



# Pharmacology of Novel Steroidal Inhibitors of Cytochrome $P450_{17\alpha}$ ( $17\alpha$ -Hydroxylase/C17-20 Lyase)

S. E. Barrie,<sup>1\*</sup> G. A. Potter,<sup>1</sup> P. M. Goddard,<sup>1</sup> B. P. Haynes,<sup>1</sup> M. Dowsett<sup>2</sup> and M. Jarman<sup>1</sup>

<sup>1</sup>Drug Development Section, Institute of Cancer Research, Sutton, Surrey SM2 5NG and <sup>2</sup>Department of Academic Biochemistry, Royal Marsden Hospital, Fulham Road, London SW3 6JJ, England

Medical or surgical castration for the treatment of prostatic cancers prevents androgen production by the testes, but not by the adrenals. Inhibition of the key enzyme for androgen biosynthesis, cytochrome  $P450_{17\alpha}$ , could prevent androgen production from both sources. The *in vivo* effects of 17-(3-pyridyl)androsta-5,16-dien-3 $\beta$ -ol (CB7598) and 17-(3-pyridyl)androsta-5,16-dien-3-one (CB7627), novel potent steroidal inhibitors of this enzyme, on WHT mice were compared with those of castration and two clinically active compounds, ketoconazole and flutamide. Flutamide and surgical castration caused significant reductions in the weights of the ventral prostate and seminal vesicles. CB7598, in its 3 $\beta$ -O-acetate form (CB7630), and CB7627 caused significant reductions in the weights of the ventral prostate, seminal vesicles, kidneys and testes when administered once daily for 2 weeks. Ketoconazole, given on the same schedule, caused no reductions. Plasma testosterone was reduced to  $\leq 0.1$  nM by CB7630, despite a 3- to 4-fold increase in the plasma level of luteinizing hormone. Adrenal weights were unchanged following treatment with CB7630 or CB7627 but were markedly increased following ketoconazole, indicating no inhibition of corticosterone production by these steroidal compounds. These results indicate that CB7598, CB7630 or CB7627 may be useful in the treatment of hormone-dependent prostatic cancers.

*J. Steroid Biochem. Molec. Biol.*, Vol. 50, No. 5/6, pp. 267-273, 1994

## INTRODUCTION

Antiendocrine therapy with luteinizing hormone-releasing hormone (LHRH) agonists has become an established alternative to orchidectomy as a means of lowering circulating androgens in patients with cancer of the prostate. This treatment ablates the testicular production of androgens but leaves the adrenal supply of androgens and their precursors unaffected. The long standing premise that this adrenal supply is critical has been tested in several clinical trials, some of which showed a significant increase in survival as a result of combining LHRH agonists with antiandrogens when compared with the use of LHRH agonists alone [1]. An alternative to this combination would be an effective and selective inhibitor of the key enzyme in the androgen biosynthetic pathway, namely cytochrome  $P450_{17\alpha}$  ( $17\alpha$ -hydroxyl-

ase/ C17-20 lyase), which is present in both the testes and the adrenals. Ketoconazole, originally developed as an antifungal agent, potently inhibits this enzyme and has been used clinically in the treatment of hormone-dependent prostatic cancers [2]. Unfortunately ketoconazole also inhibits many other cytochrome  $P450$  enzymes [3, 4] and was withdrawn from use because it caused liver damage [5, 6]. Several groups are seeking to develop more potent and selective inhibitors [7, 8]. Recently we reported briefly on the *in vitro* and *in vivo* results obtained with a novel steroidal compound, 17-(3-pyridyl)androsta-5,16-dien-3 $\beta$ -ol (CB7598) (Fig. 1), a potent inhibitor ( $K_{i,app} < 1$  nM for the lyase activity) of the human cytochrome  $P450_{17\alpha}$  [9]. In this paper the effects of CB7598 in its 3 $\beta$ -O-acetate form (CB7630), and an equally potent related compound 17-(3-pyridyl)androsta-5,16-dien-3-one (CB7627) (Fig. 1), on the circulating hormone levels and organ weights in mice are described, and compared with those of castration, ketoconazole and flutamide.

