exposed to cannabis.

*(J Dev Behav Pediatr 36:*115–123, 2015) **Index terms:** adolescent, cannabis, marijuana abuse, attention-deficit disorder with hyperactivity, child development disorders, pervasive.

In the United States and throughout the world, marijuana policy is rapidly evolving.[1–3] In many jurisdictions, marijuana is now decriminalized, meaning that possession of the drug does not lead to criminal charges.[4] In others, its use is permitted for medical purposes if a license or permit is issued to a patient or caregiver.[5] In others still, including Washington State and Colorado, as well as in the country of Uruguay, marijuana sales for recreational use among adults are now fully legal and regulated by the government.[6,7]

Many of these dramatic policy changes have occurred within the last decade, and amidst this shifting political landscape, patients and families are increasingly asking whether marijuana—often used interchangeably in the literature and in the present article with the term cannabis—has a role in the management of developmental and behavioral pediatric conditions, including attention-deficit hyperactivity disorder and autism spectrum disorders, among others.[8,9] This is occurring despite a dearth of scientific evidence supporting a role for cannabis in these conditions. Some of this interest in cannabis has been fueled by the lay press, which has recently showcased rare examples of children with certain medical conditions who had failed traditional pharmacologic management and for whom cannabis was seemingly the only effective treatment.[9,10] Accordingly, children and adolescents are increasingly being added to medical marijuana registries by their parents for a multitude of conditions.[11]

Despite an absence of known efficacy of cannabis for developmental and behavioral conditions, there is indeed mounting evidence for its role in some neurological symptoms. A recent systematic review[12] of adult patient trials showed that certain formulations of cannabinoids were useful for spasticity and central pain. This same review concluded that data were insufficient to conclude efficacy in a number of other conditions, including Tourette syndrome, epilepsy, and dystonia. Nonetheless, anecdotal evidence suggests that certain forms of marijuana, namely those enriched with cannabidiol (one of the many cannabinoid compounds present in cannabis but which does not have psychoactive properties), reduces the frequency of seizures for certain children with intractable epilepsy.[13] This anecdotal evidence is not yet supported by clinical trial data, as highlighted by a recent Cochrane review of adult studies on the subject,[14] but future studies will inevitably study this further.

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Clearly, some parents are already using or are considering using cannabis for treatment of a wide range of pediatric conditions. Given the increasing prevalence of adolescent cannabis misuse and dependence,[15–17] as well as the growing body of literature linking cannabis use to long-term and potentially irreversible adverse physical, neurocognitive, psychiatric and psychosocial outcomes,[18] it is now more important than ever for the developmental-behavioral pediatrician to understand the available evidence on cannabis. Large professional organizations, including the American Academy of Pediatrics,[19] the American Medical Association,[20] the American Society of Addiction Medicine,[21,22] and the American Academy of Child and Adolescent Psychiatry,[23] all have policy statements identifying marijuana use as a public health concern and currently oppose further steps toward legalization.

Here, we begin by describing important pharmacodynamic properties of cannabinoids and then report the epidemiology of cannabis use, including the susceptibility of youth with developmental and behavioral disorders to earlier and heavier substance use. We then describe the known adverse neurocognitive effects of cannabis, highlighting the unique vulnerability of the developing brain and emphasizing the role of the endocannabinoid system in normal neurodevelopment. We conclude by reviewing some of the proposed uses of cannabis for developmental and behavioral conditions that have recently received attention, highlighting the knowledge gap that currently exists.

PHARMACOLOGY

Marijuana, also referred to as cannabis, is traditionally derived from the plant *Cannabis sativa*. The dried buds and accompanying leaves of cannabis are most commonly smoked but can also be ingested, and increasingly, youth inhale it by vaporization (a process referred to as "vaping") through new delivery systems similar to those used for e-cigarettes.[24] Hash oil, which is illegal and contains a high concentration of cannabinoids, can be extracted from cannabis plant material and also can be smoked, ingested, or vaporized[25] (It is not to be confused with hemp oil, often sold legally in natural food stores, which contains very few if any cannabinoids). Onset of physiologic and psychologic effects varies based on route of administration, with peak effects occurring 30 minutes after inhalation and 2 to 4 hours after ingestion.[26] Acute effects include, on the one hand, relaxation, euphoria, heightened perception, sociability, sensation of time slowing, increased appetite, and decreased pain, and on the other hand, paranoia, anxiety, irritability, impaired short-term memory, poor attention and judgment, and poor coordination and balance.[26,27] Physiologic effects include tachycardia, hypertension, dry mouth and throat, and conjunctival injection.

