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The antiestrogen ICI 182,780 decreases the expression of estrogen receptor-alpha but has no effect on estrogen receptor-beta and androgen receptor in rat efferent ductules

Cleida A Oliveira^{1,2}, Rong Nie¹, Kay Carnes¹, Luiz R Franca², Gail S Prins³, Philippa TK Saunders⁴ and Rex A Hess*¹

Address: ¹Department of Veterinary Biosciences, University of Illinois, 2001 S. Lincoln, Urbana, IL 61802, ²Departments of Morphology and Physiology, Federal University of Minas Gerais, Belo Horizonte-MG-Brazil, ³Department of Urology (M/C 955), College of Medicine, University of Illinois, Chicago, Illinois 60612-7310 and ⁴MRC Human Reproductive Sciences Unit, University of Edinburgh, Edinburgh EH16 4SB

Email: Cleida A Oliveira - cleida@mono.icb.ufmg.br; Rong Nie - rongnie97@yahoo.com; Kay Carnes - kcarnes@uiuc.edu; Luiz R Franca - lfranca@mono.icb.ufmg.br; Gail S Prins - gprins@uic.edu; Philippa TK Saunders - p.saunders@ed.ac.uk; Rex A Hess* - rexhess@uiuc.edu

* Corresponding author

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Abstract

Background: The antiestrogen ICI 182,780 has been used successfully as an alternative experimental model for the study of estrogen action in the rodent adult male reproductive tract. Although ICI 182,780 causes severe alterations in testicular and efferent ductule morphology and function, the effects on the expression of estrogen and androgen receptors in the male have not been shown.

Methods: In the present study, adult male rats were treated with ICI 182,780 for 7 to 150 days, to evaluate the time-response effects of the treatment on the pattern of ER α , ER β and AR protein expression in the efferent ductules. The receptors were localized using immunohistochemistry.

Results: ER α , ER β and AR have distinct cellular distribution in the testis and efferent ductules. Staining for ER α is nearly opposite of that for ER β , as ER α shows an increase in staining intensity from proximal to distal efferent ductules, whereas ER β shows the reverse. Androgen receptor follows that of ER α . ICI 182,780 caused a gradual but dramatic decrease in ER α expression in the testis and efferent ductules, but no change in ER β and AR expression.

Conclusions: The differential response of ER α and ER β proteins to ICI 182,780 indicates that these receptors are regulated by different mechanisms in the male reproductive tract.

Background

The efferent ductules express significant levels of the two subtypes of estrogen receptor, ER α and ER β [1], which can be co-localized in the epithelial cells of several species [2–6]. Targeted disruption of the ER α in the mouse (α ERKO) or both ER α and ER β ($\alpha\beta$ ERKO) caused abnormalities in the efferent ductules and impaired male fertility [7–12].

This is in contrast with the reproductive tract phenotype of the ER β knockout mice (β ERKO), which are fertile [11,13]. These results highlighted the importance of the efferent ductules and a functional ER α for the male reproductive tract.

ER α and ER β possess remarkable similarities to one another, but they also possess individual characteristics that suggest functional differences [14–16]. Structurally, the rat ER α and ER β have 95% identity in the DNA binding domain, but no more than 55% homology in the ligand binding domain [14]. As a consequence, different binding affinity for a variety of estrogenic and antiestrogenic compounds [17,18] and different transactivation activity depending on ligand and response element for the ER α and ER β has been reported [16,19–22]. Therefore, different responses of ER α and ER β to ligands in different tissues can be expected.

Treatment of rodents with the antiestrogen ICI 182,780 has been shown to be an alternative and efficient experimental model for the study of estrogen action in the male reproductive tract, bypassing the problems of developmental estrogen receptor absence seen in the transgenic mice [12,23–26]. ICI 182,780 is a potent steroidal antiestrogen, which can bind to both ER subtypes [16,17,27], but the binding patterns for ICI 182,780, as well as for estradiol, are distinct on both ER α and ER β [28]. Long-term treatment with ICI 182,780 promoted adult dysfunctional changes in the rat efferent ductules and culminated in testicular atrophy and infertility [25] similar to changes observed in the α ERKO male [8,9]. Changes in efferent ductules included luminal dilation (up to 200%), gradual reduction in epithelial height and transient increase in lysosomal area and microvilli height in nonciliated cells. Extending these results, a recent study established the time course of the events that led to testicular atrophy and infertility in rats after ICI-treatment and showed that effects on the efferent ductules preceded the adverse effects in the testis [26]. Although these studies are the first to demonstrate that a functional ER is essential for fertility in the rat and for maintenance of efferent ductules morphology, the molecular effects of ICI 182,780 on the expression of ER in the male have not been determined.

Given the potential importance of estrogen for the male reproductive tract function [9,29,30] and the known effects of the antiestrogen ICI 182,780 on testis and efferent ductules [12,23,25,26], we investigated the mechanism of ICI 182,780 effects, looking for alterations on the pattern of ER α and ER β protein expression in the rat efferent ductules. In addition, the expression of androgen receptors (AR) was also analyzed, given the known dependence on androgens for male tract function and the partial overlap of cellular distribution for AR and ERs [2,31,32]. It is well established that neonatal estrogen exposure causes alterations in the expression of AR [3,33–35]; therefore, we hypothesized that ER disruption in the adult could also alter AR expression in the male. Our results show that ICI 182,780 causes a dramatic decrease in ER α expression in the efferent ductules, but no change

in ER β and AR expression was observed throughout the study period.

Material and methods

Animals and treatment

Male Sprague-Dawley rats, 30 days old, were purchased from Harlan Bioproducts (Indianapolis, IN) and housed in a light (12 h of light, 12 h of darkness) and temperature (22°C) controlled environment. They were fed with commercial diet (Teklad Chow-Harlan Teklad, Madison, WI) and provided tap water ad libitum. All animal experiments were approved by the University of Illinois Division of Animal Resources and conducted in accordance with the Guide for the Care and Use of Laboratory Animals [36].

The rats were treated once per week with subcutaneous injections of ICI 182,780 (Faslodex – provided by Astra-Zeneca, Macclesfield, UK), at a dosage of 10 mg/animal in a volume of 0.2 ml of vehicle. This dosage was found to be effective for inducing effects on rat efferent ductule without inducing significant differences on body and sexual gland weights, as well as in plasma testosterone and LH levels [25,26]. The control group received the same volume of castor oil. The treatment was initiated when the rats were 30 days old and the animals were euthanized on Days 7, 15, 45, 73, 100 or 150 after the beginning of the treatment.

Immunohistochemistry

ER α , ER β and AR proteins were localized by immunohistochemistry in testes and efferent ductules of matched control and ICI 182,780 treated rats (3 animals per group). The rats were anesthetized (i.p. sodium pentobarbital 0.1 ml/100 g BW) and perfused intracardially with 10% neutral buffer formalin (NBF). After fixation, the efferent ductules were dissected out from the testes and epididymides. The efferent ductules and fragments of the testes were embedded in paraffin, sectioned at 5 μ m and mounted on electrostatically charged glass slides.

Antibodies

A mouse monoclonal antibody raised against the full-length human ER α , the NCL-ER-6F11 (Novocastra Laboratories, Newcastle, UK), was used for immunolocalization of ER α . The Genbank sequence data for the A/B region of rat and human ER α showed approximately 92% of similarity and this antibody does not cross-react with ER β [37]. For ER β detection, an affinity purified sheep polyclonal antibody (S-40) directed against a peptide specific for the hinge domain (D) of human/rat ER β was used [4]. The specificity of the ER α and ER β antibodies was confirmed by Western blot analysis and the validation for use in rat male reproductive tract was previously shown [4,37]. AR was detected by an affinity purified polyclonal

antibody (PG21-29) developed against a peptide corresponding to the first 21 amino acids of the rat/human androgen receptor [38,39].

