Potentiation of the antitumor activity of adriamycin against osteosarcoma by cannabinoid WIN-55,212-2

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Abstract. Osteosarcoma is the most frequent primary malignant bone tumor that occurs in children and adolescents. The present study aimed to identify novel therapeutic strategies for osteosarcoma, by assessing the antitumor activity of the cannabinoid WIN-55,212-2 and its combined effect with adriamycin (ADM) against the MG-63 human osteosarcoma cell line. To evaluate the antiproliferative action of these molecules, a Cell Counting kit-8 (CCK-8) assay was used. The ability of cannabinoid to inhibit the migration, invasion and angiogenic activity of MG-63 cells were assessed by scratch, Transwell® chamber and angiogenesis assays, respectively, in vitro. To examine the alterations in expression of targeted genes, quantitative polymerase chain reaction and western blot analysis were used. The administration of cannabinoid combined with ADM was demonstrated to inhibit the growth of MG-63 cells, resulting in a cell viability of 32.12±3.13%, which was significantly lower (P<0.05) compared with the cell viability following treatment with cannabinoid (70.86±7.55%) and ADM (62.87±5.98%) alone. Greater antimetastasis and antiangiogenic activities were also observed following the coadministration of the two agents compared with individual treatments and controls. In addition, the expression levels of Notch-1, matrix metalloproteinase-2 (MMP-2) and vascular endothelial growth factor (VEGF) in MG-63 cells were downregulated following the treatments with cannabinoid alone or in combination with ADM. In conclusion, the present findings demonstrated that cannabinoid WIN-55,212-2 may significantly potentiate the antiproliferative, antimetastasis and antiangiogenic effects of ADM against MG-63 cells via the downregulation of Notch-1, MMP-2 and VEGF. These findings may offer a novel strategy for the treatment of osteosarcoma.

Introduction

Osteosarcoma is a bone malignancy that predominantly affects children and adolescents, and exhibits high invasion and metastasis rates. It has been reported that the five-year survival rate of patients who suffer from this disease remains at only 20% due to a high rate of systemic spread at the early phase and the strong chemotherapy resistance of osteosarcoma (1). Although adriamycin (ADM) is an effective benchmark agent for the management of osteosarcoma, it also results in harmful side-effects including toxicity and chemoresistance that substantially affect the quality of life of patients (2-4). Therefore, novel therapeutic approaches and drugs must be sought for the treatment of osteosarcoma.

Natural products which have potential antitumor activities have become a focus of attention for study in previous years (5,6). Cannabinoids, the active components naturally derived from the marijuana plant Cannabis sativa L., have been reported as potential antitumor drugs based on their ability to limit inflammation, cell proliferation and cell survival (7). To date, several cannabinoids have been identified and characterized, including Δ(9)-tetrahydrocannabinol (THC), cannabidiol, cannabino (CBN) and anandamide, as well as synthetic cannabinoids, including WIN-55,212-2, JWH-133 and (R)-methanandamide (7). In the early 1970s, THC and CBN were shown to inhibit tumor growth in Lewis lung carcinoma (8). Subsequently, cannabinoids were found to induce apoptosis and inhibit the proliferation of various cancer cells, including those of glioma (9) and lymphoma (10), and prostate (11-13), breast (14), skin (15) and pancreatic cancer (13,16).

Previous studies have speculated about the possible mechanisms responsible for the physiological and behavioral effects of cannabinoids. There is a view that cannabinoids exert their diversified activities via the activation of G-protein-coupled receptors which are normally bound by endocannabinoids (8). Two types of receptors, CB1 and CB2, have been cloned and characterized from mammalian tissues. CB1 and CB2 are primarily expressed in the brain and immune system, respectively (17,18). Another viewpoint states that cannabinoids suppress tumor cell growth and induce apoptosis by modulating different cell signaling pathways and the expression of associated molecules, such as downregulating...
phosphoinositide 3-kinase (PI3K), protein kinases, extracellular signal-regulated kinase (ERK) signaling pathways and cell division cycle gene 2 (Cdc2), coupled with an activation of the proapoptotic function of Bad protein and small guanosine triphosphatase (9,19,20). An effect on the stress-regulated protein p8 and its downstream targets has also been identified as a mechanism of the antitumor action of THC (21).

At present, it is believed that the development of novel combinational therapies may contribute to the enhancement of the therapeutic effect on tumors. In line with this hypothesis, trials have been conducted to investigate the synergistic antitumor effect of multiple drugs. It has been reported that the combined administration of cannabinoids and temozolomide (TMA) exert a strong antitumor action in glioblastoma multiforme (22). Combinations of thymoquinone and diosgenin have also shown potent antiproliferative and apoptotic effects on squamous cell carcinoma (20). Therefore, the present study aimed to investigate the antitumor activity of cannabinoid WIN-55,212-2 and its synergistic effects with ADM against osteosarcoma cells in vitro. In addition, the present study explores the possible mechanisms of these antitumor actions, in order to set the basis for novel strategies for the management of osteosarcoma.

