



HAL
open science

Dimethylcelecoxib inhibits mPGES-1 promoter activity by influencing EGR1 and NF- κ B

Klaus Deckmann, Florian Rörsch, Ramona Steri, Manfred Schubert-Zsilavecz,
Gerd Geisslinger, Sabine Grösch

► **To cite this version:**

Klaus Deckmann, Florian Rörsch, Ramona Steri, Manfred Schubert-Zsilavecz, Gerd Geisslinger, et al..
Dimethylcelecoxib inhibits mPGES-1 promoter activity by influencing EGR1 and NF- κ B. *Biochemical
Pharmacology*, 2010, 80 (9), pp.1365. 10.1016/j.bcp.2010.07.032 . hal-00623304

HAL Id: hal-00623304

<https://hal.science/hal-00623304>

Submitted on 14 Sep 2011

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Accepted Manuscript

Title: Dimethylcelecoxib inhibits mPGES-1 promoter activity by influencing EGR1 and NF- κ B

Authors: Klaus Deckmann, Florian Rorsch, Ramona Steri, Manfred Schubert-Zsilavecz, Gerd Geisslinger, Sabine Grösch



PII: S0006-2952(10)00570-8
DOI: doi:10.1016/j.bcp.2010.07.032
Reference: BCP 10665

To appear in: *BCP*

Received date: 31-5-2010
Revised date: 20-7-2010
Accepted date: 23-7-2010

Please cite this article as: Deckmann K, Rorsch F, Steri R, Schubert-Zsilavecz M, Geisslinger G, Grösch S, Dimethylcelecoxib inhibits mPGES-1 promoter activity by influencing EGR1 and NF- κ B, *Biochemical Pharmacology* (2010), doi:10.1016/j.bcp.2010.07.032

This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Dimethylcelecoxib inhibits mPGES-1 promoter activity by influencing EGR1
and NF- κ B

Klaus Deckmann*, Florian Rörsch*, Ramona Steri#, Manfred Schubert-Zsilavecz#,
Gerd Geisslinger*, Sabine Grösch*

**pharmazentrum frankfurt/ZAFES*, Institute for Clinical Pharmacology, Johann
Wolfgang Goethe-University Frankfurt, Theodor Stern Kai 7, 60590 Frankfurt/Main,

#Institute of Pharmaceutical Chemistry, LiFF/ZAFES/FIRST, Johann Wolfgang-
Goethe-University, Max-von-Laue-Str. 9, D-60438 Frankfurt/Main, Germany,

Classification: Antibiotics and Chemotherapeutics

Corresponding author:

Sabine Grösch, PhD

Institute for Clinical Pharmacology

Johann Wolfgang Goethe-University

Theodor Stern Kai 7

60590 Frankfurt/Main, Germany

Tel.: 0049/69-6301 7820, Fax.: 0049/69-6301 7636

Email: groesch@em.uni-frankfurt.de

Abstract

DMC (dimethylcelecoxib = {4-[5-(2,5-dimethylphenyl)-3(trifluoromethyl)- 1H-pyrazol-1-yl]benzenesulfonamide}) is a close derivative of celecoxib, without cyclooxygenase inhibiting properties up to very high concentrations. Nevertheless, after stimulation of various human cell lines with IL-1 β /TNF α and simultaneous treatment with DMC PGE₂ synthesis is inhibited [1]. Here we investigated the effect of DMC on mPGES-1 promoter activity, using a reporter-gene assay. Our data demonstrate that DMC inhibits mPGES-1 promoter activity by blocking nuclear EGR1 expression and repressing NF- κ B transcriptional activity. Other putative transcription factors, known to regulate mPGES-1 expression, such as SP1 or CREB are not affected by DMC. Over-expression of EGR1 completely prevents the inhibitory effect of DMC on mPGES-1 promoter activity, indicating that the repressing effect of DMC on mPGES-1 expression is mainly dependent on blocking EGR1 expression. mPGES-1, EGR1 and NF- κ B are important proteins involved in many pathological conditions such as inflammation and cancer. Therefore, DMC seems to be a promising substance to treat inflammatory and carcinogenic processes, although it does not inhibit cyclooxygenases.

1. Introduction

1 Prostaglandin E₂ (PGE₂) plays an important role in physiological and
2
3 pathophysiological processes. It is produced along the enzymatic pathway consisting
4
5 of phospholipases, cyclooxygenases and PGE synthases. So far three PGE
6
7 synthases are known: the cytosolic PGE synthase (cPGES), the microsomal PGE
8
9 synthase-1 (mPGES-1), and the microsomal PGE synthase-2 (mPGES-2). The
10
11 various PGE synthases vary in their expression levels and in their nature to
12
13 metabolize PGH₂ from different sources. It is postulated that cPGES is mainly
14
15 coupled with COX-1, whereas mPGES-1 is coupled with COX-2 [2]. mPGES-2
16
17 transforms PGH₂ from both COX enzymes [3]. Furthermore, cPGES and mPGES-2
18
19 are expressed constitutively in most tissues whereas mPGES-1 is barely basally
20
21 expressed, but is inducible by different stimuli and frequently co-expressed with
22
23 COX-2. Inhibition of PGE₂ production could be achieved by blocking the
24
25 cyclooxygenases either with unselective or selective COX-inhibitors such as
26
27 ibuprofen and diclofenac, or celecoxib and etoricoxib, respectively. Due to the fact
28
29 that long-term treatment with COX-inhibitors is associated with severe side effects
30
31 like thromboembolic events, liver and skin toxicity, alternatives are sought after to
32
33 inhibit PG production, especially PGE₂ production. DMC (dimethylcelecoxib = {4-[5-
34
35 (2,5-dimethylphenyl)-3(trifluoromethyl)- 1H-pyrazol-1 yl]benzenesulfonamide}) is a
36
37 close derivative of celecoxib, without cyclooxygenase inhibiting properties up to high
38
39 concentrations. Nevertheless, after stimulation of various human cell lines with IL-
40
41 1 β /TNF α and simultaneous treatment with DMC PGE₂ synthesis is inhibited [1]. Our
42
43 investigations revealed that DMC prevents mPGES-1 upregulation after IL-1 β /TNF α
44
45 treatment in these cells [1]. mPGES-1 is mainly responsible for the synthesis of PGE₂
46
47 after stimulation of cells with various cytokines, growth factors or stress inducible
48
49 stimuli and play a decisive role in cancer, pain and inflammatory processes. Today,
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

several groups as well as large pharmaceutical companies are developing mPGES-1 inhibitors. mPGES-1 inhibition is achieved by two methods: 1) PGE₂ production could either be prevented by inhibition of mPGES-1 activity, or 2) by suppression of mPGES-1 transcription and therefore protein expression [4-6]. DMC has been shown to inhibit both mPGES-1 activity and its expression [1]. However, the intracellular signaling pathway controlling mPGES-1 expression by DMC is at present still unknown. The human mPGES-1 gene structure and promoter sequence was first cloned by the group of Jakobsson in 2000 [7]. The mPGES-1 promoter does not contain a TATA box; instead it comprises several putative transcription factor binding sites like two GC boxes, two tandem barbie boxes and a hydrocarbon response element [7]. The GC boxes are binding sites for SP1 as well as EGR1 (early growth response factor-1) and are responsible for basal transcription of the mPGES-1 [8]. In tumor cell lines activation of EGR1 after stimulation with IL-1 β , TNF α or LPS is a key event leading to an upregulation of mPGES-1 expression [9]. In human lung carcinoma cells Catley et al. were able to show that IL-1 β promotes mPGES-1 expression via NF- κ B activation [10]. However, the NF- κ B binding site is located on the anti-sense strand of the mPGES-1 promoter; therefore, it is questionable whether NF- κ B has a direct or indirect effect on mPGES-1 transcriptional regulation or whether another NF- κ B binding site is located further upstream of the mPGES-1 promoter [11]. In addition, a potential CREB binding site is located 5' nearby the NF- κ B binding site of the mPGES-1 promoter.

