Cannabidiol as potential anticancer drug

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Over the past years, several lines of evidence support an antitumourigenic effect of cannabinoids including Δ9-tetrahydrocannabinol (Δ9-THC), synthetic agonists, endocannabinoids and endocannabinoid transport or degradation inhibitors. Indeed, cannabinoids possess anti-proliferative and pro-apoptotic effects and they are known to interfere with tumour neovascularization, cancer cell migration, adhesion, invasion and metastasization. However, the clinical use of Δ9-THC and additional cannabinoid agonists is often limited by their unwanted psychoactive side effects, and for this reason interest in non-psychoactive cannabinoid compounds with structural affinity for Δ9-THC, such as cannabidiol (CBD), has substantially increased in recent years. The present review will focus on the efficacy of CBD in the modulation of different steps of tumourigenesis in several types of cancer and highlights the importance of exploring CBD/CBD analogues as alternative therapeutic agents.

The endocannabinoid system: a brief overview

The endocannabinoid system (eCB) is a recently discovered signalling system comprising the cannabinoid CB1 and CB2 receptors, their intrinsic lipid ligands, endocannabinoids (eCBs), such as the N-arachidonoylanthanolamide (anandamide, AEA) and the 2-arachidonoylglycerol (2-AG), and the associated enzymatic machinery (transporters, biosynthetic and degradative enzymes).

The cannabinoid CB1 and CB2 receptors are both G protein-coupled receptors: CB1 receptors are highly distributed in the central nervous system (CNS), with low to moderate expression in periphery, whereas CB2 receptors are high in the immune system, with much lower and more restricted distribution in the CNS [1, 2].

Endogenous ligands for the cannabinoid receptors were discovered soon after their characterization. The two major known endogenous ligands are anandamide (AEA) and 2-AG [3–6]. Both are arachidonic acid derivatives produced from phospholipid precursors through activity-dependent activation of specific phospholipase enzymes [7]. Later on, a number of other eCB ligands have been discovered, including N-arachidonoyldopamine, N-arachidonoylglycerol ether and O-arachidonoyl ethanolamine [8].

AEA and 2-AG do not share the same biosynthetic or metabolic pathways. Different pathways can produce AEA from the phospholipid precursor N-arachidonoyl-phosphatidylethanolamine, the most important being a direct conversion catalyzed by an N-acyl-phosphatidylethanolamine-selective phosphodiesterase. 2-AG is mainly synthesized through activation of phospholipase C and subsequent production of diacylglycerol, which is converted to 2-AG by diacylglycerol lipase. After its re-uptake, AEA is hydrolyzed by the enzyme fatty acid amide hydrolase (FAAH), producing arachidonic acid and ethanolamine, while 2-AG is primarily metabolized by monoacylglycerol lipase, leading to the formation of arachidonic acid and glycerol [9]. Apart from their binding to CB1 and CB2 receptors, eCBs may bind to other receptors. For example, AEA may intracellularly activate the potential vanilloid receptor type 1 (TRPV1) [10]. Moreover, other putative cannabinoid receptors are the orphans G protein-coupled receptor, GPR55 [11], and the peroxisome proliferator-activated receptor, PPAR [12, 13]. However, CB1 and CB2 receptors are certainly the most known targets for...
AEA and 2-AG, which activate them with different affinity. AEA has the highest affinity in both cases, whereas 2-AG has the highest efficacy in both cases [14].

Physiological or pathological stimuli induce synthesis and release of endocannabinoids, which can subsequently activate cannabinoid receptors. Therefore eCBs are synthesized and released ‘on demand’ through the cleavage of membrane phospholipid precursors.

Multiple sclerosis and spinal cord injury, neuropathic pain, cancer, atherosclerosis, stroke, myocardial infarction, hypertension, glaucoma, obesity/metabolic syndrome and osteoporosis are some of the diseases in which alterations in the eCB system have been demonstrated, thus paving the way for new therapeutic strategies aimed at restoring normal eCB system functionality [15].