Materials and methods

Cell culture and reagents. The MG-63 human osteosarcoma cell line was obtained from Nanjing KeyGen Biotechnology, Co., Ltd. (Nanjing, China). The human umbilical vein endotheial cells (HUVECs) were obtained from the Institute of Biochemistry and Cell Biology, Shanghai Institutes for Biological Sciences, Chinese Academy of Sciences (Shanghai, China). The two cell lines were cultured in RPMI-1640 medium containing 10% fetal bovine serum (FBS) (Gibco-BRL) was added. Fresh medium without any drugs was used as the control. Serial photographic images of the same scraped section were captured at 0, 12, 24 and 36 h using a Leica TCS 4D microscope (Leica Camera AG, Wetzlar, Germany).

Invasion assay. The invasive capacity of MG-63 cells was measured using a Transwell® chamber (Corning, NY, USA). All reagents and the Transwell® chamber were pre-incubated at 37°C. The suspension of exponentially growing MG-63 cells (2x10⁵ cells/ml) was placed into the upper compartment in serum-free medium. Subsequently, 20 µM cannabinoid WIN-55,212-2, 20 µM ADM or ‘Cannabinoid + ADM’ (Gibco-BRL) was added. Fresh medium without any drugs was removed using cotton swabs. Invading cells were fixed with 4% paraformaldehyde (Sigma-Aldrich) for 40 min, stained with 0.1% crystal violet (Sigma-Aldrich) for 30 min and counted in six random image fields by microscopy (TCS 4D; Leica Camera AG). The invasion rates were calculated as follows:

\[
\text{Invasion rates} = \frac{N \text{ (treated)}}{N \text{ (Control)}} \times 100\%
\]

In which N (control) was the number of invading cells in the control group and N (treated) was the number of invading cells in the groups with cannabinoid and/or ADM treatment.

Angiogenesis assays in vitro. The angiogenic properties of MG-63 cell-conditioned medium were assessed using the angiogenesis assay with HUVECs in vitro. Exponentially growing MG-63 cells (1x10⁵ cells/ml) were seeded in a 24-well plate and incubated with 20 µM cannabinoid WIN-55,212-2, 20 µM ADM or ‘Cannabinoid + ADM’ for 24 h at 37°C with 5% CO₂. Conditioned medium was obtained by collecting the supernatant following centrifugation at 1,000 x g for 10 min. Exponentially growing HUVECs were cultured in the mixed medium containing equal amounts of conditioned and serum-free medium, and then seeded into 12-well plates.
precoated with Matrigel™ at a density of 5x10^5 cells/ml. Plates were incubated at 37°C with 5% CO₂ for 8 h. The tube formation of HUVECs was observed by microscopy (TCS 4D; Leica Camera AG) and counted in five random image fields. The assay was performed in triplicate.

**Total RNA extraction and reverse transcription quantitative polymerase chain reaction (RT-qPCR).** Following treatment with 20 µM cannabinoid (WIN-55,212-2), 20 µM ADM or 'Cannabinoid + ADM' and incubation for 24 h at 37°C with 5% CO₂, MG-63 cells were harvested. MG-63 cells without treatment served as the control group. The total RNA was extracted from each sample of 1x10⁶ cells using TRIzol® (Invitrogen Life Technologies, Carlsbad, CA, USA) following the manufacturer's instructions. M-MLV reverse transcriptase (Takara, Japan) using SYBR® Green Master Mix (ToyoBo, Osaka, Japan). The RT-PCR program was as follows: 95°C for 10 sec, followed by 40 cycles of 95°C for 10 sec, 56-65°C for 5 sec and 72°C for 10 sec. The GAPDH gene, which served as the reference gene for the internal standard, was amplified with forward and reverse primers. The PCR primers used to detect each gene were synthesized by SBS Genetech Co., Ltd. (Beijing, China) and the sequences and information are listed in Table I.