\*Correspondence to S. E. Barrie.  
Received 31 Jan. 1994; accepted 9 May 1994.

## EXPERIMENTAL

CB7598, CB7630 and CB7627 were prepared from dehydroepiandrosterone where the key step involved a novel palladium catalysed cross-coupling of a steroidal enol triflate with a pyridyl borane [10, 11]. Ketoconazole was a gift from Janssen Pharmaceuticals (Beerse, Belgium) and flutamide was a gift from Kirby-Warwick Pharmaceuticals Ltd. (Bury St Edmunds, England) The WHT mice came from the Gray Lab (Mount Vernon Hospital, Mddx, England).

### Adrenal cell assay

Guinea pig adrenal cells were obtained and assayed for the ACTH stimulated production of androstenedione and cortisol as described previously [12].

### Radioimmunoassays

Testosterone was analysed using the DPC total testosterone coat-a-count kit. The detection limit was 0.1 nM and the within and between assay CVs were 8.0 and 12.9%, respectively at an assay value of 2.5 nM. The assay for luteinizing hormone (LH) used the Amersham International rat LH<sup>[125I]</sup> assay system employing a magnetic separation system which cross-reacts with mouse LH. The detection limit was 0.4 ng/ml and the within and between assay CVs were 6.5 and 6.6%, respectively at an assay value of 4.5 ng/ml.

### In vivo studies

Adult male WHT mice (12 weeks old) were housed under conditions of 12 h light-dark and were allowed free access to food (SDS expanded rodent diet) and water.

CB7598 was used in its 3 $\beta$ -O-acetate form (CB7630) as this was easier to formulate than the free 3 $\beta$ -hydroxy compound. CB7630, CB7627 and ketoconazole were prepared in 5% benzyl alcohol, 95% safflower oil. The preparations were given intraperitoneally, 5 ml/kg, to the mice once daily for 14 days. Flutamide was prepared in 5% dimethylsulphoxide, 95% arachis oil and was given subcutaneously, 5 ml/kg, following the same schedule. The doses given ranged from 0.02 to 0.5 mmol/kg/day. On day 15, the animals were anaesthetized with fluothane, the blood collected by cardiac puncture into heparinized tubes, and the organs of interest dissected out and weighed. After weighing, the organs from the animals treated with CB7627 were stored in modified methacarn for histological examination. The plasma was separated by centrifugation and stored at -20°C.

For the pharmacokinetic experiment, a single intraperitoneal dose of 0.5 mmol/kg CB7630 was given to the mice which were sacrificed at various times up to 24 h afterwards, and the blood taken by cardiac puncture as above. CB7598 and CB7630 plasma concentrations were determined by high pressure liquid

chromatography. Plasma samples (250  $\mu$ l) were mixed with acetonitrile (375  $\mu$ l) and centrifuged. Aliquots (100–200  $\mu$ l) of the supernatant so obtained were injected onto a 15 cm Spherisorb S3PC18 cartridge column (4.6 mm i.d.) with an eluent of acetonitrile–50 mM ammonium acetate buffer (60:40, v/v) flowing at 1.5 ml/min. Eluates were detected using a Perkin-Elmer LC-240 fluorescence detector set up with an excitation wavelength of 262 nm and an emission wavelength of 353 nm. The detection limit of the assay was 20 ng/ml (~50 nM) for both compounds.