Currently, the term ‘cannabinoid’ refers to more than 100 terpenophenols derived from Cannabis sativa [16], as well as to synthetic compounds that directly or indirectly interact with cannabinoid receptors. Δ⁹-THC is the most psychoactive component of the plant Cannabis sativa, and its biological actions as well as the ones of synthetic cannabinoid compounds (synthetic compounds active on cannabinoid receptors) are primarily mediated by CB₁ and CB₂ receptors. Cannabinoids are further classified into phytocannabinoids (subclassified in different categories according to their chemical structures, such as Δ⁹-THC, Δ⁸-THC, cannabiol, CBD and cannabicyclol), synthetic compounds active on cannabinoid receptors (i.e. JWH133, WIN55212-2, SR141716) and endocannabinoids (i.e. AEA and 2-AG) which are produced endogenously (Figure 1).

**Cannabinoids in the treatment of cancer**

Cannabinoids are currently used in cancer patients to palliate wasting, emesis and pain that often accompany cancer. A significant advancement in cannabinoid use in cancer treatment came from the discovery of a potential utility of these compounds for targeting and killing cancer cells. In 1975 Munson *et al.* [17] demonstrated that the administration of Δ⁹-THC, Δ⁸-THC and cannabinol inhibited the growth of Lewis lung adenocarcinoma cells in vitro as well as in vivo after oral administration in mice. The interest in anticarcinogenic properties of cannabinoids was even renewed after the discovery of the eCB system and the cloning of the specific cannabinoid receptors. Since then, several cannabinoids have been shown to exert anti-proliferative and pro-apoptotic effects in various cancer types (lung, glioma, thyroid, lymphoma, skin, pancreas, uterus, breast, prostate and colorectal carcinoma) both *in vitro* and *in vivo* [18–26]. Moreover, other antitumourigenic mechanisms of cannabinoids are currently emerging, showing their ability to interfere with tumour neovascularization, cancer cell migration, adhesion, invasion and metastasis [27].

However, the clinical use of Δ⁹-THC and additional synthetic agonists is often limited by their unwanted psychoactive side effects, and for this reason interest in non-psychoactive phytocannabinoids, such as CBD, has substantially increased in recent years. Interestingly CBD has no psychotropic activity and, although it has very low...
affinity for both CB₁ and CB₂ receptors, it has been recently reported to act with unexpectedly high potency in vitro as an antagonist of CB₁ receptors in the mouse vas deferens [28] and brain [29] tissues. Additionally, CBD displays inverse agonism at human CB₂ receptors [29]. Moreover, other putative molecular targets of CBD are TRPV, 5-HT₁A, GPR55 and PPARγ receptors (see Figure 2). Besides its beneficial effects in the treatment of pain and spasticity and other CNS pathologies, several reports demonstrated that CBD possesses anti-inflammatory, pro-apoptotic effects and inhibits cancer cell migration, adhesion and invasion.

This review will focus on the most recent evidence regarding the efficacy of CBD in the modulation of tumourigenesis in several types of cancer. The data available so far are summarized in Table 1 and are discussed in detail in the following paragraphs.

**CBD and breast cancer**

In 2006 Ligresti et al. [30] demonstrated for the first time that CBD potently and selectively inhibited the growth of different breast tumour cell lines (MCF7, MDA-MB-231), with an IC₅₀ of about 6 μM and exhibited significantly lower potency in non-cancer cells. CBD and CBD-rich extracts (containing approximately 70% CBD together with lesser amounts of other cannabinoids) also inhibited the growth of xenografts, obtained by s.c. injection into athymic mice of human MDA-MB-231 cells, and reduced infiltration of lung metastases derived from intrapaw injection of breast carcinoma cells. Among the possible cellular and molecular mechanisms underlying these effects, CBD seemed to involve direct TRPV1 activation and/or CB₂ indirect activation (via FAAH), as well as induction of oxidative stress. Later on, McAllister’s group [31] demonstrated that, besides proliferation, CBD also interfered with two other crucial steps of breast cancer cell progression, invasion and metastasization. Among the three different groups of cannabinoid compounds tested (phytocannabinoids with affinity for CB₁ and CB₂ receptors, phytocannabinoids with no appreciable affinity for CB₁ and CB₂ receptors and synthetic compounds with affinity for CB₁ and CB₂ receptors), CBD was shown to be one of the most effective inhibitors of human breast cancer cell proliferation, being equipotent to Δ⁹-THC and CP55940 in inhibiting, respectively, MDA-MB-231 and MDA-MB-436 cell growth, and being the most potent inhibitor of the MDA-MB-231 cell migration. Interestingly, CBD regulated the expression of key genes involved in the control of cell proliferation and invasion through the downregulation of Id-1 expression, an inhibitor of basic helix-loop-helix transcription factors, whose overexpression in breast cancer cells is responsible for proliferation, migration and invasion. Therefore, the ability of CBD to decrease significantly Id-1 expression in breast cancer cells was associated with its efficacy in reducing tumour aggressiveness.