Procedure

The immunohistochemical procedure was similar for all receptors. Tissue sections from treated and control animals at each time point were run in parallel, and the staining was performed in three different sets using one animal of each time point per set to confirm the results. Sections were dewaxed in xylene, rehydrated through a graded series of ethanol, washed in distilled water and phosphate buffer saline (PBS) and then blocked for endogenous peroxidase by incubation with 0.6% H₂O₂ in methanol for 30 min. The sections were subjected to antigen retrieval procedure by microwave irradiation in 0.01 M sodium citrate buffer pH 6.0. After washing in PBS, the avidin-biotin non-specific binding was blocked using a Vector blocking kit (Vector Laboratories, Burlingame, CA). Additional washing in PBS was performed before the next 30 min incubation in 10% normal goat or rabbit serum, for ER α , AR and ER β respectively, to prevent nonspecific binding of the antibodies. The sections were incubated overnight at 4 °C with the respective primary antibody. The dilution of the antibodies used was 1:500 for ER α and AR, and 1:1000 for ER β . For negative controls, the sections received PBS in place of the primary antibody. Prostate and testis tissue were used for positive control of the ER β and AR, respectively. Because the efferent ductules are known to express high levels of ER α [1], they served as its own positive control. After washing in PBS, the sections were exposed for 1 h to a biotinylated secondary antibody goat anti-mouse (for ER α) (Dako, Carpinteria, CA), rabbit anti-sheep (for ER β) (Vector, Burlingame, CA) and goat anti-rabbit (for AR) (Dako, Carpinteria, CA), all used at 1:100 dilution. After this step the sections were incubated with the avidin-biotin complex (Vectastain Elite ABC kit – Vector Laboratories, Burlingame, CA) for 30 min. To visualize the immunoreaction, sections were immersed in 0.05% 3,3' diaminobenzidine containing 0.01% H₂O₂ in 0.05 M Tris-HCl buffer, pH 7.6. The reaction was monitored microscopically and stopped by immersion in distilled water, after a brown color staining was visualized in control sections. Sections were finally dehydrated in ethanol, cleared in xylene and mounted. Sections stained for ER β and AR were slightly counterstained with Mayer's hematoxylin before dehydration.

Quantification

Digital images from immunohistochemical staining from efferent ductules of treated and control animals were captured. ER α on days 15, 45 and 150, ER β and AR on day 150 were analyzed. In Adobe Photoshop (San Jose, California), the images were first adjusted to equalize the background across all images to a white color. Ten nuclei

with a well-defined edge from three different efferent ductules per animal (3 animals per treatment) were pasted onto a new image for import into IPLab software (Scanalytics, Inc., Fairfax, VA). Then the mean intensity of particles per nucleus was determined after segmentation to provide complete nuclear identification. Pixel intensity means were analyzed first by One-way ANOVA followed by the Student-Newman-Keuls multiple comparisons test to detect differences between control and ICI-treatment, at individual time points. Results are presented as Means \pm SEM (Table 2) and significant differences are indicated by different superscript letters.

Results

The rat testis and efferent ductules expressed ER α and ER β , as well as AR, and the antiestrogen ICI 182,780 induced different alterations in the expression of these receptors (Table 1). Distinct cellular distribution was observed for all receptors analyzed. ER α expression was predominately expressed in the testicular interstitial space (Fig. 1) and the efferent ductule epithelium (Fig. 2). In contrast, ER β and AR were found more widely expressed in the testis (Fig. 1), rete testis, efferent ductules and initial segment of the epididymis (Fig. 3 and 4). Longitudinal sections of the efferent ductules allowed the analysis of labeling intensity in different regions of the organ (proximal, conus and terminal region) simultaneously. Immunoreactive product was not observed in the sections when PBS replaced the primary antibody.

In the testis, ER α was immunodetected in nuclei of Leydig cells and some peritubular myoid cells (Fig. 1), whereas the seminiferous epithelium and rete testis were negative (Fig. 2). The Leydig cells were stained moderately to weakly positive. The efferent ductule epithelium was stained intensely positive for ER α (Fig. 2), but the initial segment of the epididymis was negative (Fig. 2).

In the efferent ductules, ER α was located in both ciliated and nonciliated cell nuclei. However, staining intensity did vary throughout the efferent ductules, from proximal to distal regions. At the proximal end of the ducts, adjacent to the rete testis, the ciliated cells showed a more intense nuclear staining for ER α compared to the nonciliated cells (Fig 2E), but the nonciliated cell nuclear staining reached its strongest intensity in approximately the middle of the proximal region and staining intensity continued into the conus and common efferent ductules. Another interesting difference in staining in the proximal efferent ductule region was the presence of cytoplasmic staining for ER α in the ciliated cells, which contrasted with the strictly nuclear staining in the nonciliated cells (Fig. 2A, 2E, 2I). A slight cytoplasmic staining was also observed in nonciliated cells in the conus and terminal regions (Fig. 2B, 2F, 2J). ICI 182,780 caused ER α down-

Table 1: Comparison of immunohistochemical staining for ER α , ER β and AR in the testis, efferent ductules and initial segment of the epididymis of control and ICI 182,780 treated rats, as observed after 150 days of treatment.

	SC	GC	LC	PC	ED-P	ED-D	IS
ER α							
Con	-	-	++	-/+	+++	++++	-
ICI	-	-	-	-	-	+	-
ER β							
Con	+++	+	+	-/+	++++	+++	++++
ICI	+++	+	+	-/+	++++	+++	++++
AR							
Con	+++/+	-	+++	+++	++	+++	++++
ICI	+++/+	-	+++	+++	++	+++	++++

SC = Sertoli cells; GC = germ cells; LC = Leydig cells; PC = peritubular myoid cells; ED-P = proximal efferent ductules; ED-D = distal efferent ductules; IS = initial segment of the epididymis; Con = control; ICI = ICI 182,780 treated; - = negative; + = weak stain; ++ = moderate stain; +++ = strong stain; ++++ = strongest stain; -/+ = intermittent stain; +++/+ = variable intensity of stain depending on the seminiferous tubules stage.

Table 2: Quantification of immunohistochemistry for ER α , ER β and AR in the efferent ductules of control and ICI 182,780 treated rats.

Receptor	Day post treatment					
	15 ^b		45 ^b		150 ^b	
	Control	ICI	Control	ICI	Control	ICI
ER α	102.7 ± 7.0 ^a	82.3 ± 2.6 ^a	115.9 ± 3.8 ^{a, b}	78.8 ± 11.9 ^{a, c}	131.7 ± 11.1 ^{a, b}	56.3 ± 3.8 ^d
ER β					117.5 ± 10.7 ^a	131.7 ± 9.1 ^a
AR					126.3 ± 6.4 ^a	130.6 ± 9.7 ^a

Pixel intensity per unit area of the nucleus was determined and means ± SEM are reported. Significant differences are indicated by different superscripts (P < 0.05) based on ANOVA one way-analysis of variance.

regulation in efferent ductules at all time points analyzed (Fig. 2) and also in the testis (Fig 1). At day 7 there was a slight decrease in the ER α expression when control and ICI-treated animals were compared. Pixel analysis of the immunohistochemical staining revealed significant decreases (P < 0.05) in intensity on days 45 and 150 for ER α (Table 2). On days 100 and 150 (Fig. 2), ER α down-regulation was nearly complete, reaching levels nearly undetectable. Down-regulation of ER α was more pronounced in the proximal region of the efferent ductules (Fig. 2).