Cannabis exerts its effects primarily through the compound Δ-9-tetrahydrocannabinol (THC) acting on endogenous cannabinoid receptors present through the central and peripheral nervous system.[28] THC is lipophilic and readily crosses the blood-brain barrier and placenta.[29] Also owing to its lipophilicity, THC accumulates in fat and therefore has a long elimination half-life of several days to a week. Similarly, many of the byproducts of marijuana smoke are lipophilic, with as yet poorly understood effects on health and development.[30] The high fat solubility of many cannabinoids results in a large volume of distribution and long half-life of elimination from the body.[29] The ability of cannabinoids to cross the placenta and affect fetal neurodevelopment may underlie the observation that prenatal exposure to cannabis is associated with hyperactivity, impulsivity, and inattention symptoms in childhood,[31] among other adverse cognitive and behavioral outcomes summarized in a recent review.[32]

Potential health effects of cannabis may be exacerbated by the doubling of THC concentration in marijuana preparations that has occurred in the last two decades.[25] In recent years, numerous synthetic cannabinoids, often marketed as herbal mixtures and referred to as "Spice," "K2," or "Kronic," have been synthesized and sold for recreational purposes (often through the Internet), and the rapidity of their development and distribution has outpaced attempts to classify them as Schedule I substances in the United States.[33]

Legal formulations also exist in several jurisdictions, including some in the United States. Dronabinol and nabilone, both synthetic THC-based cannabinoids, are US Food and Drug Administration-approved and marketed for use for children and adults as an antiemetic in chemotherapy and as an appetite stimulant. As outlined earlier, cannabinoids without psychoactive properties, such as cannabidiol, are also increasingly receiving attention since they may impart medicinal benefits with fewer psychologic effects but remain poorly understood and require more study before approval and regulation. Nabiximols represents a combined THC and cannabidiol formulation administered as an oromucosal spray available outside the United States and used for alleviation of symptoms in multiple sclerosis.

EPIDEMIOLOGY

In the United States and other developed countries, cannabis is the second most commonly used substance among adolescents after alcohol.[15–17,34] Three recurrent surveys track cannabis use in the United States general adolescent population. Monitoring The Future[16] and the Youth Risk Behavior Surveillance System[15] are school-based surveys, and the National Survey on Drug Use and Health[17] is a household-based survey. Collectively, the surveys demonstrate that as many as 4 in 10 adolescents have ever used marijuana, that prevalence of marijuana use is rising even as prevalence of alcohol and tobacco are falling (indeed, in 2009, cannabis use became more prevalent than tobacco use),[16] and that daily or near-daily

use is becoming more common.[15–17] Specifically, daily use of marijuana is reported by 6.5% of high school seniors, 3.3% by 10th graders, and 1.2% by eighth graders, all of which represent an increase in prevalence of daily use occurring since 2008, previous to which daily use had been declining.[16] Use typically begins early in adolescence, with approximately 1 in 3 males and 1 in 4 females having tried marijuana by the ninth grade.[15]

In recent years, as the movement toward decriminalization and legalization of cannabis has progressed, adolescents' perceptions of the harms of marijuana have fallen. Indeed, since 2004, adolescents seeing "great risk" in regularly using marijuana has steadily fallen; in 2013, fewer than half of all 10th graders and high school seniors reported perceiving risk in regular use, whereas previously a majority of all adolescents had perceived risk.[16] Commensurate with this, emergency department visits related to marijuana increased 52% from 2004 to 2011 in the United States.[35] Meanwhile, accidental ingestions by smaller children of cannabis preparations may be increasing, with emergency room visits at a Colorado pediatric hospital increasing from 0% (none reported) to 2.4% of all unintentional ingestions following change in state drug enforcement laws allowing possession of marijuana for medical purposes.[36] Calls made to Poison Control centers in the United States have also been noted to increase in states where medical marijuana policies have been implemented or are underway.[37]