In this study we investigated the effect of DMC on the human mPGES-1 promoter in HeLa cells after stimulation with IL-1 β and TNF α . Using different mPGES-1 promoter deletion constructs we characterized the impact of the various transcription factor binding sites on mPGES-1 expression after IL-1 β and TNF α stimulation and DMC co-treatment

2. Materials and methods

2.1 Cells and reagents

HeLa (human cervix carcinoma) cells were purchased from Deutsche Sammlung für Mikroorganismen und Zellkulturen (DSMZ, Braunschweig, Germany) and cultured in RPMI medium 1640. Medium contained high glucose, GlutaMAX, 10% FCS. Medium and FCS were purchased from Invitrogen (Germany) as well as 100 units/ml penicillin G and 100 mg/ml streptomycin. Cells were cultured at 37°C in an atmosphere containing 5% CO₂. DMC was synthesized by WITEGA Laboratorien Berlin-Adlershof GmbH. The identity and purity of Dimethylcelecoxib was determined using ¹H NMR and liquid chromatography tandem mass spectrometry (LC/MS–MS) as described previously [12-13] and was >99%. Recombinant human IL-1 beta (IL-1β) and recombinant human tumor necrosis factor alpha (TNFα) were purchased from PeproTech (London, UK).

2.2 Plasmid Constructs

The genomic DNA fragment of the human mPGES-1 promoter (Figure 1A) was amplified by PCR with primers containing a HindIII or XhoI restriction site (5'-tga ctc gag tct cccatc tca aat cct-3' and 5'-tga aag ctt ctc tgg cca gcg cag ctc aa-3') using genomic DNA of HeLa cells as template and HotStartTaq Plus DNA Polymerase (Qiagen). PCR conditions: 10min 95°C, 3min 95°C, 1min 63°C, 2min 72°C, repeated 30 times, ending with a final 72°C step for 10min. The resulting mPGES-1 promoter PCR product was digested with XhoI and HindIII and cloned into the pGL3-basic vector (Promega) (Figure 1B; construct A). Deletion constructs of this "full length" mPGES-1 promoter were generated by digestion of construct A with SacI and relegation (Figure 1B; construct B) or by digestion of construct A with SacI and

1 HindIII and subcloning the 450bp fragment into the GL3-basic vector (Figure 1B;
2 construct C).
3

4 A 3xkB luc reporter gene (three copies of a NF- κ B motif immediately upstream of a β
5 globin TATA box) was used as a NF- κ B control vector (kindly provided by Prof. G.
6 Fritz, Mainz, Germany) (Figure 6A). EGR1 overexpression was achieved by
7 transfection of the pCMV-Sport6 EGR1 vector (1 μ g) purchased from imaGenes
8 (Berlin, Germany).
9
10
11
12
13
14
15
16
17
18

19 2.3 Transfection and Luciferase Assay

20 Transient transfection was performed with TransPass HeLa transfection reagent
21 (New England Biolabs) according to the manufacturer's protocol for adherent cells.
22 HeLa cells (1×10^5) were seeded on Greiner 6 well plates with 1ml of culture medium
23 1 day before transfection. The cells were transfected with 1.5ng of the distinct firefly
24 luciferase reporter vectors and 1ng of the Renilla luciferase control reporter vector
25 (pRL-TK, Promega) using 7.5 μ l TransPass HeLa transfection reagent. 1 day after
26 transfection, the cells were stimulated for 24 h with or without TNF α (5ng/ml) + IL-1 β
27 (1ng/ml) and simultaneously treated with increasing concentrations of DMC (0.1–
28 30 μ M) or 0.1% DMSO (dimethyl sulfoxide) (DMC was solved in DMSO). The
29 Luciferase Assay was performed with the Dual Luciferase Assay kit (Promega) and a
30 luminometer (AutoLumat LB953, EG&G Berthold, Bad. Wildbad, Germany) according
31 to the manufacturer's instructions. The activity of firefly luciferase was normalized to
32 the RLU of Renilla luciferase. Data represent the mean \pm S.E.M of at least three
33 independent experiments.
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57

58 2.4. Western blot assay

59
60
61
62
63
64
65

1 HeLa cells were seeded at a density of 1.8×10^6 cells per dish in medium containing
2 10% FCS and incubated for 48 h at 37°C. Cells were then stimulated with or without
3
4 TNF α (5ng/ml) + IL-1 β (1ng/ml) and simultaneously treated with increasing
5
6 concentrations of DMC (10–30 μ M) for 1 h. Nuclear extracts for western blot were
7
8 prepared in the following manner: Cells were gently scrapped and washed in ice-cold
9
10 phosphate-buffered saline. Cells were aspirated in NP-40 lysis buffer (10mM Tris pH
11
12 7.4, 10mM NaCl, 3mM MgCl₂, 1mM EDTA, 0.1% NP-40, and Roche complete
13
14 (Roche Mannheim)) and centrifuge for 10min at 4°C. Pellets were washed with TKM
15
16 (TKM=Tris-potassium-magnesium) buffer (50mM Tris pH 7.4, 250mM sucrose, 25
17
18 mM KCl, 5mM MgCl₂, 1mM EDTA and Roche complete), briefly centrifuged and
19
20 resuspended by sonification in TKM buffer. Immunoblotting was performed as
21
22 described previously [14]. Briefly, the protein content of lysates was quantified using
23
24 the Bradford method (Biorad, Germany) and aliquots of 50 μ g protein were separated
25
26 onto a 10–15% SDS-polyacrylamide gel and transferred to nitrocellulose membranes
27
28 (Hybond-C, Amersham). Blocked membranes were incubated with the respective
29
30 primary antibody directed against EGR1 (rabbit polyclonal, EGR1 (H-250); Santa
31
32 Cruz), SP1 (rabbit polyclonal, SP1 (PEP 2); Santa Cruz) CREB (rabbit monoclonal,
33
34 CREB (48H2); Cell Signaling) NF- κ B (rabbit polyclonal, NF- κ B (p65); Cell Signaling).
35
36 Anti- β -Actin antibody (mouse monoclonal; Sigma) was used as loading control. The
37
38 blots were incubated with IRDye 680 conjugated goat anti-rabbit IgG(H+L) or IRDye
39
40 800CW conjugated goat anti-mouse IgG(H+L) secondary antibodies purchased from
41
42 LI-COR (Bad Homburg, Germany). Membranes were analyzed on the Odyssey
43
44 infrared scanner from LI-COR (Bad Homburg, Germany).
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

61 2.5 Nuclear Extract Preparation and Electrophoretic Mobility Shift Assay (EMSA)

62
63
64
65

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

For EMSA HeLa cells were seeded and treated like described above for western blot assay. Nuclear extracts for EMSA were prepared as following: Cells were gently scrapped and washed in ice-cold phosphate-buffered saline. Then the cells were allowed to swell in ice-cold hypotonic buffer containing 10mM HEPES-KOH, pH 7.9, 10mM KCl, 1.5mM MgCl₂, 0.5mM DTT, 1mM PMSF, 1mM Na₃VO₄ and Roche complete for 15 min on ice afterwards NP-40 to a final concentration of 0.5% were added. The nuclei were recovered by centrifugation (2500rpm, 5min, 4°C). The pellets were resuspended in high-salt buffer containing 20mM HEPES, pH 7.9, 420mM NaCl, 1.2mM MgCl₂, 0.5mM DTT, 0.2mM EDTA, 25% glycerol, 0.5mM PMSF, 1mM Na₃VO₄ and Roche complete, followed by incubation on ice for 20 min. The nuclear extracts were recovered by centrifugation and protein concentration was determined by the method of Bradford (Bio-Rad). The oligonucleotides were synthetic double-stranded oligonucleotides corresponding to the EGR1 binding motifs in the human mPGES-1 promoter (5`-gtg ggg cgg ggc gtg ggc ggt gca-3`), and EGR1 consensus motif (5`-ccc ggc gcg ggg gcg att tcg agt ca-3`) both were 5`-labeled with IRD700. For competition assays the identical unlabeled oligonucleotides were used. The 5x binding buffer consisted of 60mM HEPES, pH 7.9, 20mM Tris-HCl, pH 7.9, 300mM KCl, 3mM DTT, 3mM EDTA, 25mM MgCl₂ and 60% glycerol. Binding reactions were conducted with 5µg of nuclear extract, 1µg of poly-(dl-dC) and 250 fmol IRD700 end labeled oligonucleotide probe at 22°C for 30 min in a final volume of 20µl. For supershift assays, an antibody against EGR1 (3µg/reaction) was incubated with the reaction mixture for 30 min at 22°C before the addition of IRD700 labeled oligonucleotide. For competition assays, 100-fold molar excess of mPGES-1 or consensus oligonucleotide was used. Binding complexes were resolved on non-denaturing 4% polyacrylamide gel electrophoresis in a tris borate buffer system, after which the gel was analyzed on an infrared Odyssey scanner.