<table>
<thead>
<tr>
<th>Target gene</th>
<th>Accession number</th>
<th>Primer</th>
<th>Sequence</th>
<th>Annealing length (bp)</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Notch-1</td>
<td>NM_017617.3</td>
<td>F</td>
<td>5'-TCAGCGGGATCCACTGTGAG-3'</td>
<td>104</td>
<td>65</td>
</tr>
<tr>
<td>MMP-2</td>
<td>NM_004530.4</td>
<td>F</td>
<td>5'-GAGGAATGAATCTGGATCTACT-3'</td>
<td>173</td>
<td>65</td>
</tr>
<tr>
<td>VEGF</td>
<td>NM_001025370.1</td>
<td>F</td>
<td>5'-GAGGATTTGCCCCCGTCGCTCT-3'</td>
<td>138</td>
<td>58</td>
</tr>
<tr>
<td>GAPDH</td>
<td>NM_002046.3</td>
<td>F</td>
<td>5'-GCACCGTCAAGGCTGAGAAC-3'</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

MMP-2, matrix metalloproteinase-2; VEGF, vascular endothelial growth factor; F, forward; R, reverse.

**Statistical analysis.** Statistical analysis was performed with a Student's t-test using SPSS 20.0 (IBM SPSS, Armonk, NY, USA). All data are presented in the form of the mean ± standard deviation. Qualitative data were analyzed using the χ² test. Differences between the treatment and control groups were considered significant at P<0.05.

**Results**

**Cannabinoid and ADM inhibit the proliferation of MG-63 cells.** Cannabinoid and ADM were tested individually and as a combined treatment to ascertain whether these agents inhibited the proliferation of MG-63 cells. The groups, 'Cannabinoid,' 'ADM,' and 'Cannabinoid + ADM,' in which cells were incubated with 20 µM cannabinoid (WIN-55,212-2), 20 µM ADM and or the two agents for 24 h, were shown to effectively inhibit the growth of MG-63 cells. The viability rates of cells in the 'Cannabinoid,' 'ADM' and 'Cannabinoid + ADM' treatment groups were 70.86±7.55, 62.87±5.98 and 32.12±3.13%,
respectively, which were all significantly reduced (P<0.05) compared with those in ‘Control’ (100%). Notably, the viability rate of cells in the ‘Cannabinoid + ADM’ group was significantly lower (P<0.05) than those in ‘Cannabinoid’ and ‘ADM’ groups (Fig. 1).

**Cannabinoid and ADM inhibit the migration and invasion of MG‑63 cells.** MG‑63 cells were treated with 20 µM cannabinoid (WIN-55,212-2) and ADM alone or combined, and cell migration was measured by scratch assay. The results demonstrated that the individual and combined treatments of cannabinoid and ADM had time-dependent inhibition effects on the migration of cells. This inhibition was enhanced as time progressed. Compared with the control treatment, the number of cells that had migrated after 24 h to heal the wound was fewer in the cells with cannabinoid and/or ADM treatment, and the scraped sections in these treatment groups were also wider (Fig. 2). Notably, these phenomena were observed most markedly in ‘Cannabinoid + ADM’. In the cell invasion assay, as shown in Fig. 3A, the number of invading cells in the treatment groups with cannabinoid and ADM alone or combined was reduced compared with the control group, and the number of invading cells in ‘Cannabinoid + ADM’ was the lowest in all the three treatment groups. Consistently, the invasion rate of cells in ‘Cannabinoid + ADM’ was significantly lower than those in the groups with the individual treatments of either cannabinoid or ADM (Fig. 3B).

**Cannabinoid and ADM inhibit the angiogenic activity of HUVECs treated with MG‑63 cell-conditioned medium.** The
The angiogenic properties of MG-63 cell-conditioned medium were assessed using the angiogenesis assay with HUVECs in vitro. The results showed that tube formation of HUVECs was observed with the drug-free MG-63 cell-conditioned medium. However, tube formation was significantly reduced when the HUVECs were cultured with the cannabinoid and ADM alone, or the combined conditioned medium. The combined treatment reduced the angiogenesis to the greatest extent (Fig. 4).

Notch-1, MMP-2 and VEGF expression levels were downregulated by cannabinoid and ADM. The expression levels of Notch-1, MMP-2 and VEGF genes were measured by RT-qPCR (Fig. 5). The results showed that the mRNA expression levels of these genes in MG-63 cells with cannabinoid and/or ADM treatment reduced significantly (P<0.05) compared with those in the control group without any drug treatment. Furthermore, the expression levels of Notch-1, MMP-2 and VEGF in cells with the combined treatment of cannabinoid and ADM were significantly lower (P<0.05) compared with cells that received individual treatment of either cannabinoid or ADM. Western blotting further confirmed these downregulation effects (Fig. 6).