Positive staining for ER β was detected in the nuclei of the rete testis, efferent ductules and initial segment epithelial cells, as well as endothelial and some stromal cells (Fig. 3). An intermittent ER β positive staining was seen in smooth muscle cells surrounding the efferent ductules. The staining was weaker in the efferent ductule epithelium compared to that of the initial segment of the epididymis. There was a gradient of epithelial ER β immunoeexpression, with stronger staining at the proximal ducts than the distal region of the efferent ductules. In the testis, positive stain-

ing was present in the Sertoli and germ cells (Fig. 1). Sertoli cells were the most intensely stained for ER β , independent of the stage in the cycle of the seminiferous epithelium. A slight staining of Leydig cells was occasionally found. In the ICI-treated rats, no detectable change in ER β expression pattern was found in the testis, efferent ductules or initial segment compared to controls at all time points investigated (Fig. 1 and 3). There was no statistical difference in mean pixel intensities for ER β between control and treatment nuclei (Table 2).

Immunoreaction for AR was detected in the nuclei of ciliated and nonciliated cells of the efferent ductules, in addition to peritubular and some connective tissue cells; including smooth muscle cells of the vascular walls (Fig. 4). The peritubular cells were strongly stained throughout the efferent ductules, but a gradient of AR expression was observed for the efferent ductule epithelium. AR staining in the epithelium increased from the proximal to distal region. Rete testis and initial segment epithelial cells were strongly positive for AR in both epithelial and stromal cells. Staining of the initial segment epithelium was

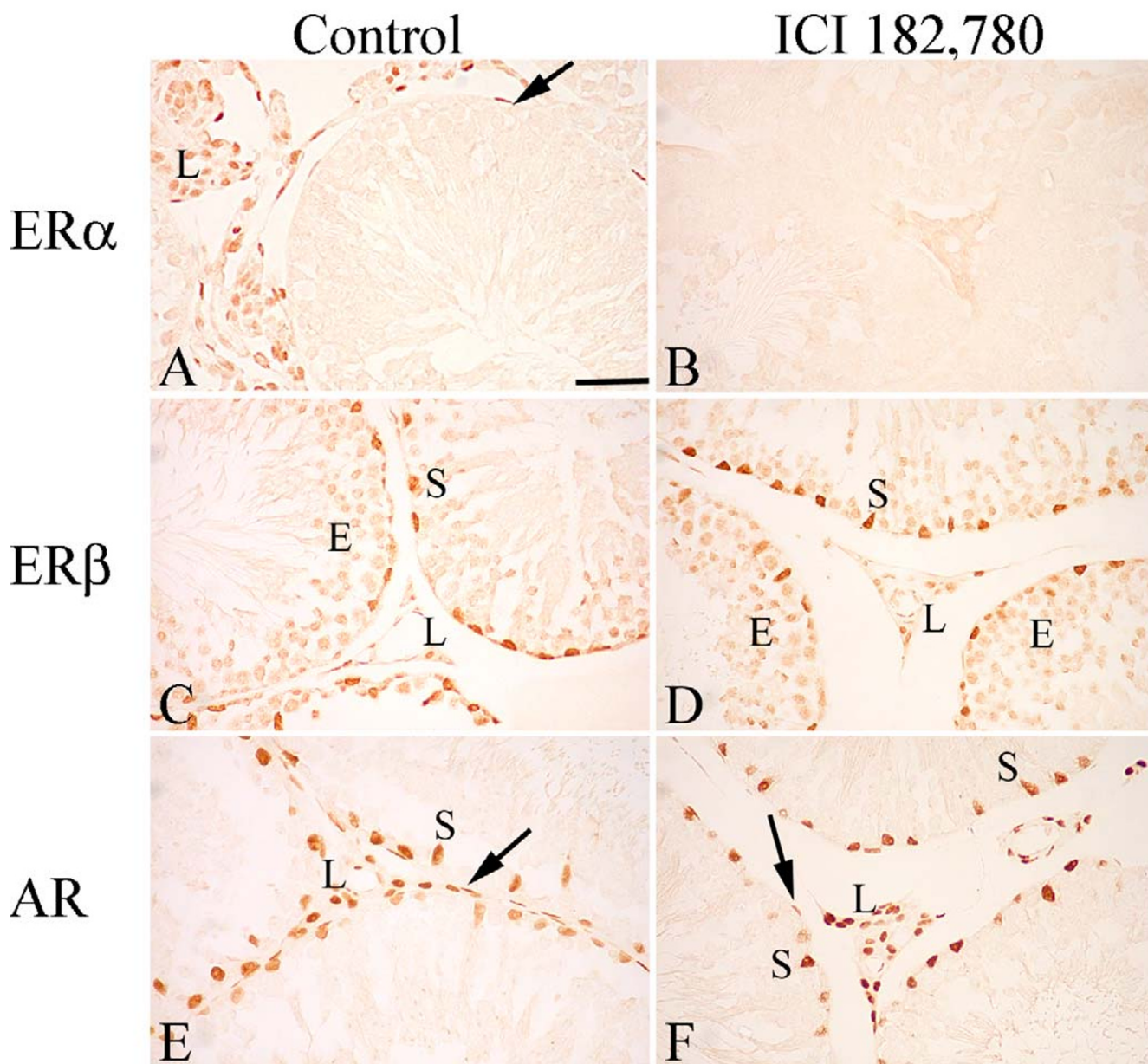


Figure 1

Effects of ICI 182, 780 in the expression of ER α , ER β and AR in the rat testis. **(A)** Leydig cells (L) and some myoid cells (arrow) are positive for ER α in the control rats. **(B)** ER α immunostaining is not detected after 100 days of ICI treatment. **(C)** ER β was strongly expressed in the Sertoli cells (S) and slightly expressed in the germ cells in the seminiferous epithelium (E) and interstitial cells (L). **(D)** The ER β expression was unaffected by the ICI treatment, as shown at day 45. **(E)** AR expression was found in the Sertoli cells (S), Leydig cells (L) and peritubular myoid cells (arrow). **(F)** There were no detectable effects on the AR expression after ICI treatment, as shown at day 45. Bar in A = 50 μ m.

stronger than that in efferent ductules. In the testis, nuclear AR-positive staining was detected in Leydig, Sertoli, peritubular myoid cells and vases smooth muscle

cells (Fig. 1). In the Sertoli cells the intensity of AR expression varied depending upon the stage of the cycle of the seminiferous epithelium. ICI 182,780 failed to alter the