2.6. Statistics

Data are presented as mean +/- standard error of the mean (S.E.M.). The GraphPad Prism 5 computer software was used for statistical analyses. Statistics were analyzed using univariate analysis of variance (ANOVA) followed by t-tests. p values of < 0.05 were considered statistically significant.

3. Results

3.1. Effect of DMC on the mPGES-1 promoter

Previous data demonstrated that DMC inhibits mPGES-1 expression after stimulation of HeLa cells with IL-1 β and TNF α on mRNA as well as on protein level [1]. Here we examined if this inhibition belongs to a repression of the mPGES-1 promoter activity by DMC. Therefore, HeLa cells were transiently transfected with the human mPGES-1 promoter-luciferase construct (Figure 1B; construct A), stimulated with IL-1 β /TNF α and co-treated with increasing concentrations of DMC or vehicle. Treatment of HeLa cells with IL-1 β /TNF α increased luciferase activity of the transfected mPGES-1 promoter-luciferase construct about threefold. Simultaneous treatment with increasing concentrations of DMC led to a dose-dependent, significant down-regulation of luciferase activity of about 40% (Figure 2 A).

To examine which of the transcription factor binding sites of the mPGES-1 promoter are affected by DMC, leading to the depression of the mPGES-1 promoter activity, we cloned two mPGES-1 promoter deletion constructs, one missing the NF- κ B and CREB binding sites (Figure 1B; construct B) and another missing the EGR1 and SP1 binding sites (Figure 1B; construct C). Figure 2B shows that both deletion constructs are less inducible by IL- β /TNF α stimulation than the full-length promoter-luciferase construct. Nevertheless, the activity of both mPGES-1 promoter deletion constructs

1
2 could be inhibited by DMC treatment. Interestingly, only the activity of the promoter
3 construct containing the SP1/EGR1 binding sites was significantly inhibited by DMC.
4
5
6

7 3.2. Effect of DMC on EGR1 and SP1

8
9 Next we examined by western blot analysis the effects of DMC on nuclear expression
10 of EGR1 and SP1 protein in HeLa cells after IL-1 β /TNF α treatment (Figure 3).
11 Nuclear expression of EGR1 was enhanced about twofold after IL-1 β /TNF α treatment
12 and was significantly reduced by co-treatment with increasing concentrations of DMC
13 (Figure 3A). Nuclear expression of SP1 was not affected, neither by treatment of
14 HeLa cells with IL-1 β /TNF α nor by co-treatment with DMC (Figure 3B). To verify if
15 changes in nuclear expression of EGR1 have also an effect on its DNA-binding
16 activity, we examined the influence of IL-1 β /TNF α treatment and DMC co-treatment
17 on the binding capability of EGR1 to the EGR1 binding site of the mPGES-1
18 promoter. Therefore, we performed electro mobility shift assays (EMSA) with an
19 oligonucleotide containing the EGR1/SP-1 binding site of the mPGES-1 promoter
20 (mPGES-1 oligo) as well as an oligonucleotide comprising the EGR1 consensus
21 sequence (consensus oligo). Figure 4A demonstrates a typical pattern of the
22 mPGES-1 oligo. With supershift analysis, using an anti-EGR1 antibody, as well as by
23 using the consensus oligo containing the EGR1 binding site, we clearly identified the
24 signal for EGR1-DNA complex. The upper band was identified as SP1-DNA complex
25 whereas other bands are non-specific.
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52

53 After identification of the EGR1-DNA complex we examined the effect of DMC on the
54 EGR1 DNA binding characteristics (Figure 4B). IL-1 β and TNF α treatment lead to an
55 upregulation of EGR1 binding capability, which was diminished by simultaneous
56 treatment with DMC. Competition experiments, using 100-fold molar excess of
57
58
59
60
61
62
63
64
65

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

unlabeled mPGES-1 oligo or unlabeled consensus oligo, confirmed the specific EGR1-DNA complex. Taken together, we demonstrated that EGR1 expression is diminished by treatment of HeLa cells with DMC which subsequently leads to a reduced DNA binding capability of EGR1 at the mPGES-1 promoter.

3.3. Effect of DMC on CREB and NF- κ B

Next we investigated if also other transcription factors with possible binding sites at the mPGES-1 promoter are influenced by DMC. Therefore, we examined the influence of DMC on the nuclear expression levels of CREB and NF- κ B by western blot analysis. Nuclear expression of phospho-CREB or CREB protein were neither affected by treatment of HeLa cells with IL-1 β and TNF α nor after simultaneous treatment with DMC (Figure 5A). Only nuclear expression of NF- κ B increased slightly after IL-1 β and TNF α treatment but enhanced further after treatment with increasing concentrations of DMC (Figure 5B). This result was rather unexpected, because our Luciferase Assay, using the mPGES-1 deletion construct C (contains only the NF- κ B and CREB binding site), demonstrates that the luciferase activity slightly decreases after DMC treatment (Figure 2). So we investigated the transcriptional activity of NF- κ B using a luciferase construct which contains three NF- κ B binding sites directly cloned behind a TATA box [15] (Figure 6A). We transfected HeLa cells with the NF- κ B-Luc construct and treated them with IL-1 β /TNF α and simultaneously with increasing concentrations of DMC. Figure 6B shows that the luciferase activity increased after IL-1 β /TNF α treatment but co-treatment with DMC diminished the luciferase activity (Figure 6B). These data let us conclude that in spite of the fact that the nuclear expression of NF- κ B increased after DMC treatment, its transcriptional activity decreased.

3.4. Impact of EGR1 overexpression on the mPGES-1 promoter activity

Until now our data demonstrate that out of the four potential transcription factors regulating the human mPGES-1 promoter, only the expression and transcriptional activity of EGR1 and NF- κ B are affected by DMC. To make sure that the expression level of EGR1 has a direct impact on the mPGES-1 promoter activity after DMC treatment, we transfected an EGR1 expression plasmid isochronous with construct A, B or C in HeLa cells, treated them with or without IL-1 β /TNF α and simultaneously with increasing concentrations of DMC. To ensure that EGR1 is successfully overexpressed we checked EGR1 expression by western blot analysis (Figure 7A). Transfection of HeLa cells with the pCMV-sport6-EGR1 expression vector led to an increase of nuclear EGR1 protein. As shown in Figure 7B the basal activity of the co-transfected mPGES-1 promoter-luciferase construct A was slightly augmented by EGR1 overexpression but its activity could be further increased by treating cells with IL-1 β /TNF α . Isochronous treatment with DMC had no effect on the mPGES-1 promoter activity. Also co-transfection of the EGR1 expression vector with construct B prevented the inhibitory effect of DMC on the luciferase activity, whereas EGR1 had no effect on the mPGES-1 promoter construct C that contains only the NF- κ B and CREB binding site (Figure 7C and D).

Taken together we were able to show that DMC influences the mPGES-1 expression transcriptionally. Our data indicate that treatment of HeLa cells with DMC leads on the one hand to a decrease of nuclear EGR1 expression that is affiliated with a decrease in its DNA-binding capability. On the other hand, DMC increases nuclear NF- κ B expression but this was accompanied with a reduced transcriptional activity of NF- κ B. The data obtained with the mPGES-1 promoter deletion constructs indicate

1 both mechanisms contribute to a reduced mPGES-1 promoter activity after DMC
2 treatment.
3
4
5
6

7 4. Discussion

8
9 Dimethylcelecoxib was first published by Song et al., who investigated the anti-tumor
10 activity of celecoxib and various celecoxib derivatives with the aim to dissociate
11 between the apoptosis-inducing activity from the COX-2-inhibitory activity of
12 celecoxib [16]. The first evidence showing that DMC is not a COX-2 inhibitor was
13 published by Schönthal [17]. However, we were able to demonstrate that DMC
14 nevertheless inhibits PG production [1]. We ascertained that DMC inhibits on the
15 one hand mPGES-1 activity and, on the other, prevents mPGES-1 expression after
16 stimulation of cells with IL-1 β /TNF α [1]. Here we investigated the molecular
17 mechanism contributing to the suppressive effect of DMC on mPGES-1 expression.
18
19 In general, protein expression was inhibited by transcriptional, post-transcriptional or
20 post-translational mechanisms. Because we demonstrated that DMC inhibits
21 mPGES-1 protein expression as well as mPGES-1 mRNA levels [1] we decided to
22 look for transcriptional mechanisms that may be influenced by DMC. Nevertheless,
23 thus far we cannot exclude that also other mechanisms such as reduced mRNA
24 stabilization or enhanced protein degradation play a role in the suppressive effect of
25 DMC on mPGES-1 expression.
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47