**Discussion**

Despite its potent antitumor activity, ADM, the conventional medicine against osteosarcoma, has side-effects. Therefore,
there is a requirement to search for novel therapeutic drugs and approaches aimed at improving the poor prognosis of patients with osteosarcoma. The results obtained in the present study demonstrated that WIN-55,212-2, the synthetic cannabinoid from the main active component of marijuana, reduced the growth of osteosarcoma MG-63 cells. This is consistent with reports of the suppressive effects of cannabinoids on lung, prostate, breast, skin and pancreatic cancer cells (8-16,24). These data together indicate that cannabinoids may have potential as antitumor drugs for osteosarcoma therapy. Notably, the present data also demonstrated that the combined administration of ADM and cannabinoid exerted an enhanced antiproliferation effect on MG-63 cells. Similar synergistic effects of drugs were also observed with cannabinoids and TMA against glioblastoma multiforme (22). Cannabinoids have been shown to be devoid of the strong side-effects associated with other chemotherapeutic agents (25,26) and no overt toxic effects of cannabinoids in patients have been reported in clinical trials for various applications (8,27). Thus, the synergistic effects of cannabinoid and ADM in the present study indicated a novel strategy that may possibly reduce the side-effects and also enhance the antitumor activity of ADM, while requiring a lower dosage.

Metastasis has been shown to be the main cause of mortality in patients with osteosarcoma, which must be suppressed for improved prognosis (28). The present results demonstrated that cannabinoid (WIN-55,212-2) and/or ADM could inhibit the migration and invasion of MG-63 cells. This was consistent with the defined role of ADM in the migration of osteosarcoma cells (3). Suppression of metastasis by THC was also reported in severe combined immunodeficient mice (29). The results implied that cannabinoid may enhance the antimetastatic effect of ADM for osteosarcoma, since the combined treatment with cannabinoid and ADM inhibited the migration and invasion of MG-63 cells to a significantly higher extent than the individual treatment with either of these two agents.

In terms of the mechanism of the antimetastatic activities, it was shown that the expression levels of Notch-1 and MMP-2 were significantly downregulated following the cannabinoid (WIN-55,212-2) and/or ADM treatments in the present study. Previous studies have demonstrated that the Notch signaling pathway is critical in cell proliferation and apoptosis (30,31). Among the Notch genes, Notch-1 has been reported to be involved in the migration and invasion of cancer cells (32) and to exhibit crosstalk with nuclear factor κB (NF-κB), another important regulatory pathway in the processes of tumor cell invasion and metastasis (33-37). The MMPs, a family of associated enzymes that degrade the extracellular matrix, are also considered to be important in facilitating tumor invasion (38). The level of active MMP-2 is considered to be a cancer metastasis indicator (39). A previous study also revealed that the invasion and metastasis of human breast cancer cells is inhibited by the knockdown of Notch-1, coupled with the inactivation of MMP expression (32). The present results showed the downregulation of Notch-1 and MMP-2 in MG-63 cells following treatments with cannabinoid and ADM alone or in combination, indicating that cannabinoid and/or ADM may inhibit the metastasis and invasion of osteosarcoma cells via the suppression of the Notch signaling pathway and MMPs. Similar observations were reported in human cervical cancer cells following cannabinoid treatment, in which the expression level of MMP-2 was downregulated (40).

In the present study, cannabinoid WIN-55,212-2 was also shown to suppress the angiogenic activity of MG-63 cells and to enhance the antiangiogenic effect of ADM as well. Similar suppressive effects of cannabinoid were also observed against gliomas in vitro (41) and human colon carcinoma xenografts in nude mice (42). The present results supported the view that cannabinoid exhibits highly effective antiangiogenic action and has a synergistic effect in combination with ADM. Additionally, previous studies revealed that VEGF is vital for tumor-associated microvascular invasion as an angiogenic factor (43,44) and its expression was shown to be associated with the distant metastasis of tumor cells (45,46). The present study also showed the inhibition of VEGF expression in MG-63 cells following cannabinoid and/or ADM treatment. Thus, the present results indicated that cannabinoid and/or ADM may exert their antiangiogenic and antimetastatic activities partially through the downregulation of VEGF expression. Furthermore, combination therapy 'Cannabinoid + ADM' was shown to be more effective in the downregulation of Notch-1, MMP-2 and VEGF expression levels compared with treatments of cannabinoid or ADM alone, which further supports the findings of synergistic antitumor effects of the two drugs against osteosarcoma.

In conclusion, the present study indicated that cannabinoid WIN-55,212-2 is antiproliferative, antitumorigenic and antiangiogenic against MG-63 cells in vitro, and presented evidence that cannabinoid WIN-55,212-2 may result in synergistic antitumor action in combination with ADM against osteosarcoma. The present data also indicated that the mechanism of cannabinoid and/or ADM antitumor activity may be based on the inactivation of the Notch signaling pathway and the downregulation of MMP-2 and VEGF, which may be useful for the development and exploration of potent, nontoxic and novel therapeutic strategies for osteosarcoma. However, further in-depth studies are required to investigate the precise and comprehensive molecular mechanisms of these antitumor activities, and whether this coadministration of cannabinoid and ADM could be effectively applied in practice.

References