Adult male WHT mice were castrated via the scrotal route while under pentobarbital anaesthesia. The sham operated group underwent the same surgical procedures as the castrates except that the testes were not

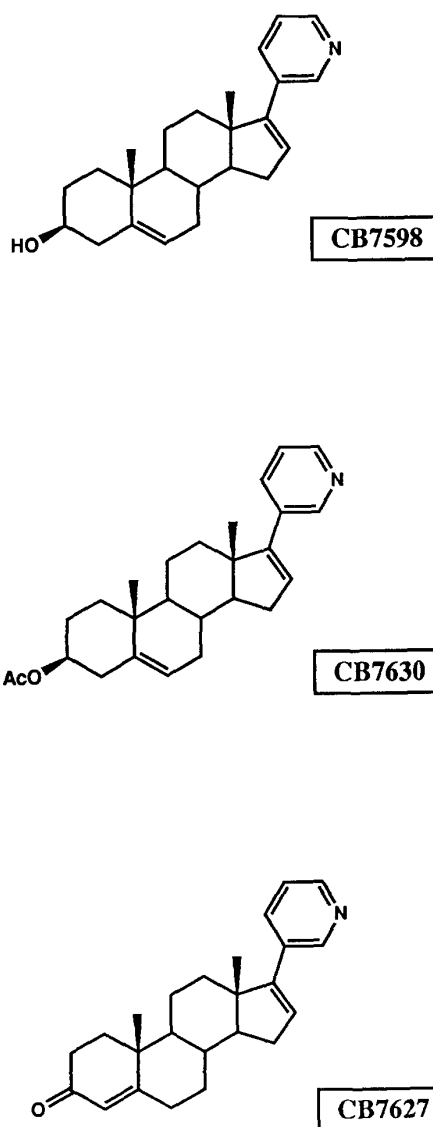


Fig. 1. Structures of the compounds CB7598, the 3-O-acetate form CB7630, and CB7627

Table 1. The effects of castration on the organ weights of WHT mice

Treatment/ time	Adrenals	Prostate	Seminal vesicles	Testes	Kidneys
Untreated	3.9 ± 0.1 (n = 21)	9.5 ± 0.4 (n = 21)	186 ± 6 (n = 21)	137 ± 2 (n = 21)	651 ± 26 (n = 8)
Sham					
1 wk (n = 7)	3.4 ± 0.1	11.1 ± 0.5	170 ± 10	124 ± 5	ND
2 wk (n = 8)	3.9 ± 0.1	9.5 ± 0.5	168 ± 6	126 ± 6	ND
4 wk (n = 8)	3.3 ± 0.1	7.1 ± 0.5	167 ± 8	137 ± 2	571 ± 23
Castrates					
1 wk (n = 8)	3.6 ± 0.1	4.2 ± 0.2*	27 ± 2*		ND
2 wk (n = 8)	3.9 ± 0.1	2.5 ± 0.2*	16 ± 1*		ND
4 wk	4.1 ± 0.1	1.9 ± 0.1*	15 ± 1*		413 ± 13*

The results are given in mg as means ± SE, with the number of animals in parentheses.

\**P* < 0.01 for the differences between the castrate groups and the sham groups; ND, not determined.

removed. After 1, 2, or 4 weeks the animals were sacrificed and the organs removed and weighed.

Statistical significance was assessed by analysis of variance, and subsequent multiple range testing used the least significant difference method using the Statgraphics 5 computer program.

## RESULTS

ACTH stimulated the production of androstenedione and cortisol by guinea pig adrenal cells *in vitro* by 1703 and 38 nM, respectively after 3 h. CB7598, CB7627 and ketoconazole were able to inhibit this, achieving almost total suppression (<10% stimulated production) at 10<sup>-5</sup> M. This concentration was much higher than the *K<sub>s</sub>* for the human cytochrome P450<sub>17α</sub> enzyme as measured *in vitro*, and may reflect the effects of protein binding and membrane transport as well as differences in the enzyme structure and environment. A similar concentration of ketoconazole was required to inhibit corticosterone synthesis in rat adrenal cells [4].

The effect of castration on the organ weights of the WHT mice is shown in Table 1. There were marked decreases in the sizes of the ventral prostate, seminal vesicles and kidneys to 20, 8, and 63% of untreated controls, respectively. The effect on the seminal vesicles was greater than on the prostate at all times. The maximum effect was seen after approx. 2 weeks, and a 2-week dosing schedule with the various drugs was therefore followed.