48 Here we demonstrated that DMC inhibits mPGES-1 transcription by blocking nuclear
49 EGR1 expression and repressing NF- κ B transcriptional activity. Other putative
50 transcription factors known to regulate mPGES-1 expression, like SP1 or CREB, are
51 not affected by DMC. Furthermore, overexpression of EGR1 completely prevented
52 the inhibitory effect of DMC on mPGES-1 promoter activity, indicating that the
53
54
55
56
57
58
59
60
61
62
63
64
65

1 repressing effect of DMC on mPGES-1 expression is mainly dependent on its effect
2 on EGR1 expression.
3

4 EGR1 has been described as a strong regulator of mPGES-1 transcription after
5 stimulation of different cells with IL-1 β or TNF α [18-20]. Inhibition of EGR1
6 expression by DMC could be due to several mechanisms. It is known that EGR1
7 expression is regulated by EGR1 itself, NF- κ B, serum response elements and AP-1
8 [21-22]. Autoregulation of EGR1 is dependent on phosphorylation and acetylation of
9 histone H3 [22]. Interestingly, also the transcriptional activity of EGR1 on the human
10 mPGES-1 promoter is dependent on acetylation mechanisms mediated by HDAC4
11 (histone deacetylase 4) which regulates among others the acetylation status of
12 histone H3 [20]. It is still not known if DMC influences HDAC activities; this will be a
13 purpose of future research. The NF- κ B element in the EGR1 promoter may be also
14 responsible for the repressive effect of DMC on EGR1 expression because deletion
15 of this element enhances EGR1 promoter activity in some fibroblast cell lines
16 indicating that NF- κ B has a repressive effect on EGR1 transcription [21]. As our
17 reporter gene assays showed that also construct C, which contains only the CREB
18 and NF- κ B bindings site of the mPGES-1 promoter, is still inducible by IL-1 β and
19 TNF α and luciferase activity reduces after DMC treatment, we assume that DMC
20 influences NF- κ B signaling. Previously it has been shown that DMC influences NF- κ B
21 signaling by inhibition of IKK activity [23], but this mechanism does not seem to play
22 a role in our cell system, because our western blot experiments demonstrate that
23 nuclear expression of NF- κ B enhanced after DMC treatment and activation of IKK is
24 one prerequisite for this effect. Therefore, we assume that NF- κ B is activated by
25 DMC but has a repressive effect on the mPGES-1 promoter after DMC treatment.
26 This effect is possibly also mainly dependent on EGR1, because treatment of HeLa
27 cells with inhibitors of IKK (BMS-345541 and IKK Inhibitor VII) decreases the
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

Luciferase activity of the mPGES-1 promoter construct A after IL-1 β and TNF α treatment, that could be influenced by co-transfection of the EGR-1 expression vector (unpublished data). The transcriptional activity of NF- κ B can be regulated by various stimuli and binding of NF- κ B to the promoter region can be influenced by different proteins leading to transcriptional activation or repression (due to the enormous flood of NF- κ B publications we refer here only to a recently published review which summarizes the regulation mechanisms of NF- κ B transcriptional activity [24]). The influence of NF- κ B on mPGES-1 and EGR1 after DMC treatment is, as a result of its complexity, the subject of another paper (Deckmann et al. in preparation). From the literature there is also a hint that activation of peroxisome proliferator-activated receptor γ (PPAR γ) inhibits IL-1 β -induced mPGES-1 expression [25]. Therefore, we checked all PPAR subtypes for their transactivation activity in a ligand-dependent luciferase reporter-gen assay (as described previously [26]) after DMC treatment. Only PPAR γ activity increases slightly but significantly after DMC treatment (supplement 1). The inhibitory effect of PPAR agonists on mPGES-1 expression has been thought to be mediated by antagonizing transcriptions factors such as NF- κ B [25]. Additionally, PPAR γ activation suppresses induction of EGR1 expression [27], so that both interference of DMC activated PPAR γ with EGR1 and NF- κ B could contribute to the suppressive effect of DMC on mPGES-1 transcription. Taken together we ascertained that DMC inhibits mPGES-1 transcription in HeLa cells by downregulation of EGR1 a key regulator of mPGES-1 expression. Furthermore, the transactivation activity of NF- κ B seems to be affected by DMC as well. Both could be influenced by PPAR γ that is activated by DMC. mPGES-1, EGR1 and NF- κ B are important proteins involved in many pathological conditions such as

1 inflammation and cancer. Therefore, DMC seems to be a promising substance to
2 treat inflammatory and carcinogenic processes.
3
4
5

6 7 Acknowledgment

8
9 The work was supported by European Graduate School "Roles of Eicosanoids in
10 Biology and Medicine", (DFG GRK 757/1) and DFG Ge 695.
11
12
13
14
15
16
17
18
19
20

21 22 Abbreviations

23
24 ANOVA, analyzed using univariate analysis of variance; CREB, cAMP-responsive
25 element-binding protein 1; cPGES cytosolic prostaglandin E synthase; COX-1/2,
26 cyclooxygenase-1/2; DMC, dimethylcelecoxib; DMSO, dimethyl sulfoxide; DTT,
27 dithiotreitol; EDTA, ethylenediaminetetraacetate; EGR1, early growth response 1;
28
29 EMSA, Electrophoretic Mobility Shift Assay; FCS fetal calf serum; IL-1 β , interleukin-1
30 beta; LC/MS-MS, liquid chromatography tandem mass spectrometry; LPS,
31 Lipopolysaccharide; mPGES-1, microsomal prostaglandin E synthase-1; mPGES-2,
32 microsomal prostaglandin E synthase-2; NF- κ B, nuclear factor NF-kappa-B p65;
33
34 NSAID, non-steroidal anti-inflammatory drug; NP-40, nonidet 40; PBS, phosphate
35 buffered saline; PGE, prostaglandin E; PGH prostaglandin H; PGES, prostaglandin E
36 synthase; PMSF, phenyl-methylsulfonylfluride; SDS-PAGE, sodiumdodecylsulfate-
37 polyacrylamide gel electrophoresis; S.E.M, standard error of the mean; SP1,
38 specificity protein 1; TKM, Tris-potassium-magnesium; TNF α , tumor necrosis factor
39 alpha;
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

