The therapeutic potential of cannabis

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Research of the cannabinoid system has many similarities with that of the opioid system. In both instances, studies into drug-producing plants led to the discovery of an endogenous control system with a central role in neurobiology. Few compounds have had as much positive press from patients as those of the cannabinoid system. While these claims are investigated in disorders such as multiple sclerosis spasticity and pain, basic research is discovering interesting members of this family of compounds that have previously unknown qualities, the most notable of which is the capacity for neuroprotection. Large randomised clinical trials of the better known compounds are in progress. Even if the results of these studies are not as positive as many expect them to be, that we are only just beginning to appreciate the huge therapeutic potential of this family of compounds is clear.


Cannabis has been used recreationally for millennia and is the third most commonly used drug after tobacco and alcohol; there are an estimated 3 million frequent users in the UK alone.1 There has been a steady stream of medical claims throughout history that cannabis eases limb-muscle spasms, migraine, and pain.2 Although there is evidence of medical use in Europe from the 13th century, it became more popularised in the early 19th century when cannabis was noted to have anticonvulsive, analgesic, anxiolytic, and antiemetic properties. Cannabis became widely used for the treatment of cramps, asthma, and dysmennorrhoea, for which it was prescribed to Queen Victoria. However, the availability of alternative treatments and, importantly, sociopolitical pressure led to a decline in the medical use of cannabis by the beginning of the 20th century.2

Although cannabis was effectively banned in the USA in 1937, cannabis was in the British pharmacopoeia and was in occasional use until the Misuse of Drugs Act (1971) declared that it was of no medical benefit and its use was outlawed. Despite its illegality, people have continued to obtain cannabis on the black market for self-medication. This patient-led self-investigation has fuelled claims of various benefits in many disorders.4 In response to such claims, patient pressure, and some small-scale clinical studies,5 the UK parliament6 felt there was sufficient evidence of benefit in some disorders, such as multiple sclerosis and pain, to warrant further investigation in large controlled trials. The current legal position in the UK is that possession and supply of cannabis is illegal. The proposed reclassification of cannabis as a schedule C drug is not an endorsement of safety but a recognition that it does not carry the same risks as other schedule B drugs, such as amphetamine and barbiturates. Should trials show an acceptable benefit, the UK Government is likely to rethink legalisation, but only for medical use.

Biology of cannabis

The acute effects of cannabis use are well recognised;1,6 it induces a psychoactive, mildly euphoric, relaxing intoxication or "high", which leads to slight changes in psychomotor and cognitive function.10 In some limited cases, cannabis can also induce unpleasant effects including anxiety, panic, and paranoia, and very rarely it may lead to acute psychosis involving delusions and hallucinations.11 Frequent users may develop an amotivational syndrome.12 Cannabis also induces an increase in heart rate, a lowering of blood pressure due to vasodilatation (which causes the classic "red eye"), appetite stimulation (known as "the munchies"), dry mouth, and dizziness.16 These may be thought of as adverse effects but all are due to a basic biology, which is now beginning to be understood.

The cannabis plant (Cannabis sativa) contains many compounds, but Δ⁹-tetrahydrocannabinol (THC) is the main psychoactive ingredient. THC breaks down to produce cannabinol and was identified—along with cannabidiol (the main non-psychoactive component)—in the 1940s.2,7 However, THC was not isolated, synthesised, and stereochemically defined until the 1960s (figure 1).2 THC is concentrated in the flowering head of the female plant and selective growing in the past 5–10 years has substantially increased THC content from 1–3% THC in the "flower-power" era to 6–13% and above. Thus, current users of cannabis may have very different experiences to those of the past. Cannabis may contain over 60 "classical" cannabinoid (tricyclic dibenzopyran) compounds and some, such as cannabidiol, may modulate the response to THC.2,17 How these different compounds act has only started to become clear in the past decade.