Four years later, the same group [32] demonstrated that the observed effect of CBD on Id-1 expression was mediated by the upregulation of the extracellular signal-regulated kinase phosphorylation (pERK). Indeed, the ERK inhibitor, U0126, partially reverted CBD-induced inhibition of proliferation and invasion as well as its effect on Id-1 expression. Besides ERK upregulation, also the production of reactive oxygen species (ROS) was shown to mediate CBD-induced effects on cell proliferation and Id-1 expression, since the use of a ROS scavenger (tocopherol) reversed the aforementioned CBD effects. Moreover, these authors demonstrated that CBD was effective in reducing the primary tumour mass and the size and number of metastatic foci in vivo.

Finally, the excellent paper of Shrivastava et al. [33] adds fresh light on the cellular mechanism through which CBD induces cell death in breast cancer cells. These authors showed that CBD induced a concentration-dependent cell death of both oestrogen receptor-positive and oestrogen receptor-negative breast cancer cells with a mechanism independent of CB₁, CB₂ and TRPV1 receptor activation. Interestingly, the effective concentrations of CBD in tumour cells have little effect on non tumourigenic, mammary cells. Moreover, electron microscopy revealed morphologies consistent with the coexistence of apoptosis and autophagy, these events being promoted by the induction of endoplasmic reticulum (ER) stress and the inhibition of Akt/mTOR/4EBP1 signalling. In addition, CBD-driven increase in ROS production is fundamental to induce both apoptosis and autophagy. Examining further the cellular mechanism involved in CBD-induced cell death, they found that CBD reduced mitochondrial membrane potential, triggered the translocation of the Beclin1 interacting protein (Bip) to the mitochondria and the release of cytochrome C to the cytosol and, ultimately, the activation of the intrinsic apoptotic pathway.

Finally, the relationship between CBD-induced apoptosis and autophagic cell death was explored by blocking each form of cell death with specific inhibitors. Caspase
inhibition reduced CBD-induced apoptosis and the expression of protein markers in breast cancer cells, whereas the inhibition of autophagy enhanced apoptosis as a compensatory/alternative mechanism of cell death. The apoptosis:autophagy ratio in CBD-induced cell death seemed to be mediated via Beclin1, a key signalling molecule in the autophagic process. CBD treatment induced the cleavage of Beclin1 and the subsequent translocation of the cleavage product to the mitochondria where it may induce apoptosis through the enhancement of cytochrome C release [34, 35].

As a whole this work highlights the presence of a complex balance between autophagy and mitochondria-mediated apoptosis in CBD-induced breast cancer cell death and strengthens the idea that CBD can be considered as an alternative agent for breast cancer therapy. Figure 3 shows a schematic representation of the signalling pathways associated with the effect of CBD in breast cancer cell proliferation and invasion.

**CBD and glioma**

CBD also possesses anti-tumoural properties in gliomas, tumours of glial origin characterized by a high morphological and genetic heterogeneity and considered one of the most devastating neoplasms, showing high proliferative rate, aggressive invasiveness and insensitivity to radio- and chemotherapy.

After the seminal paper of Jacobsson et al. [36] demonstrating a serum-dependent effect of CBD upon C6 murine glioma cell proliferation, Massi et al. in 2004 [37] reported that CBD was effective in inhibiting U87-MG and U373 human glioma cell proliferation in vitro through the induction of apoptosis. Interestingly, CBD did not affect viability of non-transformed primary glial cells [38]. When tumour xenografts were generated in immune-deficient mice, in vivo intratumoural treatment with CBD significantly reduced tumour growth [37].

