Norelgestromin as selective estrogen enzyme modulator in human breast cancer cell lines
Effect on sulfatase activity in comparison to medroxyprogesterone acetate

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Abstract
Human breast cancer tissue contains enzymes (estrone sulfatase, 17β-hydroxysteroid dehydrogenase, aromatase) involved in the last steps of estradiol (E 2 ) formation. In this tissue, E 2 can be synthesized by two main pathways: (1) sulfatase—transforms estrogen sulfates into bioactive E 2 , and the (2) aromatase—converts androgens into estrogens. Quantitative assessment of E 2 formation in human breast tumors indicates that metabolism of estrone sulfate (E 1 S) via the sulfatase pathway produces 100–500 times more E 2 than androgen aromatization.

In the present study, we demonstrated in T-47D and MCF-7 human breast cancer cells that norelgestromin (NGMN) (a metabolite of norgestimate) is a potent inhibitory agent of the estrone sulfatase activity. After 24 h incubation of physiological concentrations of E 1 S (5 × 10−9 mol/l) the inhibitory effect of NGMN at concentrations of 5 × 10−9, 5 × 10−7 and 5 × 10−5 mol/l was 43 ± 7, 74 ± 4 and 97 ± 2%, respectively, in T-47D cells; 25 ± 4, 57 ± 5 and 96 ± 2% respectively, in MCF-7 cells. Comparative studies using medroxyprogesterone acetate (MPA) showed that this progestin also has an inhibitory effect on sulfatase activity, but significantly less intense than that of NGMN. The inhibition for MPA at concentrations of 5 × 10−9, 5 × 10−7 and 5 × 10−5 mol/l was 31 ± 5, 47 ± 3 and 61 ± 3%, respectively, for T-47D cells; 6 ± 3, 20 ± 3 and 63 ± 4%, respectively, for MCF-7 cells.

In conclusion, the present data show that NGMN is a very potent inhibitory agent for sulfatase activity in the hormone-dependent breast cancer cells, resulting in decreased tissue concentration of E 2 . The clinical significance of this finding remains to be elucidated.

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1. Introduction
Breast cancer is one of the major causes of cancer-related deaths among women and recent statistical information indicates that in the United States one woman in eight will develop this disease during her lifetime; the values are one in twelve for countries of the European Community and one in eighty for Japan. It is now well-established that estradiol (E 2 ) is an important risk factor for the genesis and evolution of breast tumors and that most (about 95%) early stage tumors are estrogen-sensitive [1–3].

About two-thirds of breast cancers occur during the post-menopausal period when estrogen produced by the ovaries has essentially ceased. Despite the low levels of circulating estrogens, the tissue concentrations of estrone (E 1 ), E 2 and their sulfates (E 1 S, E 2 S) are several times higher than those found in the plasma or in the area of the breast considered to be normal tissue, suggesting a specific tumoral biosynthesis of these hormones [4–8].

There is substantial information that mammary cancer tissue contains enzymes responsible for the local biosynthesis of E 2 from circulating precursors. Two principal pathways are implicated in the last steps of E 2 formation...
in breast cancer tissues: the “aromatase pathway” which transforms androgens, mainly androstenedione, into estrogens [9,10] and the “sulfatase pathway” which converts E\textsubscript{1}S into E\textsubscript{1} by the estrone-sulfatase (EC: 3.1.6.2) [11–15]. The final step of steroidogenesis is the conversion of the weak E\textsubscript{1} to the potent biologically active E\textsubscript{2} by the action of a reductive 17\beta-hydroxysteroid dehydrogenase type 1 activity (17\beta-HSD-1, EC: 1.1.1.62) [16,17]. Quantitative evaluation indicates that the majority of E\textsubscript{2} formation in human breast tumors is via the sulfatase pathway rather than via the aromatase pathway [5,15,18].

Norelgestromin (NGMN) is a synthetic progestin and the primary metabolic product of norgestimate, a progestin used in several marketed oral contraceptives and in a US marketed hormone replacement therapy.