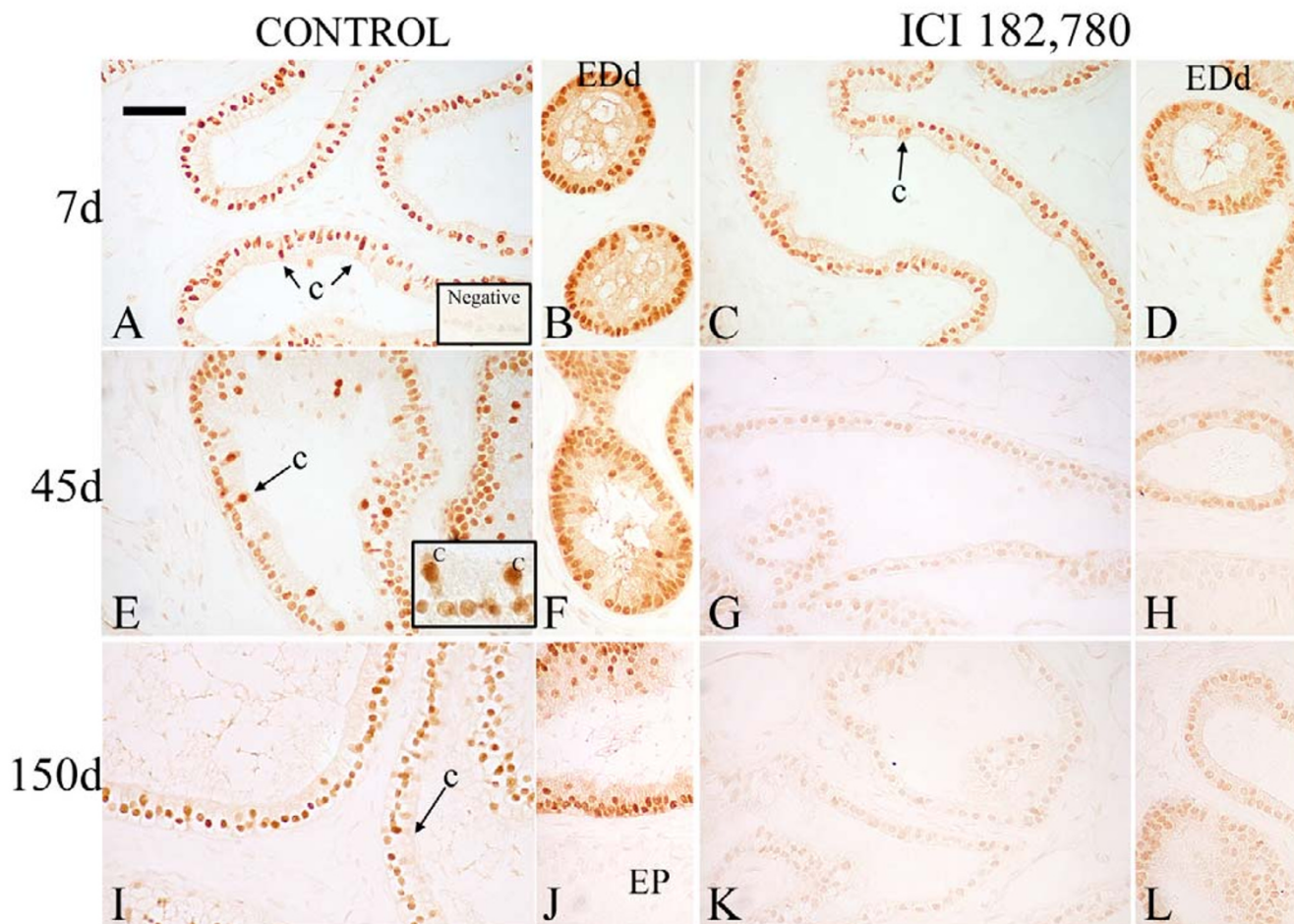


Figure 2
 Effects of ICI 182, 780 on the expression of ER α in the rat efferent ductules. In the control rats (**A, B, E, F, I, J**), ER α was expressed in the nuclei of ciliated (c) and nonciliated cells in the efferent ductules epithelium. Cytoplasmic staining was observed in the ciliated cells (c) at the proximal tubules (**A, E, I and insert in E**) and in both cell types in the distal tubules (EDd) (**B, F, J**). After 7 days of ICI treatment (**C, D**) a slight decrease in ER α was observed along the efferent ductules. On day 45 (**G, H**), ER α expression was greatly decreased with the treatment. On day 150 (**K, L**), the ER α expression was further decreased. Insert in A represents the negative control. Bar in A = 50 μ m.

pattern of expression of AR in the testis, rete testis, efferent ductules and initial segment of the epididymis compared with the respective controls at any time point studied (Fig. 1 and 4). There was no statistical difference in mean pixel intensities for AR between control and treatment nuclei (Table 2).

Discussion

ICI 182,780 treatment resulted in a dramatic decrease in ER α in the rat efferent ductules, but no detectable changes were found for ER β and AR. This study further demonstrated that ER α and ER β respond differently in the male genital tract to this antiestrogen treatment. In addition,

the present findings extend earlier data showing that these nuclear steroid receptors are expressed in the efferent ductules. However, the efferent ductule epithelium from the proximal to the distal region showed differential staining.

ER α , ER β and AR cellular distributions found in the adult rat efferent ductules and testis were consistent with those previously reported [3,32,37,40–48]. However, the present study found increasing expression of ER α and AR from the proximal to the distal region of the efferent ductules, in contrast to prior studies. The significance of this differential staining of steroid receptors along the efferent ductule epithelium is not known. However, we have