The anti-proliferative effect of CBD was cannabinoid and vanilloid receptors independent. The CB1 receptor antagonist SR144528 reverted the effect of CBD, but in a weak and transient manner [37]. More importantly, this paper demonstrated for the first time that the anti-tumour effect of CBD involved the induction of oxidative stress, through increased early production of ROS, depletion of intracellular glutathione and increased GSH-associated enzymatic activity. Accordingly, the CBD anti-proliferative effect was reversed by the anti-oxidant, tocopherol. Importantly, CBD did not induce 

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**Table 1**

Effects of cannabidiol on different types of cancer

<table>
<thead>
<tr>
<th>Cancer</th>
<th>In vitro effect</th>
<th>Receptor involvement</th>
<th>ROS production</th>
<th>Molecular cell signalling</th>
<th>Autophagy</th>
<th>Apoptosis</th>
<th>In vivo effect</th>
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<tr>
<td>Breast</td>
<td>↓ proliferation</td>
<td>CB1; TRPV1</td>
<td>↑</td>
<td>NC</td>
<td>NC</td>
<td>+</td>
<td>↓ xenografts growth</td>
<td>[26]</td>
</tr>
<tr>
<td></td>
<td>↓ viability</td>
<td>non-CB1; non-TRPV1</td>
<td>↑</td>
<td>↓ pAkt; ↑ cytochrome C</td>
<td>+</td>
<td>+</td>
<td>↓ lung metastases</td>
<td></td>
</tr>
<tr>
<td></td>
<td>↓ invasion</td>
<td>non-TRPV1</td>
<td>↑</td>
<td>Bid translocation ↓ Id-1; ↑ pERK</td>
<td>NC</td>
<td>NC</td>
<td>↓ tumour growth</td>
<td>[27, 28]</td>
</tr>
<tr>
<td>Glioma</td>
<td>↓ proliferation</td>
<td>non-CB1; partial-CB1; non-TRPV1</td>
<td>↑</td>
<td>pERK; ↓ pAkt; ↓ HIF-1α; ↑ cytochrome C caspase activation</td>
<td>NC</td>
<td>+</td>
<td>↓ tumour growth</td>
<td>[32, 33, 36, 37]</td>
</tr>
<tr>
<td></td>
<td>proliferation and invasiveness</td>
<td>NC</td>
<td>↑</td>
<td>↑</td>
<td>NC</td>
<td>NC</td>
<td>NC</td>
<td>[34]</td>
</tr>
<tr>
<td></td>
<td>↓ migration</td>
<td>non-CB1; non-CB2; non-TRPV1</td>
<td>NC</td>
<td>NC</td>
<td>↑ pAkt; ↑ cytochrome C caspase activation; ↑ Bid translocation ↑ cytochrome C</td>
<td>NC</td>
<td>NC</td>
<td>NC</td>
</tr>
<tr>
<td>Leukaemia</td>
<td>↓ viability</td>
<td>CB1; TRPV1</td>
<td>↑</td>
<td>caspase-3 activation ↓ p-p38</td>
<td>NC</td>
<td>+</td>
<td>↓ tumour burden</td>
<td>[39]</td>
</tr>
<tr>
<td></td>
<td>↓ viability</td>
<td>NC</td>
<td>↑</td>
<td>↓ p-p38; ↑ p-ERK; ↑ TIMP-1</td>
<td>NC</td>
<td>NC</td>
<td>↑ tumour cell apoptosis</td>
<td>[40]</td>
</tr>
<tr>
<td>Lung</td>
<td>↓ invasion</td>
<td>CB1; CB2; TRPV1</td>
<td>NC</td>
<td>↑ p-p38; ↑ p-ERK; ↑ TIMP-1; ↓ cytochrome C</td>
<td>NC</td>
<td>NC</td>
<td>↓ lung metastases</td>
<td>[46, 47]</td>
</tr>
<tr>
<td>Thyroid</td>
<td>cyostatic effect</td>
<td>NC</td>
<td>↑</td>
<td>↓ PAI-1</td>
<td>NC</td>
<td>+</td>
<td>↓ PAI-1 in xenografts</td>
<td>[46, 47]</td>
</tr>
<tr>
<td>Thymoma</td>
<td>↓ viability</td>
<td>NC</td>
<td>↑</td>
<td>NC</td>
<td>NC</td>
<td>+</td>
<td>NC</td>
<td>[26]</td>
</tr>
<tr>
<td>Colon</td>
<td>↓ proliferation</td>
<td>CB1; CB2; TRPV1; PPARy</td>
<td>↑ caspase-3</td>
<td>↑ Akt; ↑ 2-AG</td>
<td>NC</td>
<td>+</td>
<td>↓ ACF; polyps and tumours</td>
<td>[52]</td>
</tr>
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NC = not checked. ↑ increase; ↓ decrease.
ROS production in non-transformed primary glial cells [38].