The cannabinoid system

Cannabinoid receptors

Cannabinoids are typically highly lipophilic and were originally thought simply to diffuse through cell membranes. However, in 1990 the first cannabinoid receptor—CB₁—was identified; this finding revolutionised the study of cannabinoid biology.18 A structurally diverse range of

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cannabinoid-receptor binding compounds (known now as cannabinoids) that have been essential to the elucidation of the biology of the cannabinoid system have been generated, including potent agonists and antagonists. In the CNS, CB1 is by far the most abundant G-protein coupled receptor with seven transmembrane-spanning segments, and it is also expressed on peripheral neurons and other cell types. CB1 is negatively coupled to adenylate cyclase and is either negatively or positively associated with selective ion channels. CB1 is expressed strongly in the basal ganglia, cerebellum, and hippocampus (figure 2), which accounts for the well-known effects of cannabis on motor coordination and short-term-memory processing. Likewise, CB1 is expressed at high concentrations in the dorsal primary afferent spinal-cord regions, which are important in pain pathways, whereas it is expressed at low concentrations in the brainstem, which controls many autonomic functions. Therefore, the many effects that cannabis can have are due to the presence of CB1, in regions that control diverse neurological functions. The responsiveness of the receptor is dynamic and CB1 exists in a partly precoupled state that produces different degrees of stimulation in different brain regions.

A second receptor—CB2—seems to be expressed primarily by leucocytes and, in contrast to CB1, is not linked to ion channels. CB2 has no known neurological activity but it may function in haemopoietic development. Selective agonists, antagonists, and mice lacking both CB1 and CB2 have helped elucidate cannabinoid biology. There is increasing evidence of additional “unknown” receptors that have cannabimimetic and therapeutic effects independent of CB1 and CB2. These receptors are more likely to be functionally rather than structurally related, as there is currently no evidence for additional cannabinoid receptors in the human genome. Furthermore, cannabinoids may also influence other receptor systems through other messenger pathways or through allosteric effects due to membrane insertion of cannabinoids. Mice that lack CB1 receptors seem...
remarkably normal, despite some minor behavioural deficits, which suggests that there is a compensatory mechanism. However, when normal homeostasis is lost, as happens in disease, control of the cannabinoid system may be particularly important.

Endocannabinoids

Several endogenous fatty-acid ligands known as endocannabinoids, have been found. The first to be discovered—in 1992—was anandamide (arachidonylethanolamide) followed by 2-arachidonoylglycerol (2-AG; figure 1).10,17,18 In the past 2 years, noladin ether, virodhamine (O-Arachidonoylethanolamine), N-arachidonoyldopamine (NADA), and docosatetraenylethanolamide (DEA) have been found in the CNS. These compounds have cannabinoid receptor binding activity, but their exact physiological roles are unknown.19,20 Of the endocannabinoids, anandamide and 2-AG are the most studied.21 Both are produced “on demand” from membrane associated precursors by distinct biochemical pathways involving phospholipases D and C. The endocannabinoids then bind and stimulate the CB receptors. Anandamide and NADA can also weakly stimulate vanilloid receptors (VR1), which are heat-gated, non-selective ion channels associated with hyperalgesia and account for some non-CB mediated effects of anandamide on vascular beds.22,23 Consistent with a homeostatic role of cannabinoids, there is also a degradation system (figure 3) that involves reuptake into the cell by putative diffusion-facilitated endocannabinoid selective transporters and hydrolysis by fatty-acid-amide hydrolase for anandamide and 2-AG or a monoacylglycerol lipase for 2-AG.25,26 Noladin ether is degraded by acylation.20 Fatty-acid-amide hydrolase is expressed strongly in the liver, is postsynaptic to CB, and is involved in degradation of oleamide, an endogenous sleep-inducing compound related to endocannabinoids.27 This degrades anandamide to arachidonic acid and ethanolamine, which do not have CB, binding activity.23

Function of the cannabinoid system

The main function of the endocannabinoid system is to regulate synaptic neurotransmission. The CB, endocannabinoid system regulates synaptic neurotransmission of excitatory and inhibitory circuits.28–30 In response to depolarisation and Ca2+ fluxes and in some instances postsynaptic group I metabotropic-glutamate receptor activation, endocannabinoids are released that inhibit further neurotransmitter via stimulation of presynaptic CB receptors (figure 4).31 As a regulator of neurotransmission, the cannabinoid system seems to influence many different functions. There is experimental evidence that cannabinoids affect the activity of most neurotransmitters (table). What actually happens after stimulation depends on the location of the receptor within the excitatory or inhibitory neural circuit being stimulated. The sometimes paradoxical findings that cannabis suppresses or induces certain phenotypical signs (eg, convulsions, tremor)
is probably because these signs are controlled by different neuronal circuits. Many neurological diseases occur due to inappropriate neuronal signals leading to too much excitation, too little inhibition, or vice versa. Dopamine activity may be inhibited by cannabinoids in motor-control centres. Nabilone has been shown to inhibit levodopa-induced dyskinesia in Parkinson’s disease. However, in different brain regions dopamine production can be associated with reward, addiction, and psychosis. Several studies have indicated that many people with schizophrenia use cannabis. One explanation is that they may be attempting to self-medicate excessive dopamine. Recent evidence suggests cannabinoids enhance dopamine release in reward centres and that teenagers and young adults who smoke cannabis have a slightly higher than normal risk of developing psychosis. CB1 is developmentally regulated, particularly during neural development and may be important in neuronal plasticity during fetal, postnatal, and adolescent life. Exogenous interference in the natural brain-modelling process may have risks to behavioural development during these times. Chronic cannabis smoking can also lead to cognitive impairment in some individuals. Cannabinoids adversely affect short-term memory processing and could be disadvantageous to cognitive ability. However, sometimes patients with disorders such as post-traumatic fear responses also have to “remember to forget” and here stimulation of the cannabinoid system may be useful to extinguish certain aversive memories. Thus, cannabis may have positive and negative outcomes, and therefore its clinical use must balance these effects against the nature of the disorder.