61 62 5. References

- 1 [1] Wobst I, Schiffmann S, Birod K, Maier TJ, Schmidt R, Angioni C, et al.
2 Dimethylcelecoxib inhibits prostaglandin E2 production. *Biochem Pharmacol*
3 2008;76:62-9.
- 4 [2] Murakami M, Naraba H, Tanioka T, Semmyo N, Nakatani Y, Kojima F, et al.
5 Regulation of prostaglandin E2 biosynthesis by inducible membrane-associated
6 prostaglandin E2 synthase that acts in concert with cyclooxygenase-2. *J Biol Chem*
7 2000;275:32783-92.
- 8 [3] Murakami M, Nakashima K, Kamei D, Masuda S, Ishikawa Y, Ishii T, et al. Cellular
9 prostaglandin E2 production by membrane-bound prostaglandin E synthase-2 via
10 both cyclooxygenases-1 and -2. *J Biol Chem* 2003;278:37937-47.
- 11 [4] Koeberle A, Rossi A, Zettl H, Pergola C, Dehm F, Bauer J, et al. The molecular
12 pharmacology and in vivo activity of 2-(4-chloro-6-(2,3-
13 dimethylphenylamino)pyrimidin-2-ylthio)octanoic acid (YS121), a dual inhibitor of
14 microsomal prostaglandin E2 synthase-1 and 5-lipoxygenase. *J Pharmacol Exp Ther*
15 2010;332:840-8.
- 16 [5] Rorsch F, Wobst I, Zettl H, Schubert-Zsilavec M, Grosch S, Geisslinger G, et al.
17 Nonacidic inhibitors of human microsomal prostaglandin synthase 1 (mPGES 1)
18 identified by a multistep virtual screening protocol. *J Med Chem* 2010;53:911-5.
- 19 [6] Guerrero MD, Aquino M, Bruno I, Riccio R, Terencio MC, Paya M. Anti-inflammatory
20 and analgesic activity of a novel inhibitor of microsomal prostaglandin E synthase-1
21 expression. *Eur J Pharmacol* 2009;620:112-9.
- 22 [7] Forsberg L, Leeb L, Thoren S, Morgenstern R, Jakobsson P. Human glutathione
23 dependent prostaglandin E synthase: gene structure and regulation. *FEBS Lett*
24 2000;471:78-82.
- 25 [8] Ekstrom L, Lyrenas L, Jakobsson PJ, Morgenstern R, Kelner MJ. Basal expression of
26 the human MAPEG members microsomal glutathione transferase 1 and
27 prostaglandin E synthase genes is mediated by Sp1 and Sp3. *Biochim Biophys Acta*
28 2003;1627:79-84.
- 29 [9] Naraba H, Yokoyama C, Tago N, Murakami M, Kudo I, Fueki M, et al. Transcriptional
30 regulation of the membrane-associated prostaglandin E2 synthase gene. Essential
31 role of the transcription factor Egr-1. *J Biol Chem* 2002;277:28601-8.
- 32 [10] Catley MC, Chivers JE, Cambridge LM, Holden N, Slater DM, Staples KJ, et al. IL-
33 1beta-dependent activation of NF-kappaB mediates PGE2 release via the expression
34 of cyclooxygenase-2 and microsomal prostaglandin E synthase. *FEBS Lett*
35 2003;547:75-9.
- 36 [11] Fahmi H. mPGES-1 as a novel target for arthritis. *Curr Opin Rheumatol* 2004;16:623-
37 7.
- 38 [12] Brautigam L, Nefflen JU, Geisslinger G. Determination of etoricoxib in human plasma
39 by liquid chromatography-tandem mass spectrometry with electrospray ionisation. *J*
40 *Chromatogr B Analyt Technol Biomed Life Sci* 2003;788:309-15.
- 41 [13] Franzen R, Pautz A, Brautigam L, Geisslinger G, Pfeilschifter J, Huwiler A.
42 Interleukin-1beta induces chronic activation and de novo synthesis of neutral
43 ceramidase in renal mesangial cells. *J Biol Chem* 2001;276:35382-9.
- 44 [14] Maier TJ, Schilling K, Schmidt R, Geisslinger G, Grosch S. Cyclooxygenase-2 (COX-
45 2)-dependent and -independent anticarcinogenic effects of celecoxib in human colon
46 carcinoma cells. *Biochem Pharmacol* 2004;67:1469-78.
- 47 [15] Nubel T, Dippold W, Kleinert H, Kaina B, Fritz G. Lovastatin inhibits Rho-regulated
48 expression of E-selectin by TNFalpha and attenuates tumor cell adhesion. *FASEB J*
49 2004;18:140-2.
- 50 [16] Song X, Lin HP, Johnson AJ, Tseng PH, Yang YT, Kulp SK, et al. Cyclooxygenase-2,
51 player or spectator in cyclooxygenase-2 inhibitor-induced apoptosis in prostate
52 cancer cells. *J Natl Cancer Inst* 2002;94:585-91.
- 53 [17] Schonthal AH. Antitumor properties of dimethyl-celecoxib, a derivative of celecoxib
54 that does not inhibit cyclooxygenase-2: implications for glioma therapy. *Neurosurg*
55 *Focus* 2006;20:E21.

- 1 [18] Monneret G, Boumiza R, Gravel S, Cossette C, Bienvenu J, Rokach J, et al. Effects
2 of prostaglandin D(2) and 5-lipoxygenase products on the expression of CD203c and
3 CD11b by basophils. *J Pharmacol Exp Ther* 2005;312:627-34.
- 4 [19] Subbaramaiah K, Yoshimatsu K, Scherl E, Das KM, Glazier KD, Golijanin D, et al.
5 Microsomal prostaglandin E synthase-1 is overexpressed in inflammatory bowel
6 disease. Evidence for involvement of the transcription factor Egr-1. *J Biol Chem*
7 2004;279:12647-58.
- 8 [20] Chabane N, Li X, Fahmi H. HDAC4 contributes to IL-1-induced mPGES-1 expression
9 in human synovial fibroblasts through up-regulation of Egr-1 transcriptional activity. *J*
10 *Cell Biochem* 2009;106:453-63.
- 11 [21] Aicher WK, Sakamoto KM, Hack A, Eibel H. Analysis of functional elements in the
12 human Egr-1 gene promoter. *Rheumatol Int* 1999;18:207-14.
- 13 [22] Wang B, Chen J, Santiago FS, Janes M, Kavurma MM, Chong BH, et al.
14 Phosphorylation and acetylation of histone H3 and autoregulation by early growth
15 response 1 mediate interleukin 1beta induction of early growth response 1
16 transcription. *Arterioscler Thromb Vasc Biol* 2010;30:536-45.
- 17 [23] Kardosh A, Soriano N, Liu YT, Uddin J, Petasis NA, Hofman FM, et al. Multitarget
18 inhibition of drug-resistant multiple myeloma cell lines by dimethyl-celecoxib (DMC), a
19 non-COX-2 inhibitory analog of celecoxib. *Blood* 2005;106:4330-8.
- 20 [24] Wan F, Lenardo MJ. The nuclear signaling of NF-kappaB: current knowledge, new
21 insights, and future perspectives. *Cell Res* 2010;20:24-33.
- 22 [25] Mendez M, LaPointe MC. PPARgamma inhibition of cyclooxygenase-2, PGE2
23 synthase, and inducible nitric oxide synthase in cardiac myocytes. *Hypertension*
24 2003;42:844-50.
- 25 [26] Ulrich S, Loitsch SM, Rau O, von Knethen A, Brune B, Schubert-Zsilavec M, et al.
26 Peroxisome proliferator-activated receptor gamma as a molecular target of
27 resveratrol-induced modulation of polyamine metabolism. *Cancer Res* 2006;66:7348-
28 54.
- 29 [27] Okada M, Yan SF, Pinsky DJ. Peroxisome proliferator-activated receptor-gamma
30 (PPAR-gamma) activation suppresses ischemic induction of Egr-1 and its
31 inflammatory gene targets. *FASEB J* 2002;16:1861-8.
- 32
33
34
35
36
37

38 6. Legend

39 **Figure 1. Schematic diagram of the mPGES-1 promoter**

40
41
42 (A) mPGES-1 promoter (B) mPGES-1 luciferase reporter gene constructs: "full
43 length" construct A (-631 to -1bp); construct B (-177 to -1bp), construct C (-631 to -
44 177bp) (C) structural formula of dimethylcelecoxib

45 46 47 48 49 **Figure 2. Luciferase Assay of mPGES-1 promoter reporter gene constructs in** 50 51 52 **HeLa cells after IL-1 β /TNF α stimulation and DMC treatment.**

53
54 (A) HeLa cells were transiently transfected with the "full length" mPGES-1-luc -
55 construct (construct A), stimulated with IL-1 β /TNF α and simultaneously treated with
56 increasing concentrations (0.1-30 μ M) of DMC. (B) HeLa cells were transiently
57
58
59
60
61
62
63
64
65

1 transfected with construct A, B or C, stimulated with IL-1 β /TNF α and simultaneously
2 treated with 10 μ M of DMC. Luciferase activity was measured by the use of the Dual
3 Luciferase Assay kit. Renilla luciferase was used as transfection control. All
4 experiments were carried out at least three times; data are the mean \pm S.E.M. *p <
5 0.05; **p < 0.01; ***p < 0.001
6
7
8
9
10

11 **Figure 3. Western blot analysis of EGR-1 and SP1 after DMC treatment**

12 Western blot analysis of (A) EGR1 or (B) SP1 in IL-1 β /TNF α stimulated HeLa cells
13 incubated with increasing amounts of DMC. Nuclear extract of HeLa cells were
14 prepared and 50 μ g protein were separated onto a 12% SDS polyacrylamide gel and
15 transferred to nitrocellulose membranes. EGR1 and SP1 were detected using
16 specific rabbit polyclonal antibodies. The expression of β -Actin was used as loading
17 control. A representative experiment is shown. All experiments were carried out at
18 least three times; data are the mean \pm S.E.M. *p < 0.05; **p < 0.01; ***p < 0.001.
19
20
21
22
23
24
25
26
27
28
29
30