In this study, we explored the effects of NGMN and medroxyprogesterone acetate (MPA) on the sulfatase activity in two hormone-dependent breast cancer cells: MCF-7 and T-47D.

2. Materials and methods

2.1. Chemicals

[6,7-\textsuperscript{3}H/(\textsuperscript{3}H)]-estrone sulfate (\textsuperscript{3}H-E\textsubscript{1}S), ammonium salt (specific activity 53 Ci/mmol) and [4-\textsuperscript{14}C-estradiol] (\textsuperscript{14}C-E\textsubscript{2}) (specific activity 57 mCi/mmol) were purchased from New England Nuclear Division (DuPont de Nemours, Les Ulis, France). The purity of the radiospecies was assessed by thin-layer chromatography (TLC) in the appropriate system before use. E\textsubscript{1}S, ammonium salt, unlabeled E\textsubscript{2} and E\textsubscript{1} (analytical grade) were obtained from Sigma–Aldrich Chimie (St. Quentin Fallavier, France). NGMN (13-ethy17-hydroxy-18,19-dinor-17\alpha-pregna-4-en-20-yn-3-one oxime) was a gift from the Johnson & Johnson Chemistry Department (Raritan, NJ, USA); medroxyprogesterone acetate (MPA; 17α-acetoxy-6α-methylprogesterone) was obtained from Sigma–Aldrich Chimie. All other chemicals were of the highest grade commercially available.

2.2. Cell culture

The hormone-dependent MCF-7 and T-47D human mammary cancer cell lines were kindly provided by Dr. R.B. Dickson (Georgetown University, Washington, DC, USA). The cells were grown in Eagle’s Minimal Essential Medium (MEM) buffered with 10 mmol/l HEPES (pH 7.6) supplemented with 2 mmol/l L-glutamine, 100 U/ml penicillin–streptomycin and 5% fetal calf serum (FCS) (ATGC, Marine-la-Valleé, France) for T-47D, or 10% FCS for MCF-7 cells, and incubated at 37 °C in a humidified atmosphere of 5% CO\textsubscript{2}. Media were changed twice a week. The cells were passed every 10–12 days and replated in 75 cm\textsuperscript{2} flasks (ATGC) at 3 × 10\textsuperscript{5} cells per flask. Four days before the experiments, the cells were transferred to MEM containing 5% steroid-depleted treated FCS. The FCS had been treated overnight at 4 °C with dextran-coated charcoal (DCC) (0.1–1% w/v, DCC–FCS).

2.3. Isolation and quantification of [\textsuperscript{3}H]-estradiol from human mammary cancer cells incubated with [\textsuperscript{3}H]-estrone sulfate

Preconfluent cells were cultivated in MEM–DCC–FCS with the addition of 5 × 10\textsuperscript{–5} mol/l of [\textsuperscript{3}H]-E\textsubscript{1}S alone (control cells) or in combination with the different compounds: NGMN or MPA, dissolved in ethanol (final concentration <0.2%) at a range of concentrations from 5 × 10\textsuperscript{–3} to 5 × 10\textsuperscript{–5} mol/l. Control cells received ethanol vehicle only. Twenty-four hours later the medium was removed, the cells washed twice with ice-cold Hank’s Buffered Saline Solution (HBSS; calcium–magnesium-free) (ATGC) and harvested by scraping. After centrifugation, the pellet was treated with 80% ethanol and the radioactivity extracted for at least 24 h at −20 °C. The cellular radioactivity uptake was determined in the ethanolic supernatant and the DNA content in the remaining pellet was evaluated according to Burton [19]. [\textsuperscript{14}C]-E\textsubscript{2} (5000 dpm) was added to monitor analytical losses, and unlabeled E\textsubscript{2} and E\textsubscript{1} (50 μg) were used as carriers and reference indicators. In the total ethanolic extracts, E\textsubscript{2} was isolated by TLC on silica gel 60F\textsubscript{254} (Merck, Darmstadt, Germany) developed with chloroform–ethylacetate (4:1, v/v) system. After visualization of the estrogens under UV at 254 nm, the appropriate areas were cut off into small pieces, placed in liquid scintillation vials with ethanol (0.5 ml) and allowed to extract for 30 min. Three milliliter of Opti-fluor (Packard, Rungis, France) were added and the vials were analyzed for \textsuperscript{3}H and \textsuperscript{14}C contents with quench correction by external standardization. The quantitative evaluation of E\textsubscript{2} was calculated as a percentage of the total radioactivity associated with the cells and then expressed as fmol of E\textsubscript{2} formed/mg DNA.