Among the cellular events involved in glioma cell death, CBD produced a time-dependent release of cytochrome C and activation of caspase-8, -9 and -3, suggesting the involvement of both the intrinsic and extrinsic apoptotic pathways [38]. Marcu et al. [39] later confirmed the efficacy of CBD in inhibiting the growth of multiple glioblastoma cell lines in a more potent way than Δ⁹-THC. Interestingly, combined treatment of Δ⁹-THC with CBD demonstrated that CBD enhanced the Δ⁹-THC inhibitory effect on glioblastoma cell growth, but not on invasiveness [39]. In line with this, more recently Torres et al. [40] confirmed that combined treatment with CBD and Δ⁹-THC greatly reduced human glioma cell viability enhancing both autophagy and apoptosis and triggering caspase-3 activation. Moreover, combined administration of submaximal doses of CBD and Δ⁹-THC reduced the growth of U87-MG cell-derived tumour xenografts in nude mice to a greater extent than treatment with the individual compounds, suggesting the potential use of combination therapy which would reduce the amount of the psychoactive Δ⁹-THC.

The synergistic effect of combined therapy implied in vitro cell cycle arrest, ROS induction and apoptosis through sustained activation of caspases-3, -7 and -9, as well as specific modulation of the extracellular signal-regulated kinase, ERK [39]. These effects were not observed with either compound individually, indicating them as a prerogative of combination treatment. Differently from Marcu’s data [39], our recent results [41] showed that, both in U87-MG and in Δ⁹-THC-resistant T98G human glioma cell lines, CBD per se strongly down-regulates two signalling molecules crucial in tumour cell proliferation, ERK and PI3K/Akt. In addition it inhibited the hypoxia-inducible transcription factor HIF-1α, one of the most critical stimuli for cell survival, motility and tumour angiogenesis. Thus, inhibition of these three molecules appears as part of the multiple molecular targets for CBD anti-neoplastic activity [41].

Further biochemical analysis of glioma tumour tissues excised from nude mice treated in vivo with CBD indicated a significant decrease of activity and content of 5-LOX, as well as a marked stimulation of FAAH and a decrease of AEA content [42].

Besides cell growth, CBD reduced glioma cell migration [43] and invasiveness in a Boyden chamber test [39], at concentrations lower than those required to inhibit cell proliferation. The CBD anti-migratory effect was not antagonized by the selective cannabinoid receptor antagonists or by pretreatment with pertussis toxin, indicating no involvement of classical cannabinoid receptors and/or G protein-coupled receptors.

CBD seems to counteract glioma cell proliferation and invasion through multiple mechanisms, as summarized in Figure 4.
**CBD and leukaemia/lymphoma**

Gallily et al. [44] provided first evidence of a possible exploitation of CBD in the treatment of lymphoblastic diseases. They demonstrated that CBD treatment induced apoptosis, through caspase-3 activation in human acute myeloid leukaemia HL-60 cell line, whereas it had no effect on human monocytes from normal individuals.

Later on, McKallip et al. [45], using the murine EL-4 lymphoma cell line and the human Jurkat and Molt-4 leukaemia cell lines, demonstrated that CBD exposure led to a significant CB2 receptor-mediated decrease in the number of viable cells as well as to the induction of apoptosis, both in vitro and in vivo.

In Jurkat cells, CBD exposure resulted in the activation of caspase-8, -9, and -3, the cleavage of poly(ADP-ribose) polymerase and the decrease in full-length Bid, suggesting a possible cross-talk between the intrinsic and extrinsic apoptotic pathways. Moreover, exposure to CBD led to the loss of mitochondrial membrane potential and subsequent release of cytochrome C. As in other tumour cells, CBD-induced apoptosis required an increase of ROS production. Finally, CBD decreased the levels of phospho-p38 mitogen-activated protein kinase [45], and this effect was blocked by treatment with a CB2-selective antagonist or ROS scavenger. In addition, CBD treatment caused a significant reduction in tumour burden and increased the level of apoptotic tumours in EL-4-bearing mice [45].