Preclinical data: rationale for clinical application

The clinical potential of the cannabinoids is large; some people suggest that cannabis could be the “aspirin of the 21st century”. However, much of the evidence for the use of cannabinoids is anecdotal and is too broad in scope to review in detail here. The lack of appropriate animal models with the complexity of the human brain hampers the study of the behavioural effects of these compounds. Therefore, most experimental studies have concentrated on measurable physiological effects, and, as a result, the understanding of the underlying biology is improving. Most claims made by patients suggest that cannabis may be useful in symptom management and there is now experimental support for the clinical investigation of cannabis in the control of pain and spasticity in multiple sclerosis (MS). We will concentrate on these areas in order to highlight potential therapeutic uses.

**Pain and spasticity**

Cannabinoids inhibit pain in virtually every experimental pain paradigm either via CB1 or CB2, and there is now experimental support for the clinical investigation of cannabis in the control of pain and spasticity in multiple sclerosis (MS). We will concentrate on these areas in order to highlight potential therapeutic uses.
The therapeutic potential of cannabis

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The future of cannabinoid therapeutics
New neurological indications: neuroprotection

Although the current clinical use of cannabinoids focuses on symptom management, the biology of the cannabinoid system suggests that there may be other benefits in the treatment of neurological disease, notably the slowing of progression in neurodegenerative disorders. Selective loss of CB1 receptors in the striatum is associated with the onset of signs in Huntington’s disease before significant axonal loss, both in human beings and in animal models, which suggests that some cannabinoid regulation is lost before significant pathology develops. However, activation of the remaining receptors through stimulation by endocannabinoids can limit experimental Huntington’s disease. Neurodegeneration is the main cause of morbidity in several diseases such as Huntington’s, Parkinson’s, Alzheimer’s, and motor-neuron diseases and stroke. Neurodegenerative processes may be the fundamental reason for progressive disease in MS, despite it being thought of as an inflammatory disorder. Although the pathways leading to neuron death will be different in these disorders, some similarities are likely, such as glutamate-induced excitotoxicity and damage from reactive oxygen species and toxic ion imbalances, which may make damaged or demyelinated axons particularly vulnerable. CB1 can regulate potentially neurodegenerative effects including the inhibition of excessive glutamate production and calcium ion influx via several ion channels and reactive oxygen species. There is increasing experimental evidence of a neuroprotective effect of cannabinoids in experimental models including ischaemia and head trauma. However, in contrast to the acute glutamate-induced injury in the penumbra during ischaemia, in chronic diseases the damage is probably a low grade insult that may be amenable to intervention with neuroprotective agents. There is experimental evidence of activity in inflammatory-mediated neurodegeneration, including experimental MS models. Although clinical neuroprotection is an exciting prospect, clinical data is lacking and will take time to assess. However, there is recent evidence to support the inhibition of abnormal glutamate hyperactivity. This is thought to cause tics associated with Tourette’s syndrome and epilepsy. Although there are no reliable data on the use of cannabis in epilepsy, a small-scale study has shown that oral THC can inhibit tics in Tourette’s syndrome. Although THC mediates many of these effects experimentally, other cannabinoids may contribute to the neuroprotective effect, such as the antioxidant properties of cannabidiol. A synthetic, non-CB binding cannabinoid (dexanabinol, HU211) is an NMDA-receptor antagonist and phase II trials have recently shown some efficacy in the treatment of head trauma. The CNS is plastic and can accommodate significant nerve loss before the development of symptoms. Agents that slow this process may have a great effect on the rate of disability in chronic neurodegenerative disease.