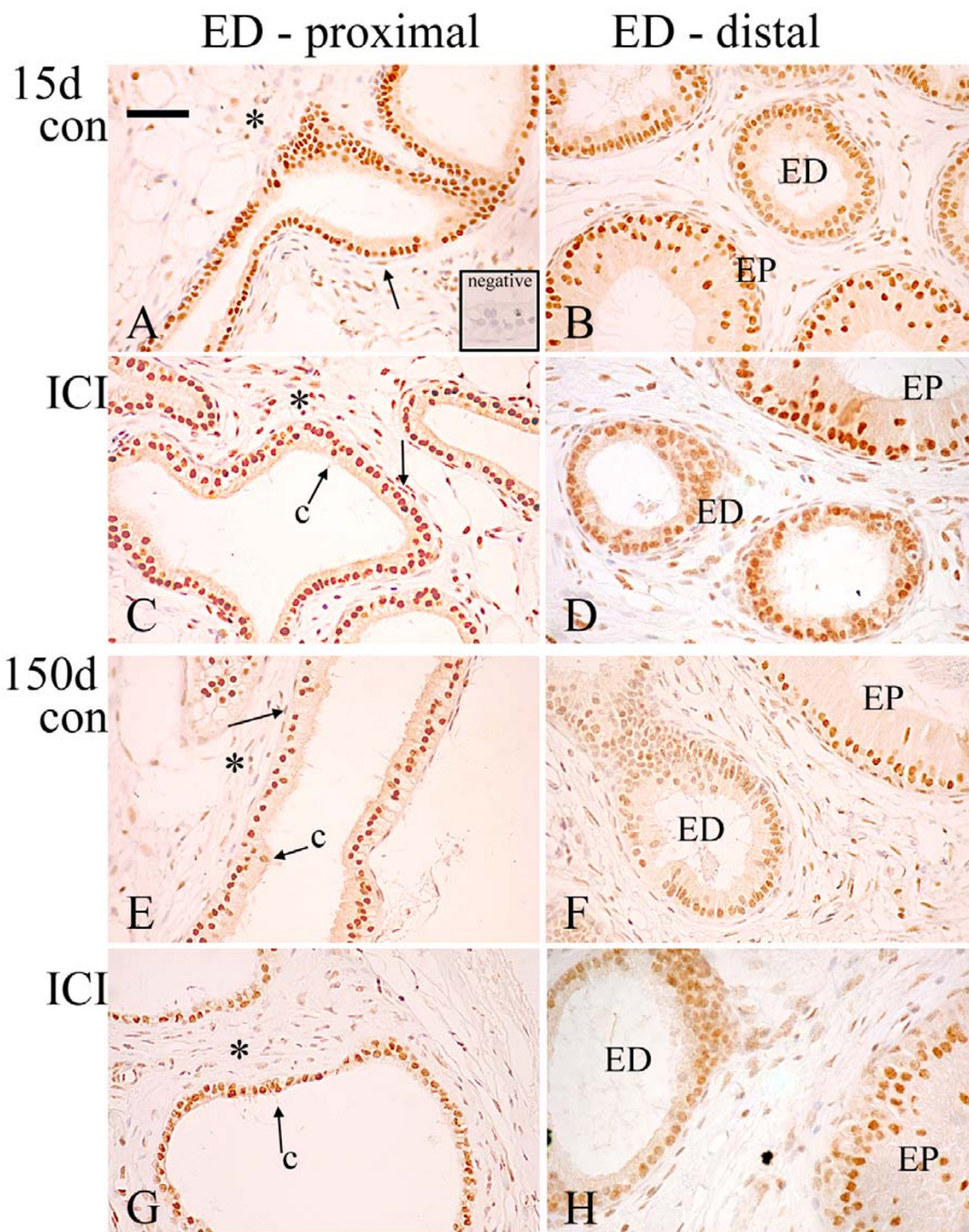


Figure 3
 Effects of ICI 182, 780 on the expression of ER β in the rat efferent ductules. In the control rats (**A, B, E, F**), ER β was expressed in the nuclei of the efferent ductules epithelial and some stromal cells (*). An intermittent staining was also detected in the peritubular cells (arrow); (c) ciliated cells. Insert in A represents the negative control. The ER β staining was stronger in the efferent ductules proximal tubules and initial segment of the epididymis when compared to the efferent ductules distal tubules. There were no detectable changes in the efferent ductules ER β expression after ICI treatment (**C, D, G, H**). EP = epididymis. Bar in A = 50 μ m.

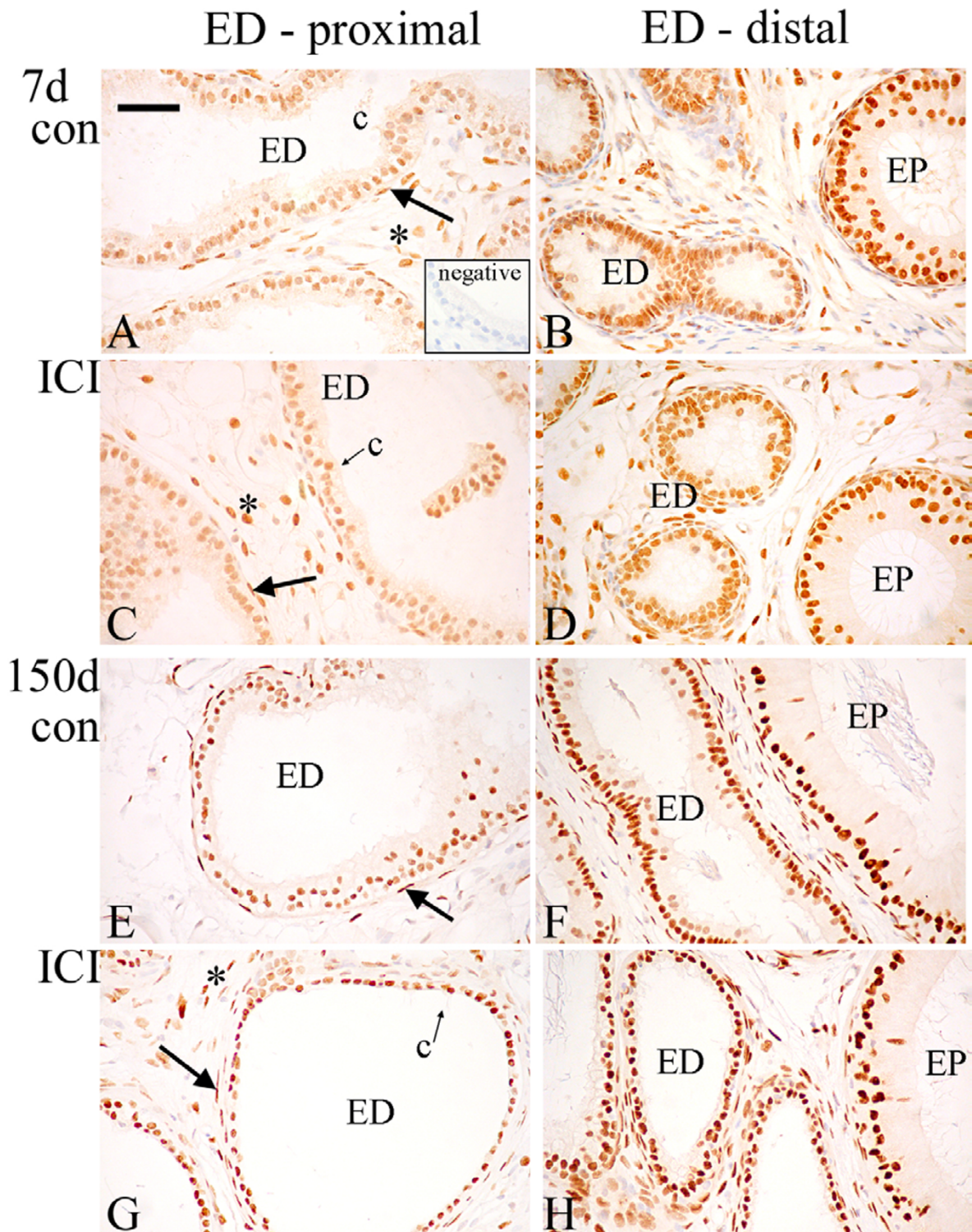


Figure 4
 Effects of ICI 182,780 on the expression of AR in the rat efferent ductules. In the control rats (**A, B, E, F**), AR expression was found in the nuclei of the efferent ductules epithelial, peritubular (arrow) and some stromal cells (*). The AR staining in the proximal tubules was weaker than that on distal tubules and initial segment of the epididymis (EP). (c) Ciliated cells. Insert in **A** represents the negative control. After ICI treatment (**C, D, G, H**), the AR expression was apparently unchanged along the efferent ductules. Bar in **A** = 50 μ m.

previously observed an expression pattern for the sodium/hydrogen exchanger (NHE3) protein that is similar to the ER α and AR staining [26]. It is noteworthy that an opposite pattern of staining was observed for ER β . NHE3 appears to be one of the most important molecules in mediating fluid reabsorption in the efferent ductules [12,49]. NHE3 expression in the efferent ductules has been shown to be regulated by estrogen at the protein and mRNA levels [12,26], therefore differential expression of NHE3 and ER α is consistent with these prior physiological studies.

The immunohistochemical demonstration of cytoplasmic staining for ER α in the ciliated cells of the efferent ductules was an intriguing observation. Although previous studies [1,2,37] did not discuss this difference, a reexamination of figures published by Hess et al (1997b) and Nie et al (2002) showed cytoplasmic staining in the ciliated cells from the rat and cat, respectively. ER α cytoplasmic distribution has also been described in other tissues [50,51]. It was shown that different accessibility of the ER to the reagents depending upon the functional activity of the estradiol-controlled cells could interfere with subcellular immunolocalization of the receptor [50,52]. In agreement with this finding, ER α and ER β were more frequently localized to the cytoplasm of resting uterine cells [51] and human breast cells [45]. In addition, species differences in the ER α staining of efferent ductules epithelial cells has also been noted, with goat and primate ciliated cells being negative [37,53]. In this sense, one possibility is that ciliated cells of the efferent ductules have a lower requirement for estradiol-induced activity than do the nonciliated cells. This would be consistent with the known function of efferent ductules, reabsorption of 96% of the luminal fluid [54], which is more dependent on the nonciliated cells than the ciliated cells.