31 **Figure 4. Electrophoretic mobility shift assay (EMSA)**

32 (A) EMSA pattern of an IR700-labeled oligonucleotide containing the two EGR1
33 binding sites of the mPGES-1 promoter after incubation with nuclear protein extract
34 from HeLa cells treated with IL-1 β /TNF α . To specify the EGR1-DNA complex and
35 SP1-DNA complex an EGR1 consensus oligonucleotide was used and anti-EGR1
36 antibody for supershift analysis (EGR1 SS). (B) EMSA pattern of the IR700-labeled
37 oligonucleotide containing the two EGR1 binding sites of the mPGES-1 promoter
38 after incubation with nuclear protein extract from HeLa cells treated with IL-1 β /TNF α
39 and increasing amounts of DMC. Specificity of binding was confirmed using 100-fold
40 molar excess of unlabeled oligonucleotides containing consensus or mPGES-1
41 EGR1 binding sites. EGR1-DNA complex (EGR1), non-specific protein DNA complex
42 (NS). A representative EMSA of at least three independent experiments is shown.
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

61 **Figure 5. Western blot analysis of CREB and NF- κ B after DMC treatment**

1 (A) Western blot analysis of phospho-CREB and CREB in stimulated HeLa cells
2 incubated with increasing amounts of DMC. (B) Western blot analysis of NF- κ B in
3 stimulated HeLa cells incubated with increasing amounts of DMC. Nuclear
4 extractions of HeLa cells were prepared and 50 μ g protein were separated onto a
5 12% SDS polyacrylamide gel and transferred to nitrocellulose membranes. phospho-
6 CREB, CREB and NF- κ B were detected using rabbit polyclonal antibodies. The
7 expression of β -Actin was used as loading control. A representative experiment out
8 of three is shown. Data are the mean \pm S.E.M. * p < 0.05; ** p < 0.01; *** p < 0.001.
9
10
11
12
13
14
15
16
17
18

19 **Figure 6. NF- κ B transcriptional activity after DMC treatment.**

20
21 (A) Schematic diagram of the luciferase construct including three NF- κ B binding sites
22 in front of a TATA box. (NF- κ B-Luc) (B) HeLa cells were transiently transfected with
23 the NF- κ B-luciferase construct, stimulated with IL-1 β /TNF α , and simultaneously
24 treated with increasing concentrations (10 μ M; 20 μ M; 30 μ M) of DMC. Renilla
25 luciferase was used as transfection control. All experiments were carried out at least
26 three times; data are the mean \pm S.E.M. * p < 0.05; ** p < 0.01; *** p < 0.001.
27
28
29
30
31
32
33
34
35

36 **Figure 7. Impact of EGR1 overexpression on the mPGES-1 promoter activity**

37 (A) HeLa cells were transiently transfected with a pCMV-sport6 plasmid containing
38 the EGR1-cDNA. Nuclear extracts of HeLa cells were prepared and 50 μ g protein
39 were separated onto a 12% SDS polyacrylamide gel and transferred to nitrocellulose
40 membranes. EGR1 were detected using a specific rabbit polyclonal antibody. The
41 expression of β -Actin was used as loading control. A representative experiment out
42 of three is shown. (B-D) HeLa cells, transiently transfected with the full length
43 mPGES-1 luciferase construct (construct A), or the two deletions constructs B or C
44 and co-transfected with or without the pCMV-sport6 EGR1 vector, were stimulated
45 with IL-1 β /TNF α and simultaneously treated with increasing concentrations (10 μ M;
46 20 μ M; 30 μ M) of DMC. Luciferase activity was measured by the use of the dual
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

1 Luciferase Assay kit. Renilla luciferase was used as transfection control. In all
2 experiments the luciferase activity of IL1 β /TNF α stimulated cells were set to 100%.
3
4 All experiments were carried out at least three times; data are the mean \pm S.E.M. *p
5
6
7 < 0.05; **p < 0.01; ***p < 0.001.
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

Graphical Abstract

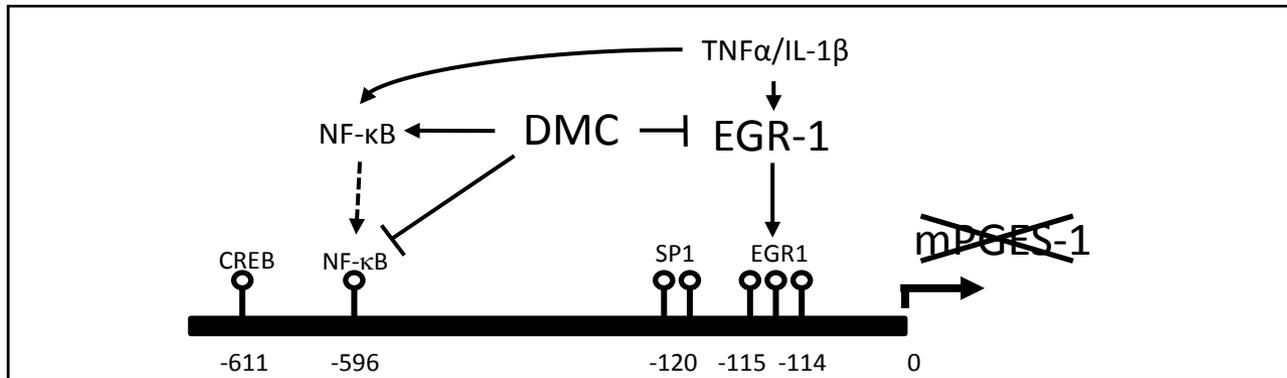


Figure 1

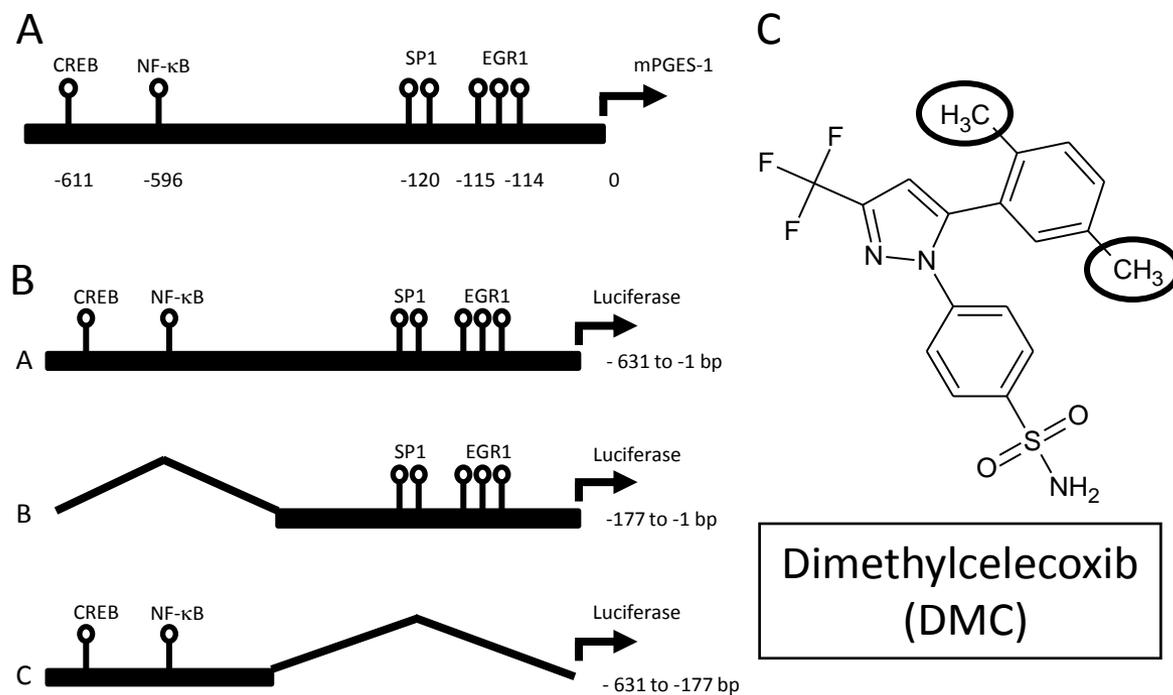
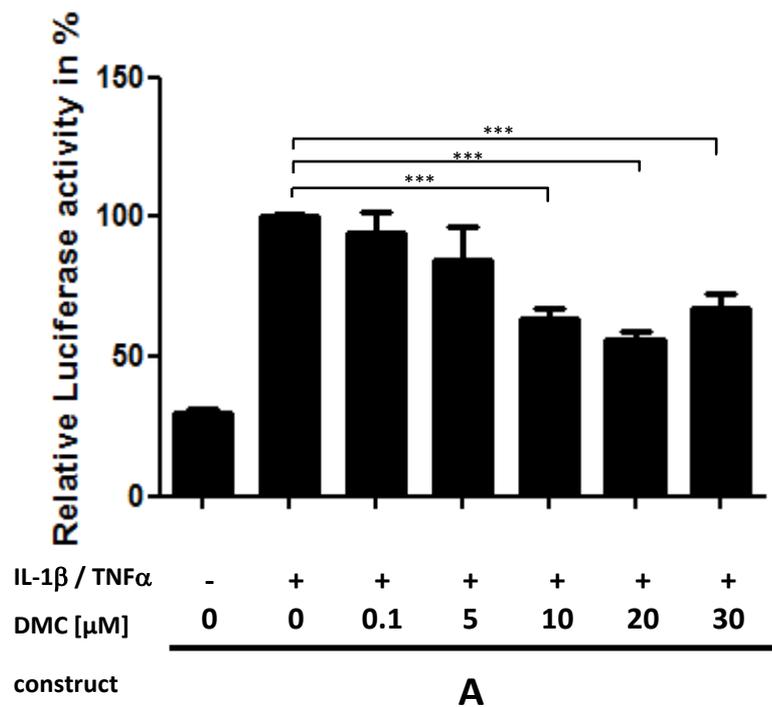