Together, the results suggest that CBD, acting through CB2 receptors and ROS production, may represent a novel and highly selective treatment for leukaemia. Moreover, previous evidence indicated that human leukaemias and lymphomas expressed significantly higher levels of CB2 receptors compared with other tumour cell lines, suggesting that tumours of immune origin may be highly sensitive to the CB2-mediated effects of CBD [46].

**CBD and lung cancer**

Given the poor response of lung cancer to available therapy and its aggressive biological nature, a series of targets and new therapeutic strategies for their treatment are currently being investigated [47–50].

Recently, Ramer et al. [51–53] investigated the effect of CBD on the invasive properties of A549 cells, a line of human lung carcinoma cells expressing both CB1 and CB2 receptors as well as TRPV1 receptors. Using Matrigel invasion assays, they found a CBD-driven impaired invasion of A549 cells that was reversed by CB1 and CB2 receptor agonists and TRPV1 antagonists.

CBD treatment concomitantly upregulated the tissue inhibitor of matrix metalloproteinases-1 (TIMP-1) and the CBD-elicited decrease in tumour cell invasiveness was reversed by knocking down TIMP-1 expression through a siRNA approach. These results suggest a causal link between TIMP-1 upregulation and CBD anti-invasive action. CBD was also shown to induce p38 and ERK phosphorylation as upstream mechanisms for TIMP-1 induction and subsequent decreased invasiveness. Interestingly all
these cellular events were blocked by cannabinoids or TRPV1 receptor antagonists.

The significant inhibition of A549 cell invasion following CBD treatment was also accompanied by the down-regulation of another important factor involved in the regulation of cell spreading, the plasminogen activator inhibitor PAI-1 [52]. CB1 and CB2, as well as TRPV1 receptor antagonists suppressed the observed effect of CBD on PAI-1 secretion and cell invasion. Recombinant human PAI-1 and PAI-1 siRNA led to a concentration-dependent up- and down-regulation of invasiveness, respectively, suggesting a crucial role of PAI-1 in A549 invasiveness.

Additionally, in vivo studies in thymic aplastic nude mice revealed a significant inhibition of A549 lung metastases following CBD treatment [51] and a significant downregulation of PAI-1 protein was demonstrated in A549 xenografts of CBD-treated rats [52].

It is worth noting that CBD decreased invasiveness in a range of therapeutically relevant concentrations (0.01 to 0.05 μM), since the peak plasma concentrations of CBD in healthy volunteers following administration of Sativex™ (1:1 ratio of Δ⁹-THC and CBD) was reported to be between 0.01 μM to 0.05 μM [54].

Together, these findings provide a novel mechanism underlying the anti-invasive action of CBD on human lung cancer cells and imply its use as a therapeutic option for the treatment of highly invasive cancers.

**CBD and endocrine tumours**

Thyroid cancer is the most common endocrine malignancy and Ligresti et al. [30] demonstrated that CBD exerted anti-proliferative effects on rat thyroid KiMol cells, transformed with the v-K-ras oncogene. This effect of CBD was associated with a cell cycle block at the G1/S phase transition, as well as the induction of apoptosis.

Later on, Lee et al. [55] demonstrated that CBD markedly induced apoptosis in both murine thymocytes and EL-4 thymoma cells, with CBD-mediated apoptosis occurring earlier in EL-4 cells than in thymocytes. The cellular events triggered by CBD were similar in both T cells, ROS generation playing a pivotal role. The presence of N-acetylcysteine (NAC), a precursor of glutathione, markedly attenuated the induction of apoptosis and restored the diminished levels of cellular thiol.

The observation that CBD induced oxidative stress in thymocytes, EL-4 cells and splenocytes [56] substantiates the notion that, unlike monocytes, T cells both primary and immortalized, are all sensitive and respond similarly to CBD, with a central role of ROS generation.