Data suggest that certain developmental-behavioral diagnoses portend higher risk of cannabis and other substance use and dependence. Attention-deficit hyperactivity disorder (ADHD) is a risk factor for earlier initiation of substance use in childhood and adolescence[38–40] and may predict heavier and more problematic substance use in adolescence and adulthood.[41,42] Of all ADHD symptoms, hyperactivity and impulsivity confer the greatest risk for adolescent cannabis use disorder.[43] Although an early meta-analysis[44] showed that stimulant treatment for adolescent ADHD reduced the risk of subsequent substance use disorders, an updated meta-analysis incorporating newer studies with null findings suggests this may not be the case.[45] Oppositional defiant disorder, conduct disorder, and autism spectrum disorders have all also been linked to problematic substance use, including use of marijuana.[38,40,46] Among adolescents and adults with intellectual disability (ID), prevalence of cannabis and other substance use is not higher than for the general population, but risk for problematic use may be higher.[47,48] Data from an adult study suggest that those with borderline or mild ID and with a comorbid psychiatric diagnosis are at even higher risk of a substance use disorder.[48]

EFFECTS OF REGULAR MARIJUANA USE ON NEUROCOGNITION AND BRAIN STRUCTURE

The high prevalence of marijuana use among adolescents, including those with developmental or behavioral disorders, is concerning given the myriad long-term consequences of regular cannabis use. Because of inconsistencies in how "regular" use is defined across studies, there is no clear indication as to whether there exists a "safe" amount of cannabis use for adolescents. In general, "regular" use is defined in studies as daily or near-daily use over several years.[16] Regardless, in interpreting study results, it is important to recognize that because studies of cannabis use are observational in design, co-occurring use of alcohol, cigarettes or other drugs may confound reported associations, and reverse causality cannot always be excluded.[49] Although chronic marijuana use is associated with a broad range of adverse physical and mental health outcomes,[49–51] here we focus on the neurocognitive effects.[12,52]

Acute effects of marijuana intoxication vary by person and by dose. Positive effects reported by users include anxiolysis, euphoria, heightened perception, increased sociability, sensation of time slowing, increased appetite, and decreased pain.[26] On the surface, some of these effects may seem desirable to an adolescent with attention-deficit hyperactivity disorder (ADHD), although it is noteworthy that a study examining whether youth with ADHD used cannabis as a form of self-medication did not find this to be the case.[53] Negative effects of marijuana include paranoia, anxiety, irritability, worsened short-term memory, poor attention, altered awareness of the passage of time, impaired judgment, decreased coordination and balance, and distorted spatial perception,[26,54] all of which could arguably exacerbate symptoms in developmental and behavioral conditions.

Clinicians should counsel youth that many of the detrimental neurocognitive effects of acute marijuana intoxication have a "hangover" effect, with effects lasting at least 1 day after last use and with some subtle effects even measurable 1 month later among adolescent users.[55] Given the adverse effects of acute intoxication on attention, coordination, and perception, it is perhaps unsurprising that a recent meta-analysis[56] demonstrated near doubling of the odds of fatal motor vehicle accident for adolescents and adults driving under the influence of cannabis. Data suggest that youth with ADHD are already at elevated risk of motor vehicle accident compared with the general adolescent population.[57–59] Therefore, counseling adolescents with ADHD to avoid driving while under the influence of marijuana is critical, particularly since many youth believe that marijuana does not affect their driving abilities.[60,61]

Over the long-term, adolescent cannabis use may be associated with a decline in intelligence quotient (IQ). A recent prospective study[62] showed that regular cannabis use during adolescence was followed by a significant decline in IQ at age 38 years, as illustrated in Figure 1. This finding persisted after adjusting for use of alcohol or other drugs, comorbid mental illness, and educational level. Additionally, among adolescent users who later became abstinent, cessation was not associated with restoration of IQ in adulthood. These results are consistent with the possibility that cannabis impairs normal brain

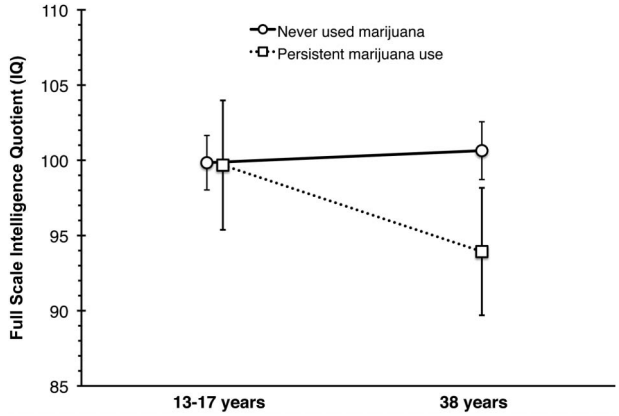

Figure 1. Full-scale intelligence quotient (IQ) among New Zealanders measured in childhood/adolescence (7–13 yr) and adulthood (38 yr). This figure highlights findings from 242 individuals who never used cannabis as compared with 38 individuals who demonstrated persistent use during study follow-up (Persistent use was defined as reporting cannabis use $\geq$4 times per week at 3 or more study follow-up visits). Error bars represent $\pm$95% confidence intervals for the estimates. Some data adapted with permission from Meier et al.[62]