The results of treating the mice with CB7630 and CB7627 are given in Figs 2 and 3 and the results obtained with ketoconazole and flutamide, agents that have been used clinically to treat hormone dependent prostatic cancer, are given in Figs 4 and 5. The mice did not lose weight or appear unwell with any of the treatments, and there were no drug related features

seen at post-mortem except in the case of ketoconazole at the highest dose when the livers looked brown (no histology was carried out).

CB7630 and CB7627 caused a marked suppression in the weights of several androgen-dependent organs in a dose-dependent way. The reductions in the seminal vesicle weights (maximum reductions 87 and 85%, respectively) were more marked than that in the ventral prostate weights (maximum reductions 48 and 51%, respectively), as had been the case following castration. The kidneys were also reduced in weight (by 37 and 28%) as were the testes (by 62 and 58%). Flutamide, in contrast, produced equal reductions in the prostate and seminal vesicles (54 and 60%, respectively), and no change in the testicular weight (kidney weights were not measured). Ketoconazole did not produce any change in the weights of these organs.

After the experiment with CB7627, the testes were histologically examined. There was a thinning of the germinal epithelium with a reduced number of mature forms. There was no obvious reduction in Leydig cell numbers, although this was difficult to estimate in the presence of marked changes in the seminiferous tubules. There were no obvious toxic effects of the drug and all the changes were consistent with a reduction in testosterone.

Following treatment of the mice with ketoconazole, there was a marked increase in adrenal weight, while treatment with CB7630, CB7627, or flutamide caused no change in the weight of the adrenals.

The plasma testosterone and LH levels 24 h after the end of treatment are given in Table 2. The level of testosterone in control animals varied considerably, and there was a dramatic reduction in the levels in the vehicle controls probably related to stress. Comparing the vehicle controls with the drug treated groups, there was a decrease in circulating testosterone after keto-

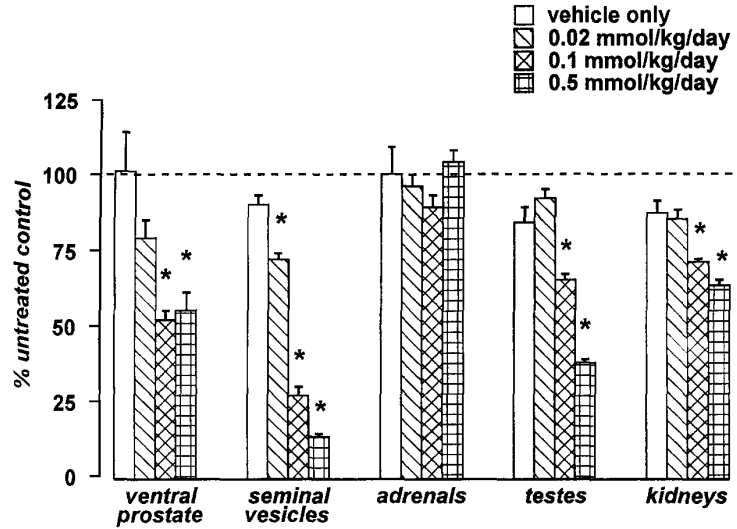


Fig. 2. Effects of 14 days treatment with CB7630 on the organ weights of WHT mice. Results are expressed as % of the untreated controls for which the values were ventral prostate  $9.5 \pm 0.3$ , seminal vesicles  $182 \pm 6$ , adrenals  $4.2 \pm 0.1$ , testes  $144 \pm 2$ , kidneys  $677 \pm 17$  mg ( $n = 20$ ). \* $P < 0.01$  for the difference from the vehicle controls.

conazole, but this was not statistically significant, and was not associated with a rise in plasma LH. However, there was a marked dose-dependent decrease in testosterone to almost undetectable levels following CB7630 and this was maintained despite the increased levels of LH which would normally stimulate the testicular production of the androgen. Following CB7627 there was also a dose-dependent decrease in plasma testosterone but not to such low levels as following CB7630. This was not statistically significant as the variability of the vehicle control group was so great.