**CBD and colon cancer**

Colon cancer is a major cause of morbidity and mortality in Western countries. A recent paper from Izzo’s group [57] demonstrated the chemopreventive effect of CBD in a preclinical animal model of colon cancer based on azoxymethane (AOM) administration in mice. AOM treatment was associated with aberrant crypt foci (ACF), polypl and tumour formation, as well as with the upregulation of phospho-Akt, iNOS and COX-2 and the downregulation of caspase-3. CBD was effective in reducing ACF, polyps and tumours and counteracted AOM-induced phospho-Akt and caspase-3 changes. In vitro studies, supported the beneficial effect of CBD. Indeed, in colorectal carcinoma cell lines, CBD protected DNA from oxidative damage, increased endocannabinoid concentrations and reduced cell proliferation in a CB1-, TRPV1- and PPARα-antagonist sensitive manner.

In the light of its safety records, these results suggest that CBD might be worthy of clinical consideration in colon cancer prevention.

**CBD and angiogenesis**

Angiogenesis consists of the formation of new blood vessels from pre-existing ones and represents another promising therapeutic target for cancer therapy. Collectively, cannabinoids have been demonstrated to act as anti-angiogenic factors by disposing tumour cells to decrease the production of pro-angiogenic factors and/or by direct modulation of endothelial cells [27].

Surprisingly, so far no study has investigated the effect of CBD on angiogenesis. Our data currently awaiting publication [58] demonstrated that CBD potently inhibited HUVEC cells proliferation, migration and invasion through the induction of endothelial cell cytostasis without triggering apoptosis. Interestingly, CBD also affected endothelial cell differentiation into tubular capillaries as well as the outgrowth of capillary-like structures from HUVEC spheroids in vitro. In addition, the anti-angiogenic properties of CBD were demonstrated also in vivo, using a matrigel sponge model. These effects were associated with down-modulation of several molecules associated with angiogenesis, including MMP2, MMP9, uPA, endothelin-1, PDGF-AA and CXCL16.

Collectively, these preliminary data demonstrate that, besides its well known pro-apoptotic anti-proliferative and anti-invasive actions, CBD may also exert anti-angiogenic effects, thus further strengthening its potential application in cancer therapy.

**Conclusion and future directions**

Collectively, the non-psychoactive plant-derived cannabinoi d CBD exhibits pro-apoptotic and anti-proliferative actions in different types of tumours and may also exert anti-migratory, anti-invasive, anti-metastatic and perhaps anti-angiogenic properties. On the basis of these results,
evidence is emerging to suggest that CBD is a potent inhibitor of both cancer growth and spread.

Interestingly, the anticancer effect of this compound seems to be selective for cancer cells, at least in vitro, since it does not affect normal cell lines. The efficacy of CBD is linked to its ability to target multiple cellular pathways that control tumourigenesis through the modulation of different intracellular signalling depending on the cancer type considered. The most common effect of CBD is the increase in ROS production that seems to be determinant for triggering its beneficial action in all the considered cancer cell types. The role of cannabinoid/vanilloid receptors in mediating CBD effects is more controversial. In some cases (lungs, leukaemia, colon) a clear contribution of these receptors has been demonstrated through the use of specific antagonists, but in other cancer types (glioma and breast) their relevance appears only marginal or absent. Besides the in vitro data, the efficacy of CBD in reducing tumour growth and, in some cases, metastasization was confirmed in experimental animal models. However, the potential clinical application of CBD for cancer therapy needs some consideration. Its low toxicity is certainly a good starting point. CBD behaves as a non toxic compound; indeed oral administration of CBD 700 mg day$^{-1}$ for 6 weeks did not show any overt toxicity in humans [59] suggesting its possible exploitation for prolonged treatment. The route of administration appears more problematic since CBD oral absorption is slow and unpredictable. However, 6 weeks of oral CBD treatment 10 mg kg$^{-1}$ day$^{-1}$ provoked a mean plasma concentration of CBD between 6 and 11 ng ml$^{-1}$ (about 0.036 μM) [60] that did not differ significantly over the 6 weeks of administration. Interestingly, this range of concentration was demonstrated to be active in inhibiting lung cancer cell invasion [52, 53], thus suggesting that in some cases the oral route could be the appropriate choice. Additionally, experimental data showed that combined treatment with CBD and Δ$^9$-THC could be more effective in reducing cancer cell proliferation, suggesting that the co-administration may represent a better choice for cancer therapy. Accordingly, oromucosal treatment with Sativex™ 10 mg (a formulation with a 1:1 ratio of CBD and Δ$^9$-THC, recently approved for multiple sclerosis) resulted in a CBD plasma concentration of effective in reducing lung cell invasion in vitro. Thus, the results obtained with Sativex™ suggest that the use of different associations of phytocannabinoids in a variable proportion might lead to a better outcome without pharmacokinetic interaction [61]. Moreover, oromucosal administration may represent a first choice in the presence of nausea and vomiting. Finally, the use of CBD/Sativex can be suggested in combination with classical chemotherapeutic agents to check for the presence of a synergistic effect that might potentially allow clinical chemotherapeutic dose reduction, thereby reducing toxicity while maintaining efficacy. In the light of its safety record and considering that CBD is already currently used in patients with multiple sclerosis, the findings here summarized suggest that CBD might be worthy of clinical consideration for cancer therapy.