Figure 2

A



B

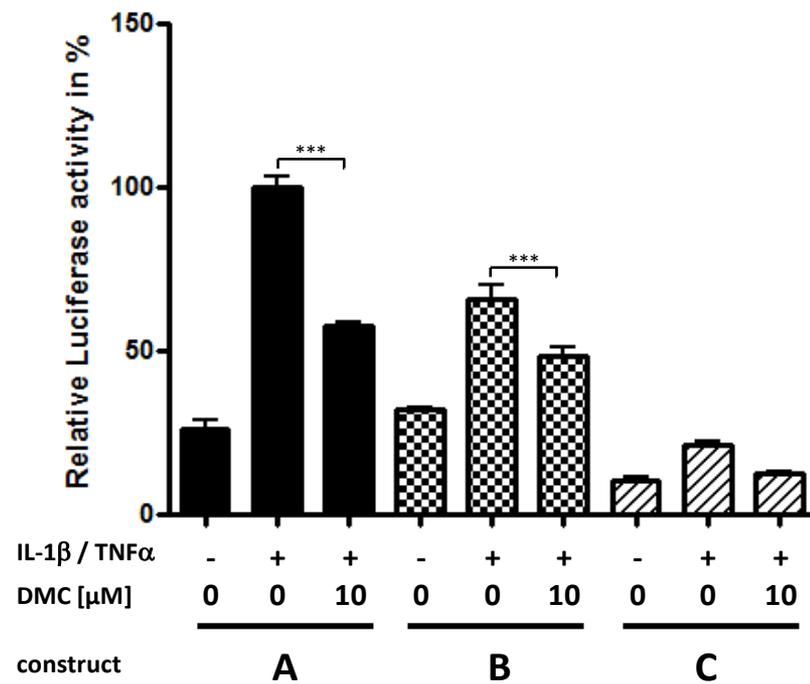


Figure 3

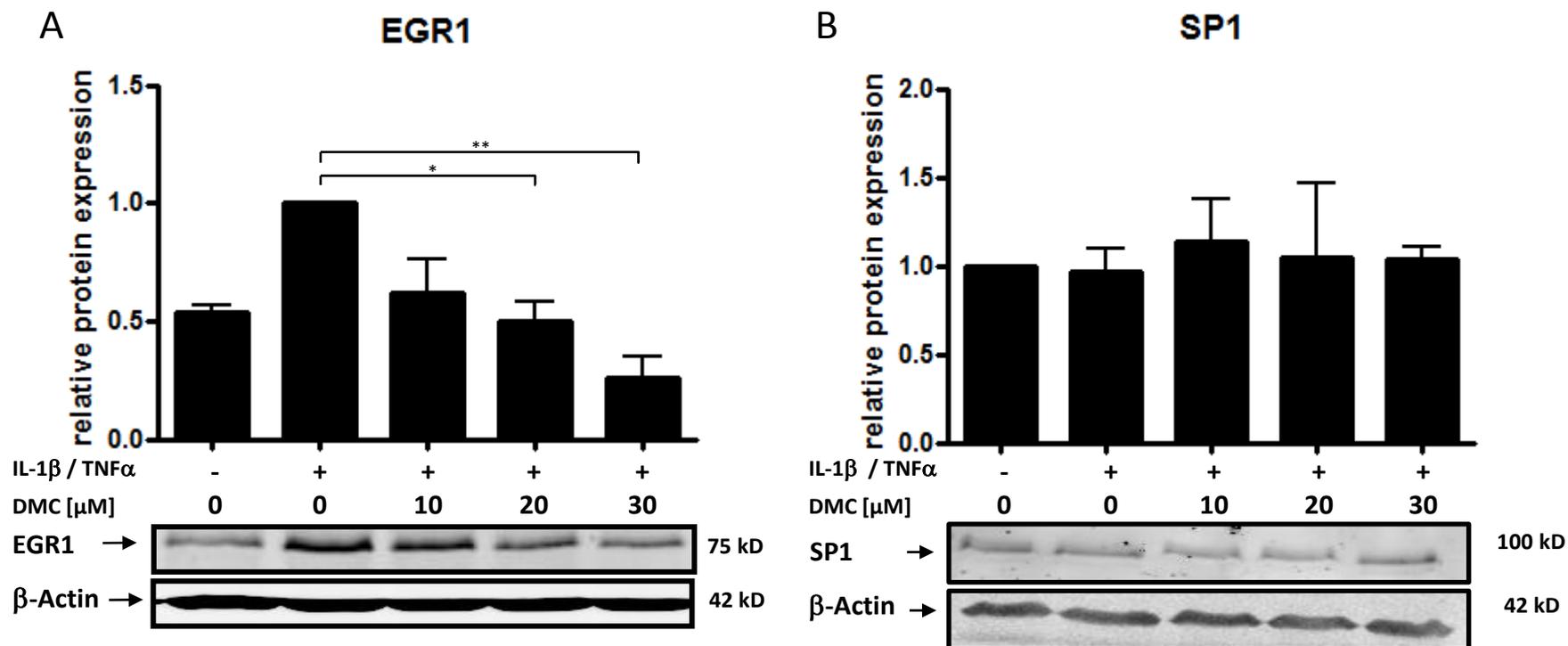


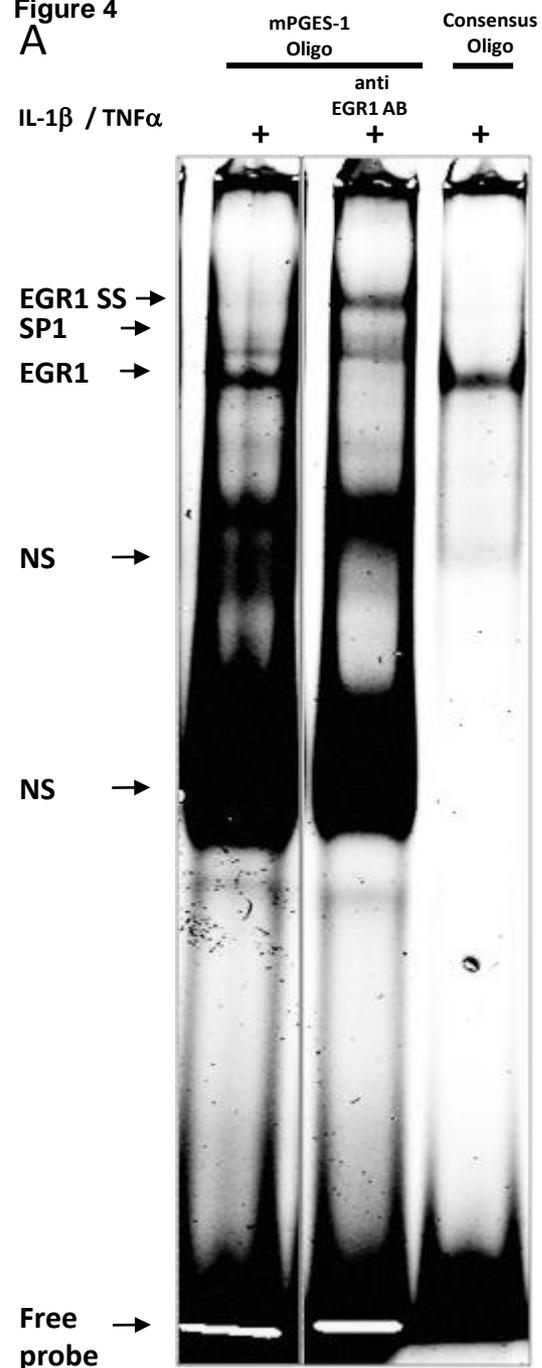
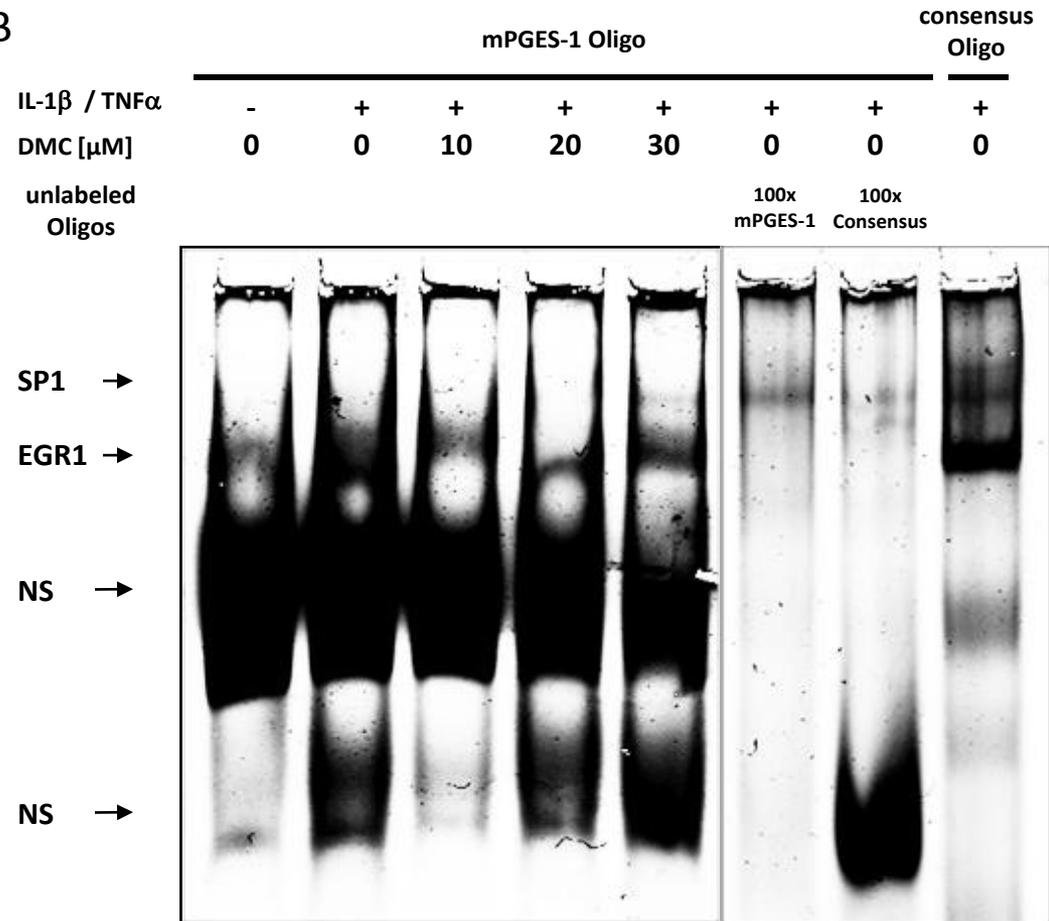