2.4. Statistical analysis

Data are expressed as the mean ± standard error of the mean (S.E.M.) values. Student’s t-test was used to assess the significance of the differences between means; P values ≤0.05 were considered significant.

3. Results

3.1. Effect of norelgestromin (NGMN) on estrone sulfatase activity in hormone-dependent MCF-7 and T-47D human breast cancer cells

As E\textsubscript{1}S is the most important precursor of E\textsubscript{2} in breast cancer tissues, the inhibition of estrone sulfatase activity can be an important way of preventing the liberation of unconjugated active estrogens from their inactive sulfo-conjugated...
forms. Previous studies in this laboratory have clearly demonstrated that various progestins (e.g. medrogestone, nomegestrol acetate) or tibolone, can act as selective estrogen enzyme modulators by inhibiting estrone sulfatase and 17β-HSD or stimulating sulfotransferase activities in breast cancer cells. To this aim, we tested the capacity of the synthetic 19-norprogestin NGMN to block the sulfatase pathway in breast cancer cells.

When physiological concentrations (5 x 10^-9 mol/l) of [3H]-E1S are incubated with the hormone-dependent T-47D and MCF-7 breast cancer cell lines for 24 h at 37 °C, the intracellular production of E2 in both cells is elevated (1805 ± 152 and 2185 ± 101 fmol/mg DNA for T-47D and MCF-7 cells, respectively) (Figs. 1 and 2).

The data show that the progestin NGMN very intensively decreases the production of E2 from E1S in a dose-dependent manner. At low concentrations (5 x 10^-9 and 5 x 10^-7 mol/l) NGMN is a potent inhibitory agent of the sulfatase pathway in T-47D cells: the inhibition is 43 ± 7 and 74 ± 4%, respectively. These effects are lower in MCF-7 cells where the inhibition found was 25 ± 4 and 57 ± 5%, respectively.

At high concentrations (5 x 10^-5 mol/l) the inhibition is very strong in both cells: 97 ± 2 and 96 ± 2% in T-47D and MCF-7 cells respectively. Using non-linear regression analyses, the IC50 values, corresponding to the concentration of NGMN which decreases the formation of E2 by 50%, are 1.27 x 10^-8 mol/l and 1.78 x 10^-7 mol/l in T-47D and MCF-7 cells, respectively, indicating that NGMN is 14 times stronger in the progesterone receptor (PR)-rich T-47D cells than in MCF-7 cells (Table 1).

3.2. Effect of MPA on estrone sulfatase activity in the hormone-dependent MCF-7 and T-47D human breast cancer cells

MPA is a synthetic progestin derived from 17-hydroxy-progesterone, used as injectable contraceptive, and at high doses as palliative treatment of breast and endometrial carcinoma. The anti-tumoral action of MPA may be due to an effect on the hypothalamo-hypophysis axis, on the estrogen receptor and/or on the metabolism of steroids in tissues.

Figs. 1 and 2 show that at low doses (5 x 10^-9 and 5 x 10^-7 mol/l) MPA significantly inhibits the E2 produc-
Fig. 2. Effects of NGMN and MPA on the conversion of estrone sulfate (E1S) to estradiol (E2) in the hormone-dependent MCF-7 human breast cancer cell line. Preconfluent cells were incubated for 24 h at 37 °C with a physiological concentration (5 × 10⁻⁹ mol/l) of [3H]-E1S alone (control: non-treated cells) or in the presence of NGMN or MPA at the range of concentrations from 5 × 10⁻⁹ to 5 × 10⁻⁵ mol/l. Qualitative and quantitative analyses of E2 in the cell compartment were performed by thin-layer chromatography and liquid scintillation counting as indicated in Section 2. Results are expressed in fmol of E2 formed/mg DNA from E1S. The data are the mean ± S.E.M. of duplicate determinations of three independent experiments. *P = 0.05 vs. control values (non-treated cells).