development during adolescence and that heavy use may result in persistent and potentially nonreversible neurocognitive changes. A recent review[52] compiled studies on changes in cognition, brain structure, and brain function among adolescent cannabis users; the interested reader is advised to refer to this review for further information. Its summary of studies demonstrating an association between earlier age of marijuana initiation and worsened outcomes is shown in Table 1 (the interested reader is referred to the full review).

Regular cannabis use during adolescence is also associated with adverse psychiatric outcomes, although these psychiatric outcomes have not been rigorously studied among patients with developmental or behavioral concerns. A recent meta-analysis[63] and large prospective cohort study[64] both reported increased odds of psychosis among adolescent cannabis users, an effect exacerbated by heavy use. Evidence linking adolescent cannabis use and depression are conflicting, with 2 recent systematic reviews[63,65] reporting an association, but acknowledging that adjustment for confounders may reduce or eliminate this association. A more recent prospective cohort study[66] of high school students demonstrated that heavy cannabis use was associated with later depression, but not suicidality. Another recent prospective study[67] showed that adolescent users have nearly triple the odds of an adult anxiety disorder, although a previous systematic review[63] examining adulthood anxiety among adolescent cannabis users reported conflicting data on this association. Figures 2, A and B show the association of heavy cannabis use with psychosis and with depression, respectively, as reported by Moore et al.[65] How the risk for subsequent psychiatric conditions differs among cannabis-using adolescents with developmental and behavioral concerns, in particular, is a critical area for further study.

To understand how these neurocognitive and psychiatric effects of cannabis might arise, 2 concepts are critical. First, as noted above, the psychoactive compound in cannabis, Δ-9-tetrahydrocannabinol (THC), is highly lipophilic and readily crosses the blood-brain barrier as well as the placenta, with implications for normal neurodevelopment in the marijuana-using adolescent as well as the developing fetus.[29] Second, the endocannabinoid system appears to play a significant role in normal neurodevelopment prenatally and extending throughout childhood and adolescence.[28] Cannabinoid receptors, which are normally activated by endogenous compounds such as anandamide, appear to modulate axonal migration and long-range subcortical projections in the brain during early brain development and affect synaptic connectivity throughout childhood and adolescence.[68] Some of these developmental processes are known to occur throughout adolescence and into young adulthood, and alterations in these processes during critical windows are believed to result in permanent irreversible deleterious effects.[69]

Although far from human application, data from rodents suggest that the endocannabinoid system may also be a potential target in developmental and behavioral conditions, although results remain conflicting.[70] Findings from rat models of Fragile X syndrome suggest that blockade of cannabinoid receptors may normalize aberrant hippocampal development, and simultaneously correct cognitive deficits, improve seizures, and reduce pain sensitivity.[71] Somewhat conflicting are additional findings from the same rat model showing that enhancing endocannabinoid signaling may correct abnormal synaptic plasticity occurring in the prefrontal cortex and ventral striatum, with simultaneous improvement in hyperlocomotion and anxiety-related behaviors.[72]

Alterations in neurodevelopment from chronic cannabis use may underlie several known brain changes present in heavy using adults. Functional imaging studies (using diffusion-weighted magnetic resonance imaging and brain connectivity mapping) show that axonal connectivity is impaired in regular marijuana users, particularly with early age of onset of use in adolescence.[73] Additionally, regular adult users who started cannabis use in adolescence exhibit decreased volume in the hippocampus and amygdala,[73,74] which are involved in memory processing, as well in other portions of the medial temporal cortex, temporal pole, parahippocampal gyrus, insula, and orbitofrontal cortex, which have high concentrations of cannabinoid receptors and are responsible for motivational, emotional, and affective processing.[75] The full extent of structural and functional neural changes from marijuana use is still not fully understood and should be the focus of future study, particularly among adolescents with developmental and behavioral concerns, for whom study findings may differ from the general adolescent population.