The pharmacokinetics of CB7598 following the intraperitoneal administration of CB7630, the acetylated form of CB7598, are shown in Fig. 6. CB7630 was detected in only 2 of the 25 mice, indicating rapid de-acetylation to CB7598. The peak plasma concentration of CB7598 of approx. 400 ng/ml ( $1.0 \mu\text{M}$ ) was seen after 6 h with the level dropping to 1/3 after 8 h. The concentration at 24 h was similar to that at 8 h, possibly due to a depot effect from the route of administration, and/or enterohepatic recirculation.

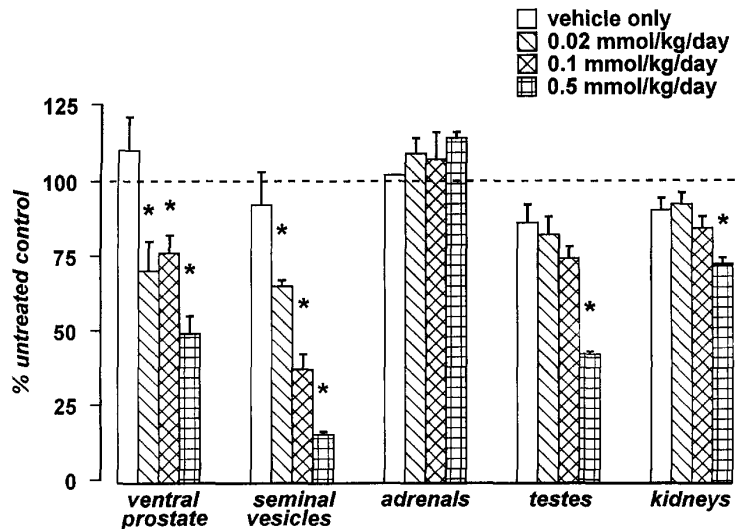


Fig. 3. Effects of 14 days treatment with CB7627 on the organ weights of WHT mice. Results are expressed as % untreated controls (values given in Fig. 2). \* $P < 0.01$  for the difference from the vehicle controls.

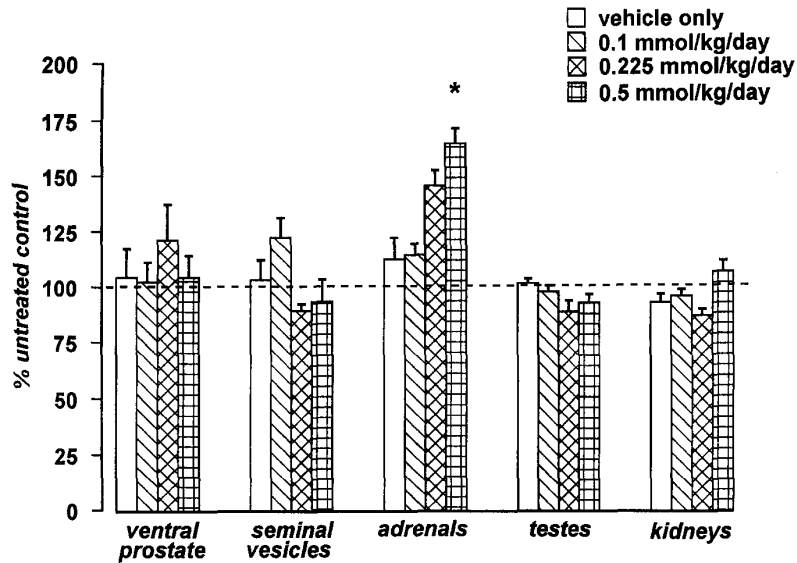


Fig. 4. Effects of 14 days treatment with ketoconazole on the organ weights of WHT mice. Results are expressed as % untreated controls (values given in Fig. 2). \* $P < 0.01$  for the difference from the vehicle controls.