ICI 182,780 decreased the expression of ER α in both testis and efferent ductules, but ER β and AR were not altered by the treatment. The down-regulation of ER α protein following ICI treatment has already been described in other tissues, but most of the studies were performed on female reproductive organs or cell cultures [55–58]. The down-regulation of ER α protein by ICI is thought to be due to a change in the ER α conformation, which leads to a rapid loss of the receptor [55,59,60]. At first, lysosomes were thought to serve as the organelle that degrades ER α after estradiol or antiestrogen treatment [51,61]. However, recent *in vitro* experiments provided evidence that the ER α degradation occurs through the 26S proteasome pathway, but not lysosomes [62–64]. In the present study, the reduction in ER α nuclear staining after ICI 182,780 treatment was not followed by an increase in the cytoplasmic staining of the nonciliated cells, as described for other cell types *in vitro* [57,65,66]. However, a transient

increase of nearly 170% in lysosomal area in ICI-treated rat nonciliated cells was recently described [25,26]. Thus, further study of proteasomal and lysosomal degradation of steroid receptors in the male is warranted.

The fact that ER α , but not ER β , was down-regulated by ICI 182,780 in the rat efferent ductules, suggests that the ER subtypes are regulated in a different manner in this tissue. In agreement with our results showing approximately 60% decrease in the ER α level after ICI-treatment, other have shown that ICI 182,780 is similar to estradiol in its ability to decrease its receptor approximately 50% [62,64]. This effect differs from that of the partial ER antagonist Tamoxifen, which was incapable of down-regulating ER α , suggesting the existence of ligand-specific regulation of ER α [64]. These data may also be helpful in the development of an appropriate antiestrogenic chemical that targets ER α function selectively in efferent ductules of the male reproductive tract, permitting the development of a novel male contraceptive.

Differential regulation of ER α and ER β should not be surprising, because regardless of their structural homology [14], several functional differences between both ER subtypes have been found [19,20,22,67]. In addition, there are now reported several differential effects of ICI 182,780 on ER α and ER β [16,28,68–71]. In support of our results, neonatal diethylstilbestrol (DES) treatment has also shown differential changes in ER α , but not ER β immunoprecipitation in the male rat reproductive tract [3]. In contrast to the data presented here, which suggests that ER α does not have a direct regulatory effect on AR expression in testis and efferent ductules, in the prostate gland AR has been shown to be down regulated by estrogens in a lobe-specific manner during development [38,72]. Although the prostate effect appears to be mediated through ER α , as AR expression in the α ERKO male is normal even following DES treatment [72], ER β cannot be ignored because DES treatment of the β ERKO males during the perinatal period also induced a lobe-dependent decreased expression of AR [72].

ER β expression in the male reproductive system is rather extensive [1,14,30,43,44], but targeted disruption of ER β has not resulted in any significant pathogenesis in the male [11,13], and estrogen and antiestrogen treatment has not caused effects on the expression of ER β . It has been proposed that ER β modulates ER α effects in the uterus [13,73,74] and cervix [75], but currently, the role of ER β in the male tract remains uncertain. A recent study using α ERKO and ICI-treated normal and α ERKO mice [24] attributed to ER β a role in mediating the estrogen down-regulation of several ion transporter (CFTR, DRA and NA/K ATPase). However, they did not account for the

maintenance of ER β expression and possibly functional activity in α ERKO and after ICI treatment.

Conclusions

The results obtained by treating adult male rats with the pure antiestrogen ICI 182,780 show that ER α and ER β expression are regulated by different mechanisms in the testis and epididymis. ICI 182,780 binds to both receptors but only causes the disappearance of the ER α protein. The expression of AR was unaffected by the antiestrogen in testis and epididymis.

Authors' contributions

CAO helped to design the study and carried out the experiments and wrote the first draft of the manuscript. RN assisted with the immunohistochemistry. KC provided laboratory assistance. LRF helped in the design of the study and served as advisor to CAO. GSP provided the AR antibody and consultation in its use. PTKS provided the ER β antibody and consultation in its use. RAH served as PI on this project and helped with study design. All authors read and approved the final manuscript.