Fig. 3. Structures of the two progestins: norelgestromin (NGMN) and medroxyprogesterone acetate (MPA).

4. Discussion

It is recognized that the “sulfatase pathway” is essentially responsible for the intratissular estradiol (E2) production in hormone-responsive mammary carcinomas or in breast cancer models. Estrone sulfatase activity is potentially relevant as it is the main factor controlling the production of unconjugated estrogens from the high concentrations of sulfoconjugated precursors which prevail in breast cancer tissues, particularly from postmenopausal patients [5].

The present data establish that the synthetic progestin NGMN can reduce the conversion of E1S to E2 in T-47D cells only, where the percentage of inhibition is 31 ± 5 and 47 ± 3%, respectively. For MCF-7 cells the inhibition is 6 ± 3 and 20 ± 3%, respectively. At a higher dose (5 × 10⁻⁵ mol/l) the inhibitory effect is significant in both cell lines: 61 ± 3 and 63 ± 4%, respectively, in T-47D and MCF-7 cells. The IC₅₀ values are 2.15 ± 10⁻⁶ and 2.61 ± 10⁻⁵ mol/l in T-47D and MCF-7 cells respectively, indicating that MPA is 12 times stronger in the PR-rich T-47D cells than in the MCF-7 cells (Table 1).

Comparatively, NGMN is 170 and 147 times stronger for inhibiting the sulfatase pathway than MPA in T-47D and MCF-7 cells, respectively. The comparative structures of these two progestins are given in Fig. 3.
and MCF-7 human mammary cancer cells by blocking the “sulfatase pathway”. Despite a similar sulfatase activity in non-treated T-47D and MCF-7 intact cells in culture, NGMN exerts a greater inhibitory effect on this enzyme in the former cell lines, particularly at low doses (5 × 10⁻⁹ and 5 × 10⁻⁷ mol/l). The concentration of NGMN needed to obtain 50% inhibition of this activity (IC₅₀ value) was 1.27 × 10⁻⁸ mol/l for the T-47D cells and 1.78 × 10⁻⁷ mol/l for the MCF-7 cells. As T-47D cells express high functional levels of PR, a PR-mediated mechanism by which NGMN inhibits estrogen production could be an attractive path to explore.

Norgestimate belongs to the 19-norprogestin series with an oxiime group on C-3 that, in combination with ethyl estradiol, is contained in widely marketed oral contraceptives. It binds to the PR and causes conversion of a proliferative to a secretory endometrium in rabbits after direct injection in the uterine horn. It inhibits luteinizing hormone response of norgestimate in postmenopausal women. Endocrine 106 (1980) 1079–1086.

NGMN, 3-keto norgestimate and levonorgestrel. NGMN is the primary active metabolite which carries the progestogenic properties of norgestimate. Significant concentrations (3500 pg/ml, 1.5 h after intake) of NGMN were found in the serum of women after administration of norgestimate and it is suggested that NGMN contributes to the pharmacologic response of norgestimate [21]. Studies using gastrointestinal mucosa show also that NGMN is the main metabolic product of norgestimate [22]. NGMN is the progesterone contained in the new FDA-approved once-weekly contraceptive patch Ortho Evra/Evra (norelgestromin/ethinyl estradiol, transdermal system). [23] The present study demonstrates previously unknown biological effects of NGMN.

MPA is extensively used in patients with advanced or recurrent breast cancer [24,25]. The fact that NGMN has more potent anti-sulfatase activity than MPA suggests possible new and interesting uses for NGMN in clinical trials of patients with breast cancer.

References


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