Clinical cannabinoid pharmacology
Results of clinical trials of oral, sublingual, and even smoked cannabis will be known soon and there will be a definitive answer as to whether cannabis, in the forms studied, has any therapeutic potential. Researchers, clinicians, and government officials will then have the knowledge to decide on the next step forward. Although the immediate future may lie in plant-based medicines, once we understand the biology of the disorders better the future for therapy must surely be in pharmaceuticals, either as single agents or in combinations that target complementary cascades. There are already indications that cannabinoids can be used in synergistic...
combination with opioids and benzodiazepines in pain relief. It is significant first-pass metabolism in the liver, which degrades THC, to the variability of circulating concentrations of orally administered cannabinoids, which makes dose titration more difficult and therefore increases the potential for adverse effects. Smoking has been the route of choice for many cannabis users because it delivers a more rapid “hit” and allows more accurate dose-titration. Smoking may also change the chemical composition such that THC carboxylic acids are readily converted to THC by heating or baking. However, this route is not a viable option because of the potential for long-term side-effects from smoke inhalation. Delivery methods need to be developed for currently available and future compounds to allow better control of side-effects. One approach has been the development of a sublingual spray. However, formulations and inhalers for delivery into the lungs, skin patches, or even the development of oral prudugs that become active once in the blood are possible alternatives. “Smart” inhalers are being developed that allow controlled doses that can only be dispensed by the appropriate device to limit illegal use, but the best form of prohibition is to develop more effective alternatives.

The pharmaceutical approach of making specific potent agonists has generated some compounds that have entered preliminary clinical studies (eg, nabilone and levonantradol). Likewise, CB, antagonists (Rimonabant) are also currently being assessed in the prevention of obesity. In addition, there are already hundreds of experimental agonists that could be used in future therapeutic trials. The variability in toleration of cannabinoids and the slight difference between effect and side-effect, however, suggest that there could be a real possibility for overdose with strong agonists. Excessive stimulation of the receptor leads to receptor tolerisation and is a particular problem of strong agonism. Therefore, the development of clinically acceptable weak agonists may be preferable for chronic use of cannabinoid-based drugs to prevent receptor desensitisation and also increase the therapeutic window. THC is only a partial CB agonist, whereas endocannabinoids are weak agonists and these agents naturally stimulate receptors without much potential for inducing psychoactive effects. These are new targets for cannabinoid therapy.

Endocannabinoid release could be stimulated either directly or indirectly through the stimulation of complementary systems (eg, metabotropic type I glutamate receptors). Importantly, these can also be stimulated through inhibition of endocannabinoid degradation (figure 3). In the case of depression, serotonin reuptake inhibitors may be preferable to direct serotonin-receptor stimulation, which might also be the case with the cannabinoids. During disease there are changes in endocannabinoid concentrations at the site of pathology. Therefore, targeting of endocannabinoid degradation through inhibition of the reuptake mechanism or enzymes that cause degradation could locally target sites of damage while limiting effects in uninvolvned cognitive areas (figure 3). Cannabis has no mechanism to selectively target CB, in the brain and its use will invariably be linked with unwanted biological activity. Therefore, the value of cannabis will depend on whether patients can titrate their dose before adverse effects become intolerable, the acceptability of which will depend on the patient’s character and the disorder in question.

Although many adverse effects originate in the brain, CB, is expressed on nerves outside the CNS (eg, nerve terminals, dorsal root ganglia, vasculature). Selective peripheral receptor agonism may therefore limit psychoactivity while producing benefits for disorders such as pain, asthma (bronchodilation), and glaucoma (neuroprotection and reduction of pressure) by either local application (eg, eye drops for glaucoma) or by developing CNS-excluded agonists.

Several experimental agents have been made that are effective in experimental spasticity and pain as full receptor agonists that do not have psychoactive effects. Ajulemic acid, a cannabinoid compound that does not directly stimulate CB, receptors significantly, has undergone safety studies in human beings. It inhibits anandamide reuptake and is antispastic, at least experimentally.

Conclusion

As we learn more about the pharmacological activities of compounds in cannabis and their biological targets outside the cannabinoid system, varieties of cannabis might be tailored to different diseases or used in combination with known drugs. Whatever the future holds, there are many challenges to be overcome before we view cannabinoids as routine medicine in neurological disorders.

Authors’ contributions

DB and AJT planned and wrote the review, GG helped with editing and GP provided some of the figures.

Conflict of interest

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