#### DISCUSSION

Plasma levels of testosterone and LH are very variable in mice [13] and can be affected by stress of varying types [14], making the detection of significant drug induced changes difficult. Both the variability and the effect of stress are illustrated by the data here for the control and the vehicle control groups. Following ketoconazole, the level of circulating testosterone was reduced but this was not associated with an increase in plasma LH, nor with regression of the androgen-dependent organs. These results suggest that the testos-

terone suppression may have been of insufficient duration to cause any regression of the androgen-dependent organs and so might have been stress induced. On the other hand, following CB7630, acting as a prodrug form of CB7598, there was a marked drop in the circulating level of testosterone which was maintained despite the reflex rise in LH, which in turn would have stimulated testosterone biosynthesis. This indicates that CB7630 produced potent inhibition of testosterone production *in vivo*. The significant regression of several androgen-dependent organs could have resulted from this reduced level of circulating

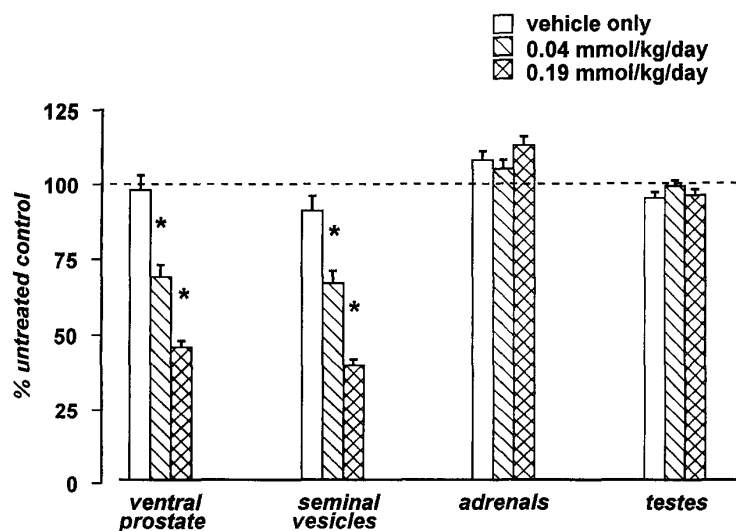


Fig. 5. Effects of 14 days treatment with flutamide on the organ weights of WHT mice. Results are expressed as % untreated controls (values given in Fig. 2). \* $P < 0.01$  for the difference from the vehicle controls.

# Explore Litigation Insights

Docket Alarm provides insights to develop a more informed litigation strategy and the peace of mind of knowing you're on top of things.

## Real-Time Litigation Alerts



Keep your litigation team up-to-date with **real-time alerts** and advanced team management tools built for the enterprise, all while greatly reducing PACER spend.

Our comprehensive service means we can handle Federal, State, and Administrative courts across the country.

## Advanced Docket Research



With over 230 million records, Docket Alarm's cloud-native docket research platform finds what other services can't. Coverage includes Federal, State, plus PTAB, TTAB, ITC and NLRB decisions, all in one place.

Identify arguments that have been successful in the past with full text, pinpoint searching. Link to case law cited within any court document via Fastcase.

## Analytics At Your Fingertips



Learn what happened the last time a particular judge, opposing counsel or company faced cases similar to yours.

Advanced out-of-the-box PTAB and TTAB analytics are always at your fingertips.

## API

Docket Alarm offers a powerful API (application programming interface) to developers that want to integrate case filings into their apps.

## LAW FIRMS

Build custom dashboards for your attorneys and clients with live data direct from the court.

Automate many repetitive legal tasks like conflict checks, document management, and marketing.

## FINANCIAL INSTITUTIONS

Litigation and bankruptcy checks for companies and debtors.

## E-DISCOVERY AND LEGAL VENDORS

Sync your system to PACER to automate legal marketing.