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References

- Hess RA, Gist DH, Bunick D, Lubahn DB, Farrell A, Bahr J, Cooke PS and Greene GL: **Estrogen receptor (a & b) expression in the excurrent ducts of the adult male rat reproductive tract.** *J Androl* 1997, **18**:602-611.
- Nie R, Zhou Q, Jassim E, Saunders PT and Hess RA: **Differential expression of estrogen receptors a and b in the reproductive tracts of adult male dogs and cats.** *Biol Reprod* 2002, **66**:1161-1168.
- Atanassova N, McKinnell C, Williams K, Turner KJ, Fisher JS, Saunders PT, Millar MR and Sharpe RM: **Age-, cell- and region-specific immunoeexpression of estrogen receptor alpha (but not estrogen receptor beta) during postnatal development of the epididymis and vas deferens of the rat and disruption of this pattern by neonatal treatment with diethylstilbestrol.** *Endocrinology* 2001, **142**:874-886.
- Williams K, Saunders PTK, Atanassova N, Fisher JS, Turner KJ, Millar MR, McKinnell C and Sharpe RM: **Induction of progesterone receptor immunoeexpression in stromal tissue throughout the male reproductive tract after neonatal oestrogen treatment of rats.** *Mol Cell Endocrinol* 2000, **164**:117-131.
- Saunders PT, Sharpe RM, Williams K, Macpherson S, Urquart H, Irvine DS and Millar MR: **Differential expression of oestrogen receptor alpha and beta proteins in the testes and male reproductive system of human and non-human primates.** *Mol Hum Reprod* 2001, **7**:227-236.
- Zhou Q, Nie R, Prins GS, Saunders PT, Katzenellenbogen BS and Hess RA: **Localization of androgen and estrogen receptors in adult male mouse reproductive tract.** *J Androl* 2002, **23**:870-881.
- Lubahn DB, Moyer JS, Golding TS, Couse JF, Korach KS and Smithies O: **Alteration of reproductive function but not prenatal sexual development after insertional disruption of the mouse estrogen receptor gene.** *Proc Natl Acad Sci USA* 1993, **90**:11162-11166.
- Eddy EM, Washburn TF, Bunch DO, Goulding EH, Gladen BC, Lubahn DB and Korach KS: **Targeted disruption of the estrogen receptor gene in male mice causes alteration of spermatogenesis and infertility.** *Endocrinol* 1996, **137**:4796-4805.
- Hess RA, Bunick D, Lee KH, Bahr J, Taylor JA, Korach KS and Lubahn DB: **A role for oestrogens in the male reproductive system.** *Nature* 1997, **390**:509-512.
- Couse JF and Korach KS: **Exploring the role of sex steroids through studies of receptor deficient mice [see comments].** *J Mol Med* 1998, **76**:497-511.
- Dupont S, Krust A, Gansmuller A, Dierich A, Chambon P and Mark M: **Effect of single and compound knockouts of estrogen receptors a (ER a) and b (ER b) on mouse reproductive phenotypes.** *Development* 2000, **127**:4277-4291.
- Zhou Q, Clarke L, Nie R, Carnes K, Lai LW, Lien YH, Verkman A, Lubahn D, Fisher JS, Katzenellenbogen BS and Hess RA: **Estrogen action and male fertility: Roles of the sodium/hydrogen exchanger-3 and fluid reabsorption in reproductive tract function.** *Proc Natl Acad Sci U S A* 2001, **98**:14132-14137.
- Krege JH, Hodgin JB, Couse JF, Enmark E, Warner M, Mahler JF, Sar M, Korach KS, Gustafsson JA and Smithies O: **Generation and reproductive phenotypes of mice lacking estrogen receptor beta.** *Proc Natl Acad Sci USA* 1998, **95**:15677-15682.
- Kuiper GG, Enmark E, Peltto-Huikko M, Nilsson S and Gustafsson JA: **Cloning of a novel receptor expressed in rat prostate and ovary.** *Proc. Natl. Acad. Sci. U.S.A.* 1996, **93**:5925-5930.
- Mosselman S, Polman J and Dijkema R: **ER beta: identification and characterization of a novel human estrogen receptor.** *FEBS Lett* 1996, **392**:49-53.
- Tremblay GB, Tremblay A, Copeland NG, Gilbert DJ, Jenkins NA, Labrie F and Giguere V: **Cloning, chromosomal localization, and functional analysis of the murine estrogen receptor beta.** *Mol Endocrinol* 1997, **11**:353-365.
- Kuiper GG, Carlsson B, Grandien K, Enmark E, Haggblad J, Nilsson S and Gustafsson JA: **Comparison of the ligand binding specificity and transcript tissue distribution of estrogen receptors alpha and beta.** *Endocrinol* 1997, **138**:863-870.
- Harris HA, Bapat AR, Gonder DS and Frail DE: **The ligand binding profiles of estrogen receptors a and b are species dependent.** *Steroids* 2002, **67**:379-384.
- Paech K, Webb P, Kuiper Ggjm, Nilsson S, Gustafsson J, Angst, Kushner PJ and Scanlan TS: **Differential ligand activation of estrogen receptors ERalpha and ERbeta at API sites.** *Science* 1997, **277**:1508-1510.
- Pennie WD, Aldridge TC and Brooks AN: **Differential activation by xenoestrogens of ERa and ERb when linked to different response elements.** *J Endocrinol* 1998, **158**:R11-R14.
- Loven MA, Wood JR and Nardulli AM: **Interaction of estrogen receptors alpha and beta with estrogen response elements.** *Mol Cell Endocrinol* 2001, **181**:151-163.
- Schultz JR, Loven MA, Melvin VM, Edwards DP and Nardulli AM: **Differential modulation of DNA conformation by estrogen receptors alpha and beta.** *J Biol Chem* 2002, **277**:8702-8707.
- Lee KH, Hess RA, Bahr JM, Lubahn DB, Taylor J and Bunick D: **Estrogen receptor alpha has a functional role in the mouse rete testis and efferent ductules.** *Biol Reprod* 2000, **63**:1873-1880.
- Lee KH, Finnigan-Bunick C, Bahr J and Bunick D: **Estrogen Regulation of Ion Transporter Messenger RNA Levels in Mouse Efferent Ductules Are Mediated Differentially Through Estrogen Receptor (ER) alpha and ERbeta.** *Biol Reprod* 2001, **65**:1534-1541.
- Oliveira CA, Carnes K, Franca LR and Hess RA: **Infertility and testicular atrophy in the antiestrogen-treated adult male rat.** *Biol Reprod* 2001, **65**:913-920.
- Oliveira CA, Zhou Q, Carnes K, Nie R, Kuehl DE, Jackson GL, Franca LR, Nakai M and Hess RA: **ER Function in the Adult Male Rat: Short- and Long-Term Effects of the Antiestrogen ICI 182,780 on the Testis and Efferent Ductules, without Changes in Testosterone.** *Endocrinology* 2002, **143**:2399-2409.
- Wakeling AE: **Similarities and distinctions in the mode of action of different classes of antioestrogens.** *Endocr Relat Cancer* 2000, **7**:17-28.
- Paige LA, Christensen DJ, Gron H, Norris JD, Gottlin EB, Padilla KM, Chang CY, Ballas LM, Hamilton PT, McDonnell DP and Fowlkes DM: **Estrogen receptor (ER) modulators each induce distinct conformational changes in ER alpha and ER beta.** *Proc Natl Acad Sci U S A* 1999, **96**:3999-4004.
- Hess RA, Bunick D and Bahr J: **Oestrogen, its receptors and function in the male reproductive tract - a review.** *Mol Cell Endocrinol* 2001, **178**:29-38.