Table 1. Select Studies[a] Demonstrating Changes in Cognition, Brain Structure, and Brain Function Associated with Cannabis Use in which Adolescent Onset Is Associated with Worsened Outcome

Reference	Cognitive	Brain Structure	Brain Function
Meier et al, 2012	↓ IQ		
Pope et al, 2003	↓ IQ		
Ehrenreich et al, 1999	↓ Attention		
Huestegge et al, 2002	↓ Visual search		
Fontes et al, 2011	↓ Executive functioning		
Solowij et al, 2012	↓ Executive functioning		
Churchwell et al, 2010		↓ Prefrontal cortex volume	
Gruber et al, 2011	↑ Impulsivity	↓ White matter integrity in prefrontal cortex	
Lopez-Larson et al, 2011		↓ Superior prefrontal cortex thickness	
Wilson et al, 2000		↓ Total gray matter, ↑ total white matter	
Becker et al, 2010a			↑ Left superior prefrontal cortex fMRI blood oxygen level dependent (BOLD) signal during working memory task
Gruber et al, 2012			↓ Anterior cingulate fMRI blood oxygen level dependent (BOLD) signal during inhibition task
Jager et al, 2010			↑ Prefrontal cortex MRI blood oxygen level dependent (BOLD) signal during novel stimuli presentation in working memory task

[a]Adapted with permission from a larger compilation of studies presented by Lisdahl et al.[52] Adaptations are themselves works protected by copyright. So in order to publish this adaptation, authorization must be obtained both from the owner of the copyright in the original work and from the owner of copyright in the translation or adaptation. fMRI, functional magnetic resonance imaging; IQ, intelligence quotient.

USE OF MARIJUANA FOR PEDIATRIC DEVELOPMENTAL AND BEHAVIORAL DIAGNOSES

Understanding these long-term adverse consequences of cannabis use is especially important as patients and families question whether cannabis may have a role in managing pediatric conditions. Cannabis has had a broad range of proposed clinical applications (predominantly for adult conditions), including for symptomatic management of nausea, poor appetite, and pain, as well as for treatment of multiple sclerosis, spinal cord injury, Tourette syndrome, epilepsy, and glaucoma.[76] At this time, good evidence is almost entirely lacking for its application in pediatric developmental and behavioral conditions. Nonetheless, online advocacy groups that support the use of "medical" marijuana for such conditions are gaining popularity, particularly on social media sites such as Facebook. At the time of press, some examples include "Mothers for Medical Marijuana Treatment for Autism,[77]" "Mothers Advocating Medical Marijuana for Autism,[78]" and "Pediatric Cannabis Therapy.[79]"

Many advocates cite scientific literature regarding benefits of cannabis for the treatment of pediatric behavioral conditions, but often, data cited are from animal model-based research that does not yet have translation to human subjects. For example, a 2013 study[80] from Stanford University showed that mice with a specific and rare gene mutation linked to autism showed altered endocannabinoid signaling in the central nervous system. These data were then cited by online and print media supporters of medical marijuana (e.g., the High Times[81]) as evidence that cannabis could be used as a treatment for autism. As another example, when another recent study[72] based on a mouse model of Fragile X syndrome (described earlier in this review) showed alterations in endocannabinoid signaling pathways, these data were referenced (in this case, by more mainstream media outlets, such as the Huffington Post[8] and Fox News[82]) as evidence for a promising role for cannabis as treatment. Although these and other high-impact studies share important insights into the pathogenesis of autism spectrum disorders (ASD) and Fragile X syndrome, based on their results alone, it is erroneous and potentially harmful to conclude that cannabis should be used as treatment for either of these disorders at this time.

Regarding human data on use of cannabis for developmental and behavioral conditions, to the best of our knowledge, the only available data are from small case series or single studies. For example, one 6-year-old boy with autism was treated with daily dronabinol for 6 months and was noted to have improvement in