Figure 4**B****Figure 4**

Figure 5

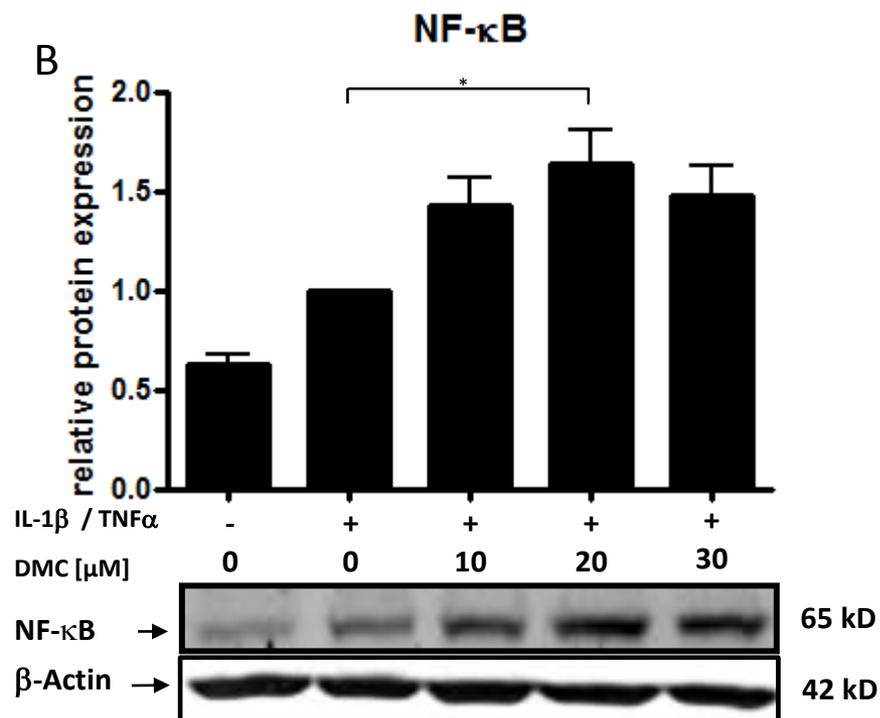
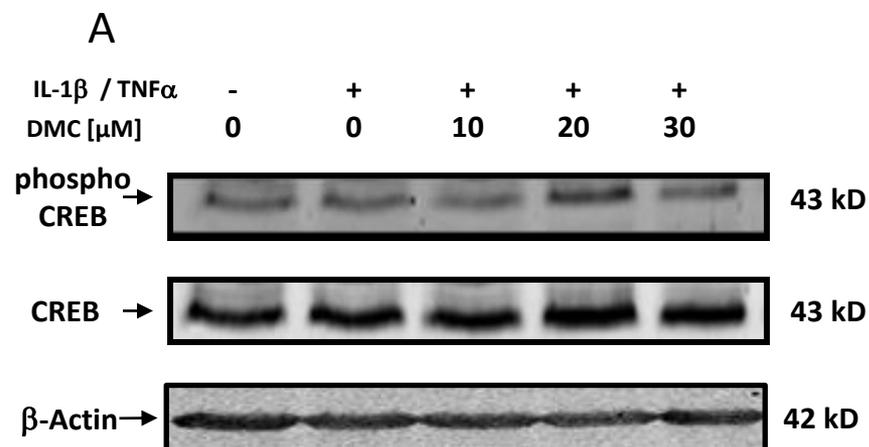


Figure 6

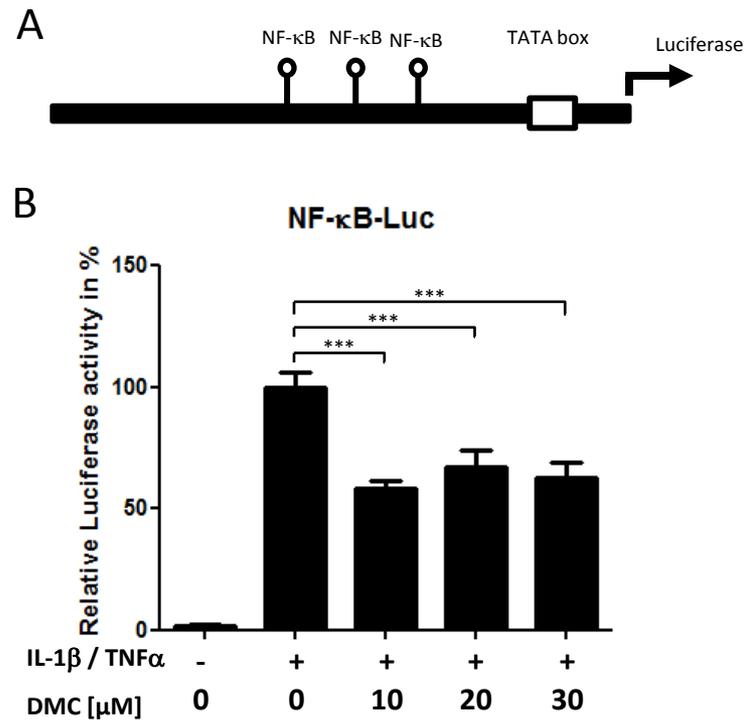


Figure 7