30. Hess RA: **Estrogen in the adult male reproductive tract: A review.** *Reprod Biol Endocrinol* 2003, **1**:52-65.
31. Sar M and Welsch F: **Oestrogen receptor alpha and beta in rat prostate and epididymis.** *Andrologia* 2000, **32**:295-301.
32. Turner KJ, Morley M, MacPherson S, Millar MR, Wilson JA, Sharpe RM and Saunders PT: **Modulation of gene expression by androgen and oestrogens in the testis and prostate of the adult rat following androgen withdrawal.** *Mol Cell Endocrinol* 2001, **178**:73-87.
33. Newbold RR, Bullock BC and McLachlan JA: **Mullerian remnants of male mice exposed prenatally to diethylstilbestrol.** *Teratog Carcinog Mutagen* 1987, **7**:377-389.
34. Tena-Sempere M, Navarro J, Pinilla L, Gonzalez LC, Huhtaniemi I and Aguilar E: **Neonatal exposure to estrogen differentially alters estrogen receptor alpha and beta mRNA expression in rat testis during postnatal development.** *J Endocrinol* 2000, **165**:345-357.
35. Prins GS, Birch L and Greene GL: **Androgen receptor localization in different cell types of the adult rat prostate.** *Endocrinol* 1991, **129**:3187-3199.
36. NRC: **Guide for the care and use of laboratory animals.** National Research Council Washington, D.C., National Academy Press; 1996:125.
37. Fisher JS, Millar MR, Majdic G, Saunders PT, Fraser HM and Sharpe RM: **Immunolocalisation of oestrogen receptor-alpha within the testis and excurrent ducts of the rat and marmoset monkey from perinatal life to adulthood.** *J Endocrinol* 1997, **153**:485-495.
38. Prins GS: **Neonatal estrogen exposure induces lobe-specific alterations in adult rat prostate androgen receptor expression.** *Endocrinology* 1992, **130**:3703-3714.
39. Prins GS and Birch L: **The developmental pattern of androgen receptor expression in rat prostate lobes is altered after neonatal exposure to estrogen.** *Endocrinology* 1995, **136**:1303-1314.
40. Cooke PS, Young P, Hess RA and Cunha GR: **Estrogen receptor expression in developing epididymis, efferent ductules, and other male reproductive organs.** *Endocrinology* 1991, **128**:2874-2879.
41. Roselli CE, West NB and Brenner RM: **Androgen receptor and 5 alpha-reductase activity in the ductuli efferentes and epididymis of adult rhesus macaques.** *Biol Reprod* 1991, **44**:739-745.
42. Zhu LJ, Hardy MP, Inigo IV, Huhtaniemi I, Bardin CW and Moo-Young AJ: **Effects of androgen on androgen receptor expression in rat testicular and epididymal cells: a quantitative immunohistochemical study.** *Biol Reprod* 2000, **63**:368-376.
43. Saunders PT, Fisher JS, Sharpe RM and Millar MR: **Expression of oestrogen receptor beta (ER beta) occurs in multiple cell types, including some germ cells, in the rat testis.** *J Endocrinol* 1998, **156**:R13-7.
44. van Pelt AM, de Rooij DG, van der Burg B, van der Saag PT, Gustafsson JA and Kuiper GG: **Ontogeny of estrogen receptor-beta expression in rat testis.** *Endocrinology* 1999, **140**:478-483.
45. Taylor AH and Al-Azzawi F: **Immunolocalisation of oestrogen receptor beta in human tissues.** *J Mol Endocrinol* 2000, **24**:145-155.
46. Sar M, Lubahn DB, French FS and Wilson EM: **Immunohistochemical localization of the androgen receptor in rat and human tissues.** *Endocrinol* 1990, **127**:3180-3186.
47. Pelletier G: **Localization of androgen and estrogen receptors in rat and primate tissues.** *Histol Histopathol* 2000, **15**:1261-1270.
48. Suarez-Quian CA, Martinez-Garcia F, Nistal M and Regadera J: **Androgen receptor distribution in adult human testis.** *J Clin Endocrinol Metab* 1999, **84**:350-358.
49. Hansen LA, Clulow J and Jones RC: **The role of Na⁺-H⁺ exchange in fluid and solute transport in the rat efferent ducts.** *Exp Physiol* 1999, **84**:521-527.
50. Sierralta WD, Bonig I and Thole HH: **Immunogold labeling of estradiol receptor in MCF7 cells.** *Cell Tissue Res* 1995, **279**:445-452.
51. Qualmann B, Kessels MM, Thole HH and Sierralta WD: **A hormone pulse induces transient changes in the subcellular distribution and leads to a lysosomal accumulation of the estradiol receptor alpha in target tissues.** *Eur J Cell Biol* 2000, **79**:383-393.
52. Sierralta WD and Thole HH: **Retrieval of estradiol receptor in paraffin sections of resting porcine uteri by microwave treatment.** *Immunostaining patterns obtained with different primary antibodies.* *Histochem Cell Biol* 1996, **105**:357-363.
53. Goyal HO, Bartol FF, Wiley AA, Khalil MK, Chiu J and Vig MM: **Immunolocalization of androgen receptor and estrogen receptor in the developing testis and excurrent ducts of goats.** *Anat Rec* 1997, **249**:54-62.
54. Clulow J, Jones RC, Hansen LA and Man SY: **Fluid and electrolyte reabsorption in the ductuli efferentes testis.** *J Reprod Fertil Suppl* 1998, **53**:1-14.
55. Wijayaratne AL, Nagel SC, Paige LA, Christensen DJ, Norris JD, Fowlkes DM and McDonnell DP: **Comparative analyses of mechanistic differences among antiestrogens.** *Endocrinology* 1999, **140**:5828-5840.
56. Bentrem D, Dardes R, Liu H, MacGregor-Schafer J, Zapf J and Jordan V: **Molecular mechanism of action at estrogen receptor alpha of a new clinically relevant antiestrogen (GW7604) related to tamoxifen.** *Endocrinology* 2001, **142**:838-846.
57. Stenoien DL, Patel K, Mancini MG, Dutertre M, Smith CL, O'Malley BW and Mancini MA: **FRAP reveals that mobility of oestrogen receptor-alpha is ligand- and proteasome-dependent.** *Nat Cell Biol* 2001, **3**:15-23.
58. Wijayaratne AL and McDonnell DP: **The human estrogen receptor-alpha is a ubiquitinated protein whose stability is affected differentially by agonists, antagonists, and selective estrogen receptor modulators.** *J Biol Chem* 2001, **276**:35684-35692.
59. Gibson MK, Nemmers LA, Beckman W. C., Jr., Davis VL, Curtis SW and Korach KS: **The mechanism of ICI 164,384 antiestrogenicity involves rapid loss of estrogen receptor in uterine tissue.** *Endocrinology* 1991, **129**:2000-2010.
60. Dauvois S, Danielian PS, White R and Parker MG: **Antiestrogen ICI 164,384 reduces cellular estrogen receptor content by increasing its turnover.** *Proc Natl Acad Sci U S A* 1992, **89**:4037-4041.
61. Borrás M, Laios I, el Khissiin A, Seo HS, Lempereur F, Legros N and Leclercq G: **Estrogenic and antiestrogenic regulation of the half-life of covalently labeled estrogen receptor in MCF-7 breast cancer cells.** *J Steroid Biochem Mol Biol* 1996, **57**:203-213.
62. Alarid ET, Bakopoulos N and Solodin N: **Proteasome-mediated proteolysis of estrogen receptor: a novel component in autologous down-regulation.** *Mol Endocrinol* 1999, **13**:1522-1534.
63. Lonard DM, Nawaz Z, Smith CL and O'Malley BW: **The 26S proteasome is required for estrogen receptor-alpha and coactivator turnover and for efficient estrogen receptor-alpha transactivation.** *Mol Cell* 2000, **5**:939-948.
64. Preisler-Mashek MT, Solodin N, Stark BL, Tyrivier MK and Alarid ET: **Ligand-specific regulation of proteasome-mediated proteolysis of estrogen receptor-alpha.** *Am J Physiol Endocrinol Metab* 2002, **282**:E891-8.
65. Dauvois S, White R and Parker MG: **The antiestrogen ICI 182780 disrupts estrogen receptor nucleocytoplasmic shuttling.** *J Cell Sci* 1993, **106**:1377-1388.
66. Htun H, Holth LT, Walker D, Davie JR and Hager GL: **Direct visualization of the human estrogen receptor alpha reveals a role for ligand in the nuclear distribution of the receptor.** *Mol Biol Cell* 1999, **10**:471-486.
67. Fournier B, Gutzwiller S, Dittmar T, Matthias G, Steenbergh P and Matthias P: **Estrogen receptor (ER)-alpha, but not ER-beta, mediates regulation of the insulin-like growth factor I gene by antiestrogens.** *J Biol Chem* 2001, **276**:35444-35449.
68. Pace P, Taylor J, Suntharalingam S, Coombes RC and Ali S: **Human estrogen receptor beta binds DNA in a manner similar to and dimerizes with estrogen receptor alpha.** *J Biol Chem* 1997, **272**:25832-25838.
69. Van Den Bermd GJ, Kuiper GG, Pols HA and Van Leeuwen JP: **Distinct Effects on the Conformation of Estrogen Receptor alpha and beta by Both the Antiestrogens ICI 164,384 and ICI 182,780 Leading to Opposite Effects on Receptor Stability.** *Biochem Biophys Res Commun* 1999, **261**:1-5.
70. Pike AC, Brzozowski AM, Walton J, Hubbard RE, Thorsell A, Li Y, Gustafsson J and Carlquist M: **Structural Insights into the Mode of Action of a Pure Antiestrogen.** *Structure (Camb)* 2001, **9**:145-153.
71. Wade JB, Welling PA, Donowitz M, Shenolikar S and Weinman EJ: **Differential renal distribution of NHERF isoforms and their colocalization with NHE3, ezrin, and ROMK.** *Am J Physiol Cell Physiol* 2001, **280**:C192-8.

72. Prins GS, Birch L, Couse JF, Choi I, Katzenellenbogen B and Korach KS: **Estrogen imprinting of the developing prostate gland is mediated through stromal estrogen receptor alpha: studies with alphaERKO and betaERKO mice.** *Cancer Res* 2001, **61**:6089-6097.
73. Hall JM and McDonnell DP: **The estrogen receptor beta-isoform (ERbeta) of the human estrogen receptor modulates ERalpha transcriptional activity and is a key regulator of the cellular response to estrogens and antiestrogens.** *Endocrinology* 1999, **140**:5566-5578.
74. Weihua Z, Saji S, Makinen S, Cheng G, Jensen EV, Warner M and Gustafsson JA: **Estrogen receptor (ER) beta, a modulator of ERalpha in the uterus.** *Proc Natl Acad Sci U S A* 2000, **97**:5936-5941.
75. Gorodeski GI and Pal D: **Involvement of estrogen receptors alpha and beta in the regulation of cervical permeability.** *Am J Physiol Cell Physiol* 2000, **278**:C689-96.

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