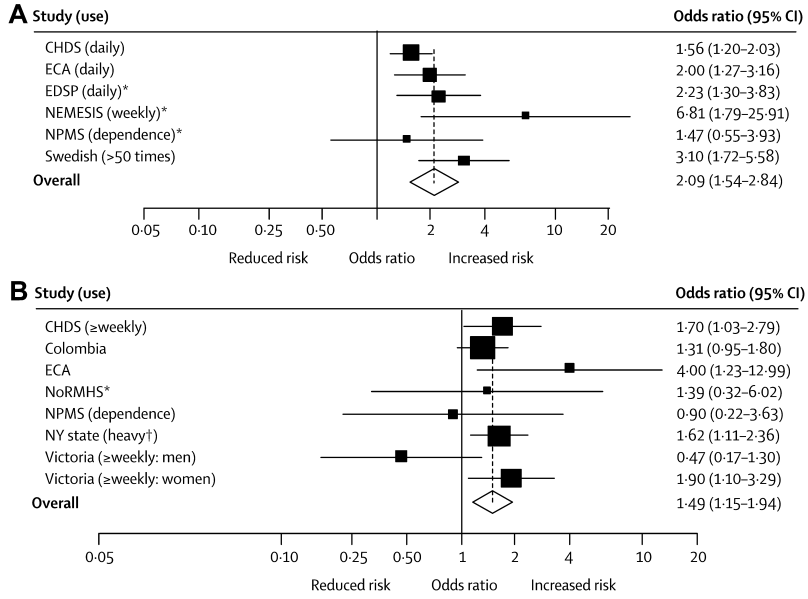

Figure 2. A, Forest plot reproduced with permission from Moore et al[63] demonstrating adjusted odds ratios and 95% confidence intervals (CI) for association of heavy cannabis use with psychosis. Frequency of cannabis use examined in the study is reported in parentheses. Asterisks denote studies in which results were not adjusted for other drug use. B, Forest plot reproduced with permission from Moore et al[63] demonstrating adjusted odds ratios and 95% CI for association of heavy cannabis use with depression. Frequency of cannabis use examined in the study is reported in parentheses.

hyperactivity, irritability, lethargy, stereotyped behaviors, and speech, as measured by the Aberrant Behavior Checklist.[83] This single case study was uncontrolled and unblinded. In another single case study[84] of a cannabis-using adult male with attention-deficit hyperactivity disorder (ADHD) off stimulants, the subject's driving skills in a simulated test during a time of abstinence improved after smoking marijuana (What is unclear is whether this subject may have actually been experiencing cannabis withdrawal from his abstinence, with alleviation of his symptoms through subsequent use of marijuana.[85]). Another small case series[86] showed an improvement in self-injurious behaviors among adolescents after dronabinol therapy, but to date, the study has not been published, leaving protocol details scarce. In sum, none of these studies provide sufficient, high-quality data to suggest that cannabis should be recommended for treatment of ASD or ADHD at this time.

Nonetheless, these data have prompted patient and family groups to advocate for the use of cannabis in children,[87] occasionally even partnering with private, for-profit organizations who may stand to gain financially from such arrangements.[88] This movement is coupled by a possibly increasing willingness of physicians to prescribe cannabis for medicinal purposes.[89] Given the significant adverse health effects of cannabis, these 2 forces may result in issuing of medical marijuana permits for developmental and behavioral diagnoses for which no data on efficacy, safety, or tolerability exist. Even if and when studies on cannabis for developmental and behavioral conditions are conducted, they will likely use formulations of oral dronabinol or cannabidiol, both of which can be administered with a known dose and predictable schedule; at this time, the bulk of medical marijuana is sold in plant form, which results in a highly variable dose of active compound and with less predictable onset of effect based on whether it is inhaled or ingested.

CONCLUSIONS

Given the current scarcity of data, cannabis cannot be safely recommended for the treatment of developmental or behavioral disorders at this time. At best, some might consider its use as a last-line therapy when all other conventional therapies have failed.[90,91] As marijuana policy evolves and as the drug becomes more readily available, it is important that practicing clinicians recognize the long-term health and neuropsychiatric consequences of regular use. Although a decades-long public health campaign has showcased the harms of cigarette smoking, similar movements to illustrate the hazards of cannabis use have not been as rigorous or successful. As a result, accurate information on regular cannabis use remains poorly disseminated to patients, families, and physicians. Furthermore, there are especially few studies examining neurocognitive and psychiatric outcomes among children and adolescents with developmental or behavioral concerns who are exposed to cannabis, and this remains a critical area for future study. In coming to the decision to use marijuana for medicinal purposes, all parties should be fully aware of the long-term hazards of regular cannabis use, recognize the lack of evidence on its efficacy in developmental and behavioral conditions, and incorporate this information into a careful risk-benefit analysis.

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