**Nomenclature**

The drug/molecular target nomenclature conforms to the BJP’s Guide to Receptors and Channels [62].

**Competing Interests**

There are no competing interests to declare.

**REFERENCES**


Cannabinoid and cancer


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USING e-ANNOTATION TOOLS FOR ELECTRONIC PROOF CORRECTION

Required software to e-Annotate PDFs: Adobe Acrobat Professional or Adobe Reader (version 8.0 or above). (Note that this document uses screenshots from Adobe Reader X)

The latest version of Acrobat Reader can be downloaded for free at: http://get.adobe.com/reader/

Once you have Acrobat Reader open on your computer, click on the Comment tab at the right of the toolbar:

This will open up a panel down the right side of the document. The majority of tools you will use for annotating your proof will be in the Annotations section, pictured opposite. We’ve picked out some of these tools below:

1. **Replace (Ins) Tool** – for replacing text.

   ![Replace (Ins) Tool](image)

   **How to use it**
   - Highlight a word or sentence.
   - Click on the Replace (Ins) icon in the Annotations section.
   - Type the replacement text into the blue box that appears.

2. **Strikethrough (Del) Tool** – for deleting text.

   ![Strikethrough (Del) Tool](image)

   **How to use it**
   - Highlight a word or sentence.
   - Click on the Strikethrough (Del) icon in the Annotations section.

3. **Add note to text Tool** – for highlighting a section to be changed to bold or italic.

   ![Add note to text Tool](image)

   **How to use it**
   - Highlight the relevant section of text.
   - Click on the Add note to text icon in the Annotations section.
   - Type instruction on what should be changed regarding the text into the yellow box that appears.

4. **Add sticky note Tool** – for making notes at specific points in the text.

   ![Add sticky note Tool](image)

   **How to use it**
   - Click on the Add sticky note icon in the Annotations section.
   - Click at the point in the proof where the comment should be inserted.
   - Type the comment into the yellow box that appears.

There is no room for extra profits and the number of (set) values are not determined by Blanchard and Kiyotaki (1987), perfect competition in general equilibriums of aggregate demand and supply classical framework assuming monopolies as an excessive number of firms...
5. **Attach File Tool** – for inserting large amounts of text or replacement figures.

   Inserts an icon linking to the attached file in the appropriate pace in the text.

   **How to use it**
   - Click on the Attach File icon in the Annotations section.
   - Click on the proof to where you’d like the attached file to be linked.
   - Select the file to be attached from your computer or network.
   - Select the colour and type of icon that will appear in the proof. Click OK.

6. **Add stamp Tool** – for approving a proof if no corrections are required.

   Inserts a selected stamp onto an appropriate place in the proof.

   **How to use it**
   - Click on the Add stamp icon in the Annotations section.
   - Select the stamp you want to use. (The Approved stamp is usually available directly in the menu that appears).
   - Click on the proof where you’d like the stamp to appear. (Where a proof is to be approved as it is, this would normally be on the first page).

7. **Drawing Markups Tools** – for drawing shapes, lines and freeform annotations on proofs and commenting on these marks.

   Allows shapes, lines and freeform annotations to be drawn on proofs and for comment to be made on these marks.

   **How to use it**
   - Click on one of the shapes in the Drawing Markups section.
   - Click on the proof at the relevant point and draw the selected shape with the cursor.
   - To add a comment to the drawn shape, move the cursor over the shape until an arrowhead appears.
   - Double click on the shape and type any text in the red box that appears.

For further information on how to annotate proofs, click on the Help menu to reveal a list of further options: