



**HAL**  
open science

**The effects of an in utero exposure to  
2,3,7,8-tetrachloro-dibenzo-p-dioxin on male  
reproductive function: identification of Ccl5 as a  
potential marker.**

Diane Rebourcet, Fanny Odet, Adélie Vérot, Emmanuel Combe, Emmanuelle Meugnier, Sandra Pesenti, Patrick Leduque, Henri Déchaud, Solange Magre, Brigitte Le Magueresse-Battistoni

► **To cite this version:**

Diane Rebourcet, Fanny Odet, Adélie Vérot, Emmanuel Combe, Emmanuelle Meugnier, et al.. The effects of an in utero exposure to 2,3,7,8-tetrachloro-dibenzo-p-dioxin on male reproductive function: identification of Ccl5 as a potential marker.. International Journal of Andrology, 2010, 33 (2), pp.413-24. 10.1111/j.1365-2605.2009.01020.x . inserm-00816469

**HAL Id: inserm-00816469**

**<https://inserm.hal.science/inserm-00816469>**

Submitted on 22 Apr 2013

**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.

1 The effects of an in utero exposure to 2,3,7,8-tetrachlorodibenzo-p-dioxin on male  
2 reproductive function. Identification of Ccl5 as a potential marker.

3  
4 short title: dioxin and male reproductive function

5  
6 Keywords: 2,3,7,8-tetrachlorodibenzo-p-dioxin, in utero exposure, testis, sperm count,  
7 transcriptomic analysis, Ccl5/Rantes

8  
9  
10 Diane Rebourcet <sup>1,2,3,4,5</sup>, Fanny Odet <sup>4</sup>, Adélie Vérot <sup>4</sup>, Emmanuel Combe <sup>1,2,3,4,5</sup>,  
11 Emmanuelle Meugnier <sup>1,2,3,4,5</sup>, Sandra Pesenti <sup>1,2,3,4,5</sup>, Patrick Leduque <sup>4</sup>, Henri Déchaud <sup>4,5,6</sup>,  
12 Solange Magre <sup>7</sup>, Brigitte Le Magueresse-Battistoni <sup>1,2,3,4,5</sup> ;

13  
14 <sup>1</sup>Inserm, U870, Oullins, France; <sup>2</sup>INRA, UMR1235, Oullins, France; <sup>3</sup>INSA-Lyon, RMND,  
15 Villeurbanne, France; <sup>4</sup>Université Lyon 1, Lyon, France; <sup>5</sup>Hospices Civils de Lyon, Lyon,  
16 France

17 <sup>6</sup>Inserm U863, Lyon ;

18 <sup>7</sup>CNRS EAC 7059, Université Paris 7.

19 Address for correspondence: Brigitte Le Magueresse-Battistoni, Inserm U870 INRA 1235,  
20 Faculté de médecine Lyon-Sud, 165 Chemin du Grand Revoyet, BP 12, 69921 Oullins cedex,  
21 France.

22 email address : [brigitte.lemagueresse@inserm.fr](mailto:brigitte.lemagueresse@inserm.fr)

23 Tel 33 4 26 23 59 19; Fax 33 4 26 23 59 16

24

25

26

27 Summary

28 TCDD (2,3,7,8-tetrachlorodibenzo-p-dioxin) and dioxin-like compounds are widely  
29 encountered toxic substances suspected of interfering with the endocrine systems of humans  
30 and wildlife and of contributing to the loss of fertility. In this study, we determined the  
31 changes in testicular gene expression caused by in utero exposure to TCDD along with the  
32 intra-testicular testosterone levels, epididymal sperm reserves, daily sperm production (DSP),  
33 and testis histology. To this purpose, female pregnant Sprague-Dawley rats orally received  
34 TCDD (10, 100 or 200 ng/kg bodyweight) or vehicle at embryonic day 15, and the offspring  
35 was sacrificed killed throughout development. Hepatic Cyp1a1 gene expression was  
36 measured in the offspring to confirm the exposure to TCDD. The gross histology of the testes  
37 and intra-testicular testosterone levels were normal among the studied groups. Sperm reserves  
38 were altered in 67-day-old rats of the TCDD-200 group, but not in 145-day-old animals or in  
39 the other TCDD-exposed groups. Nonetheless, fertility was not altered in males of the TCDD-  
40 200 group, and the F2 males generated had normal sperm reserves and DSP. Microarray  
41 analysis permitted the identification of 8 eight differentially expressed genes in the 4-week-  
42 old testes of the TCDD-200 compared with that of the control group (cut-off  $\pm 1.40$ ), including  
43 the down-regulated chemokine Ccl5/Rantes. Inhibition of Ccl5/Rantes gene expression was  
44 observed throughout development in the TCDD-200 group, and at 67 and 145 days in the  
45 TCDD-100 group (animals of younger ages were not examined). Ccl5/Rantes gene expression  
46 was mostly confined in Leydig cells. F2 males generated from males of the TCDD-200 group  
47 had normal levels of Ccl5/Rantes in testis and Cyp1a1 in liver, which might indicate that  
48 Ccl5/Rantes is a marker of TCDD exposure in testis such as Cyp1a1 in liver. In conclusion,  
49 we demonstrated a decrease in Ccl5/Rantes RNA levels and a transitory decline in sperm  
50 reserves in the testes of rats of TCDD-dosed dams.

51

52 **Introduction**

53 2,3,7,8-tetrachloro-dibenzo-*p*-dioxin (TCDD) and dioxin-like compounds are widely  
54 encountered toxic substances suspected of interfering with the endocrine systems of humans  
55 and wildlife (Hotchkiss et al., 2008; Diamanti-Kandarakis et al., 2009). They form a large  
56 group of structurally-related compounds of which the most toxic is TCDD (Van den Berg et  
57 al., 2006). Dioxins are not intentionally produced but are generated as undesired by-products  
58 in various industrial processes. They are persistent and, being fat soluble, tend to accumulate  
59 in higher animals, including humans. They are found in all environmental compartments  
60 although dioxin levels have been decreasing in the recent years in European countries for  
61 example, to secure better protection of human health, in particular of children (Lundqvist et  
62 al., 2006). Indeed, endocrine disrupters are suspected to be responsible for apparent changes  
63 seen over the recent decades, including congenital malformations, cancer and declining sperm  
64 counts. Genetic abnormalities are rare and cannot account for the rapid pace of the increase of  
65 reproductive disorders. The concept of Testicular Dysgenesis Syndrome (TDS) was therefore  
66 proposed (Skakkebaek et al., 2001). It enacts that the adverse changes, i.e., cryptorchidism,  
67 hypospadias, impaired spermatogenesis and testicular germ cell cancer, are inter-related and  
68 find common origins in fetal life or childhood. Supporting the concept of environmental  
69 influence was the demonstration in rats that foetal exposure to high doses of dibutyl phthalate  
70 causes a TDS-like phenotype (Fisher et al., 2003; Sharpe & Skakkebaek, 2008).

71 Today, dioxins are found in all humans, and exposure to dioxins in the general  
72 population of the European Union for instance, is at a level where subtle health effects might  
73 occur and it is, therefore, of utmost importance to improve the assessment of health risk (Gies  
74 et al., 2007). Dioxins are not genotoxic but cause a broad spectrum of adverse effects  
75 including hepatotoxicity, immune system suppression, developmental toxicity, and skin  
76 defects. Meanwhile, there are still controversial data regarding the impact of dioxins on the

77 male reproductive function, specifically in case of maternal exposure. Parameters previously  
78 investigated included at least measurement of testosterone levels, testis weight and sperm  
79 reserves in the offspring of dosed rat or mouse dams. Declining epididymal sperm reserves  
80 were often (Mably *et al.*, 1992; Gray *et al.*, 1995; Theobald & Peterson, 1997; Faqi *et al.*,  
81 1998; Simanainen *et al.*, 2004) but not systematically (Wilker *et al.*, 1996; Ohsako *et al.*,  
82 2001; 2002; Ikeda *et al.*, 2005; Bell *et al.*, 2007a) reported. Besides, molecular mechanisms  
83 have not been clarified.

84 TCDD mediates its toxicity by binding to the aryl hydrocarbon receptor (AhR) and  
85 subsequent alteration of the expression of target genes which exhibit dioxin response elements  
86 in their promoter moiety including the cytochrome Cyp1a1 (Mimura & Fujii-Kuriyama, 2003;  
87 Barouki *et al.*, 2007). Therefore, microarray analyses have been conducted to select the most  
88 up- and down-regulated genes in target tissues. The liver has been mostly evaluated because  
89 of the strong hepatotoxicity of TCDD, and major genes related to cholesterol biosynthesis,  
90 glucose metabolism, and lipogenesis consistent with complementary histopathology have  
91 been identified (Fletcher *et al.*, 2005; Sato *et al.*, 2008). Few data are available regarding the  
92 testicular transcriptome in rats exposed to TCDD. Two genes of germ cell origin have been  
93 identified using a representational difference analysis, and their expression was found to be  
94 down-regulated in the testes of adult mice or rats exposed to high doses of TCDD (Kuroda *et al.*  
95 *et al.*, 2005; Yamano *et al.*, 2005). In studies investigating the consequences of a maternal  
96 exposure to dioxins, foetal pituitary gonadotrophin was defined as an initial target of dioxin  
97 indirectly impacting testicular steroidogenesis (Mutoh *et al.*, 2006), although direct testicular  
98 effects have also been described (Adamsson *et al.*, 2008).

99 In this study, we determined the changes in testicular gene expression caused by an in  
100 utero exposure of female pregnant Sprague-Dawley rats to TCDD along with the

101 measurement of the intra-testicular testosterone levels, epididymal sperm reserves, daily  
102 sperm production (DSP), and testis histology in the offspring throughout development.

103

## 104 **Materials and methods**

### 105 **Experimental design**

106 Time pregnant Sprague-Dawley females of embryonic day 12 were purchased from  
107 Janvier's Breeding (Le Genest, France). They were housed individually in plastic cages with  
108 food (Altromin 1310; Genestil, Royaucourt, France) and water provided ad libitum at 23°C  
109 and a 12:12 photoperiod. Relative humidity was  $50 \pm 10\%$ . Animals were randomly assigned  
110 to treatment groups. Dams were allowed 3-day acclimatization and were given one oral dose  
111 of 2,3,7,8-TCDD (ref ED-901-C) (LGC Promochem, Molsheim, France) in sesame oil on  
112 embryonic day 15. Control animals received sesame oil. Maximal volume of gavages was 0.7  
113 ml/animal. Aliquots containing various doses of dioxins were assayed by Dioxlab (Dioxlab,  
114 Saint-Maurice, France) to ascertain doses given to the animals. A total of 24 animals were  
115 used in the reported experiments. Of these animals, nine dams received sesame oil (control  
116 group), nine dams received one dose of TCDD 200 ng/kg body weight (bw) (TCDD-200  
117 group), three dams received one dose of TCDD 100 ng/kg bw (TCDD-100 group) and three  
118 dams received one dose of TCDD 10 ng/kg bw (TCDD-10 group). The outcome of gestation,  
119 number of pups, sex-ratio and weight was recorded. Pups were not individually identified in  
120 the litters, for bw. Male fertility of the TCDD-200 group (TCDD-F1 males) was assessed  
121 using two virgin females per male. It was compared with the fertility of the control-F1 males.  
122 Males originating from TCDD-F1 and control-F1 males were considered as TCDD-F2 and  
123 control-F2 males, respectively. TCDD-F2 males have not been exposed in utero to TCDD.  
124 Rats were sacrificed by cervical dislocation under CO<sub>2</sub> anesthesia at various ages. Testes and

125 epididymes were dissected, weighed, prepared for morphological studies or frozen in liquid  
126 nitrogen and stored at -70 °C until processing for RNA analysis. Intratesticular content of  
127 testosterone and 4-androstenedione was measured by radioimmunoassay as described  
128 elsewhere (Rinaldi *et al.*, 2001). Epididymal sperm reserves and DSP were measured as  
129 described (Robb *et al.*, 1978). Livers were dissected for RNA purpose. All experiments were  
130 conducted with the approval of the local committee on animal care, and in accordance with  
131 the European guidelines (86/609/CEE).

132

### 133 **Histological analysis and immunofluorescence**

134 For histological and immunohistochemical analyses, tissues were fixed at 4 °C in 0.1 M  
135 phosphate buffer, pH 7.4, containing 4% formaldehyde plus 10% picric acid for at least 24 h,  
136 dehydrated in a graded series of ethanol, and paraffin-embedded using standard protocols.  
137 Sections 5 µm in thickness were stained with the periodic acid-Schiff (PAS)-haematoxylin  
138 technique. For immunohistochemical analyses, paraffin-embedded tissues were  
139 deparaffinized in xylene, rehydrated in graded ethanol solutions and endogenous peroxidase  
140 activity was blocked with 0.3% hydrogen peroxide in methanol for 20 minutes. The sections  
141 were sequentially incubated overnight at 4° C with the anti-Ccl5/Rantes primary antibody (sc-  
142 1410; diluted 1/100) (Santa-Cruz Biotechnologies Inc., Santa Cruz, CA), and anti-goat Ig-  
143 Alexa Fluor 555 secondary antibody (diluted 1/1000) (Invitrogen France, Cergy-Pontoise) for  
144 1 h at room temperature. Leydig cell identity was revealed using the anti-3β-hydroxysteroid  
145 dehydrogenase (3beta-HSD) antibody (diluted 1/1000; overnight incubation at 4 °C) (kindly  
146 provided by Dr I Mason, Reproductive and Developmental Sciences Division, Edinburgh,  
147 Scotland, UK) followed by incubations with anti-mouse Ig-Alexa Fluor 555 secondary  
148 antibody (diluted 1/1000; 1 h at room temperature) (Invitrogen). Fluorochrome-labeled

149 sections were mounted in vectashield containing DAPI for nuclei visualization (Vector  
150 Laboratories Canada, Burlington, ON, Canada). Slides were analyzed with Zeiss Axiovert  
151 epifluorescence microscopes (Carl Zeiss, New York, NY, USA), all connected to a digital  
152 camera (Spot RT Slider, Diagnostic Instruments, Sterling Heights, MI, USA).

153

#### 154 **Microarray analysis**

155 Total RNA was extracted from testes and livers recovered from the control and TCDD groups  
156 of rats using Rneasy mini kit (Qiagen, Courtaboeuf, France). RNA integrity was determined  
157 with the Agilent 2100 Bioanalyzer and RNA 6000 Nano Kit (Agilent Technologies, Massy,  
158 France). For microarray analysis, a pool of control testes RNA originating from three  
159 different males of three different dams was used as a common reference and compared with  
160 three testes originating from three different TCDD-200 F1 males of three different dams. One  
161 microgram of total RNA was amplified with the Amino Allyl MessageAmp II aRNA kit  
162 (Ambion, Austin, TX, USA) according to the manufacturer's instructions. This mRNA  
163 amplification procedure is well validated and it has been demonstrated that it does not distort  
164 the relative abundance of individual mRNAs within an RNA population (Wang *et al.*, 2000).  
165 Fluorescent probes were synthesized by chemical coupling of 5 µg of aminoallyl aRNA with  
166 cyanine (Cy)3 or Cy5 dyes (GE Healthcare Biosciences, Orsay, France). After purification  
167 with RNeasy Mini Kit (Qiagen), probes were fragmented with 25X RNA Fragmentation  
168 Reagents (Agilent Technologies) and hybridized with 2X Agilent Hybridization Buffer  
169 (Agilent Technologies) to *Rattus Norvegicus* opArray (Operon Biotechnologies GmbH,  
170 Cologne, Germany) in an Agilent oven at 67 °C for 16 h, following a dye swap experimental  
171 procedure to correct for gene-specific dye bias (Churchill, 2002). Microarrays were washed  
172 and scanned with a Genepix 4000B scanner (Molecular Devices, Sunnyvale, USA). TIFF



173 images were analysed using Genepix Pro 6.0 software (Molecular Devices). Signal intensities  
174 were log-transformed and normalization was performed by the intensity dependent Lowess  
175 method. To compare results from different experiments, data from each slide were normalized  
176 in log-space to have a mean of zero using Cluster 3.0 software. Only spots with signal to  
177 noise ratio above 2 were selected for further analysis. Data were analysed using the  
178 significance analysis of microarray procedure with a false discovery rate of 5% (Tuscher *et*  
179 *al.*, 2001). Microarray data are available in the GEO database under the number GSE13838.

180

### 181 **Quantitative polymerase chain reaction (Q-PCR)**

182 Quantitative polymerase chain reaction was used for validation of the microarray  
183 procedure and study of gene expression levels of testicular Ccl5/Rantes and hepatic Cyp1a1  
184 in rats from the different experimental groups including the offspring of the dosed-dams and  
185 the males of the F2 generation. Each RNA sample used for Q-PCR was prepared from rats  
186 originated from different dams. Briefly, first-strand cDNAs were synthesized from 1 µg of  
187 total RNA in the presence of 100 U of Superscript II (Invitrogen, Eragny, France) and a  
188 mixture of random hexamers and oligo(dT) primers (Promega). Real-time PCR assays were  
189 performed in duplicates for each sample with a Rotor-Gene<sup>TM</sup> 6000 (Corbett Research,  
190 Mortlake, NSW, Australia), as described elsewhere (Mazaud Guittot *et al.*, 2008). The list of  
191 the primers (Invitrogen, Eragny, France) is available in Table 1. Briefly, PCR was performed  
192 with 0.4 µM of each primer and 10 µl Absolute QPCR SYBR Green ROX mix (Thermo  
193 Fisher Scientific, Courtaboeuf, France), in a total volume of 20 µl. After the initial  
194 denaturation step of 15 min at 95 °C, the reaction conditions were 40 cycles of 95 °C for 15 s,  
195 55 or 58 °C (depending on the primers, Table 1) for 10 sec, and 72 °C for 20 sec. The  
196 fluorescence intensity of SYBR Green was read on the Rotor-Gene<sup>TM</sup> at the end of each  
197 extension step. Melting curve analyses were performed immediately following the final PCR

198 cycle to verify the specificity of the PCR product by checking its T<sub>m</sub>. Rpl19 (ribosomal  
199 protein L19) and Gusb (glucuronidase beta) genes were chosen as references for normalizing  
200 target genes in the testis (Mazaud Guittot *et al.*, 2008) and liver (unpublished data from the  
201 laboratory), respectively. Relative quantification was made by the standard curve method for  
202 both target and housekeeping gene (endogenous control) in each sample. A series of dilutions  
203 of calibrator sample (external standard) was included in each experiment to generate an  
204 external standard curve. Then the concentration of the target in each sample was divided by  
205 the concentration of the housekeeping gene in each sample, normalizing the samples. Relative  
206 quantification was carried out using the LightCycler® Relative quantification Software  
207 (version 1.0). The calculation of data was based on the crossing point (C<sub>p</sub>) values obtained by  
208 the LightCycler® Software. To correct for sample heterogeneity and variability of detection,  
209 results were calculated as the target/reference ratio of the sample divided by the  
210 target/reference ratio of the calibrator.

211

## 212 **Isolation of testicular cells and RT-PCR**

213 Obtention of highly enriched fractions of testicular cells was carried out as described  
214 elsewhere (Le Magueresse-Battistoni *et al.*, 1994; 1998; Longin *et al.*, 2001). Briefly, Sertoli  
215 and peritubular cells were isolated from 20-day old rats and cultured at 32 °C in a humidified  
216 atmosphere of 5% CO<sub>2</sub> in Dulbecco's Modified Eagle Medium (DMEM)-Ham's F12 (Life  
217 technologies, Grand Island NY) supplemented (peritubular cells) with or without 10% fetal  
218 calf serum. Sertoli cells were hypotonically-treated to eliminate the contaminating germ cells.  
219 Enrichment of Sertoli and peritubular cells cultured for 6 days was higher than 95%. Leydig  
220 cells were isolated from adult rats as previously described elsewhere (Carreau *et al.*, 1988;  
221 Mazaud Guittot *et al.*, 2008). Briefly, following a collagenase digestion, interstitial cells were  
222 purified on a discontinuous Percoll density gradient. The interface between 40 and 60% was

223 collected and washed to eliminate Percoll. The purity of the fraction ranged from 90 to 95%.  
224 It was assessed by the presence of 3beta-HSD activity (Bilinska *et al.*, 1997). Spermatogenic  
225 cells were isolated from adult rat testes by trypsinization. The resulting crude germ cell  
226 population (containing germ cells from all developmental steps) was submitted to centrifugal  
227 elutriation. Two fractions were harvested; the pachytene spermatocyte fraction enriched at 80-  
228 85% (contaminated primarily by early spermatids) and the early spermatid fraction (steps 1-8)  
229 enriched at 75-80% with primary contamination by both spermatocytes and elongated  
230 spermatids.

231 After collection, the different cell populations were processed for RNA extraction  
232 using Trizol reagent (Invitrogen, Eragny, France). RT-PCR was conducted as described  
233 (Longin *et al.*, 2001) using the primers Ccl5/Rantes (a) and Rpl19 (Table 1) to ensure equal  
234 loading in a 2 % agarose gel. A DNA ladder (Promega) was loaded and gels were stained with  
235 ethidium bromide. Negative controls contained water instead of cDNA. The PCR product for  
236 Ccl5/Rantes (a) was sequenced by GENOME Express (Grenoble, France).

237

## 238 **Data analysis**

239 Statistical analyses were carried out with the Sigmastat® 3.1 software package (Systat  
240 Software, Inc., Point Richmond, CA, USA). All values are expressed as mean  $\pm$  SEM unless  
241 specified differently. Statistical analysis was performed by ANOVA followed by Dunnett's  
242 test for multiple comparisons. Early bw were analysed with a two-way (dose group x day)  
243 ANOVA model. Significance was accepted at a confidence level of  $p < 0.05$ .

244

## 245 **Results**

### 246 **Effect of TCDD on F1 males**

247 Preliminary experiments were performed to determine the dose-range of 2,3,7,8-TCDD. We  
248 observed that doses of 270 ng/kg bw induced maternal and foetal toxicity, and death of dams  
249 was observed at the dose of 1000 ng/kg bw (Appendix S1). Therefore, doses of 10, 100 and  
250 200 ng/kg bw were administered to pregnant females at embryonic day 15. No treatment-  
251 related differences were noted with regard to the litter size, the sex-ratio or the bw of foetuses  
252 in females that were dosed with 10, 100 or 200 ng/kg bw if data were expressed per litter. No  
253 significant interaction was evidenced between dose and age (Table 2).

254 However, if male pups at a given age of 5, 7, 10, 12 or 14 days were considered instead  
255 of litter as the experimental unit, then male pups were found to be lighter (an average of 8%;  
256  $p < 0.05$ ) in the TCDD-200 group during the lactating period compared with the control group.  
257 No effect on weight gain was detected in rats exposed to TCDD from weaning onwards (not  
258 shown). The intra-testicular levels of testosterone and 4-androstenedione were in the normal  
259 range in 28-, 40-, 67- and 145-day old rats of the TCDD-200 group (not shown). The other  
260 groups were not assayed. Testicular and epididymal weights were within the normal range in  
261 rats of the differently dosed groups compared with that in the control rats, and the gross  
262 histology of the testes was also normal throughout development (not shown).

263

#### 264 **Effect of TCDD on hepatic Cyp1a1 expression levels**

265 Expression of Cyp1a1 was measured by quantitative PCR in the liver of male rats aged 5 and  
266 28 days to confirm TCDD exposure. Indeed, the induction of Cyp1a1 is regarded as one of the  
267 most sensitive endpoints of AhR activation (Vanden Heuvel *et al.*, 1994). As shown in Fig. 1,  
268 expression of Cyp1a1 was dramatically enhanced in the liver of rats of the TCDD-200 group  
269 at 5 and 28 days of age (i.e., 1.5 and 5 weeks after the females had been given TCDD),  
270 probably as a result of a continued exposure of pups to dioxin through breast milk of the

271 exposed mothers. This is consistent with the finding that the majority of TCDD in offspring of  
272 dosed dams has been shown to arise from lactational transfer of TCDD (Li *et al.*, 1995).

273

#### 274 **Sperm counts and DSP in F1 males**

275 Sperm counts were monitored in the caput, corpus and cauda of the epididymis of 67- and  
276 145-day old rats and DSP was measured at both ages (Table 3 and not shown). ANOVA and  
277 multiple comparison Dunnett's test were run to assess significance. No significant effect was  
278 evidenced at 145 days of age for any group or at 67 days of age for the TCDD-10 and TCDD-  
279 100 groups regardless of whether the data were reported per litter or per rat (range 6-12). In  
280 67 day-old rats, the *p* value was 0.06 for sperm counts in the caput epididymis, 0.056 for  
281 sperm counts in the cauda epididymis and 0.052 for DSP when the TCDD-200 group was  
282 compared with the control group and data were expressed per litter. The *p*-value was 0.013  
283 for sperm counts in the caput epididymis, 0.021 for sperm counts in the cauda epididymis and  
284 0.06 for DSP, with data expressed per rat (Table 3).

285

#### 286 **Identification of TCDD sensitive genes**

287 Microarray analysis was developed using 28 day-old rat testes RNA. A restricted number of  
288 genes were selected. Specifically, three genes were up- and five genes were down-regulated  
289 by  $\pm 1.40$  fold in testes of males from TCDD-200 dosed dams compared with that in control  
290 testes (SAM procedure with FDR < 5%). Four genes have been reported to exhibit Xenobiotic  
291 Response Elements (XRE; <http://drgap.nies.go.jp/pub/page/element>) in the 5' flanking  
292 regions of the *Mus musculus* orthologous genes (Table 4). These genes were *Insl3* produced  
293 by Leydig cells, the tumour suppressor gene *Glpr1*, and 2 chemokines *Cxcl4* and  
294 *Ccl5/Rantes*. They were selected and further studied by Q-PCR (Table 4). *Insl3* and *Cxcl4*  
295 gene expression levels which were up-regulated at 28 days of age were found not to be

296 statistically different in TCDD-200 vs. control testes at the other ages studied (5, 67 and 145  
297 days for *Ins13* and 67 and 145 days for *Cxcl4*; not shown). *Glpr1* gene expression levels were  
298 significantly ( $p < 0.05$ ) enhanced at 28 (Table 4) and 67, but not at 5 days of age (not shown).  
299 *Ccl5/Rantes* gene expression levels were down-regulated throughout development in TCDD-  
300 200 vs. control testes (Fig. 2). In control testes, gene expression levels of *Ccl5/Rantes*  
301 increased as a function of age and a plateau value was reached at 67 days of age. In TCDD-  
302 200 testes, *Ccl5/Rantes* gene expression levels also increased as a function of age. However,  
303 levels were significantly ( $p < 0.05$ ) decreased in TCDD-200 testes compared with that in the  
304 age-matched controls. Specifically, levels in TCDD-200 testes represented 45, 31, 54, 44, and  
305 71% of the control levels at 5, 28, 40, 67 and 145 days of age respectively (Fig. 2). We also  
306 surveyed *Ccl5/Rantes* levels in TCDD-10 and -100 testes from rats of 67 and 145 days of age.  
307 No effect was observed in TCDD-10 testes, and TCDD-100 testes exhibited levels of  
308 *Ccl5/Rantes* of the same range as that in TCDD-200 testes (Fig. 3). Data on RNA levels could  
309 not be extended to the protein level because the signal for *Ccl5/Rantes* was barely detectable  
310 using Western blot analysis (not shown).

311

### 312 **Identification of the testicular source of *Ccl5/Rantes***

313 Using RT-PCR analysis and specific primers for *Ccl5/Rantes*, a PCR product of the right size  
314 and sequence (not shown) was detected in Leydig cells, and to a much lower degree in Sertoli  
315 and germ cells (Fig. 3A). To extend these data, we found that the *Ccl5/Rantes*  
316 immunoreactivity was confined to interstitial cells positive for 3 $\beta$ -HSD identifying the  
317 Leydig cell population (Fig. 3B). Sections incubated without the primary *Ccl5/Rantes*  
318 antibody remained unstained (Fig. 3B).

319

### 320 **Reproductive performance of F1 males and the F2 generation**

321 F1 males from the control and TCDD-200 groups were mated with two virgin females  
322 per male during postnatal week 15. Pregnant females did not receive TCDD during gestation.  
323 All females became pregnant and no differences in the outcome of pregnancy, litter size and  
324 sex-ratio were recorded between groups (Table 5). No difference in male pup weight was  
325 detected between groups, hepatic Cyp1a1 gene expression levels remained at nadir in both  
326 groups and Ccl5/Rantes mRNA testicular levels measured in 67- and 145- dayl old rats were  
327 in the same range in both groups. Sperm counts and DSP were also in the normal range in  
328 male rats of the F2 generation, in both groups (Table 5). Expression per rat instead of per  
329 litter did not change the significance of the data in Table 5 (not shown).

330

### 331 **Discussion**

332 In this study, we demonstrated that exposure of female rats to TCDD 200 ng/kg bw at  
333 embryonic day 15 induced decreased sperm reserves in the male offspring at 67 days, but not  
334 at 145 days of age. Gene expression profile revealed that Ccl5/Rantes, a chemokine almost  
335 exclusively found in Leydig cells, was negatively-regulated in testes of males from exposed  
336 dams. No such phenotype was evidenced in males of the subsequent generation.

337 Many studies using rats as experimental models reported the use of maternal doses of  
338 up to 1000 ng/kg (Mably *et al.*, 1992; Gray *et al.*, 1995; Sommer *et al.*, 1996; Cooke *et al.*,  
339 1998; Haavisto *et al.*, 2006; Adamsson *et al.*, 2008). However, in this study, we observed  
340 maternal and foetal toxicity at the dose of 270 ng/kg, and death of dams with the dose of 1000  
341 ng/kg. Therefore, to avoid toxic effects that would render the interpretation of our studies  
342 difficult, doses of 10, 100 and 200 ng/kg were used in this study. In line with a previous study  
343 (Bell *et al.*, 2007a), we observed that neonates from TCDD-200 exposed dams (if considered  
344 individually) were about 8% lighter than pups born from control dams during the lactating  
345 period. It has been demonstrated that the majority of occurrences of TCDD in offspring of

346 dosed dams arises from lactational transfer of TCDD (Li *et al.*, 1995). Further studies will  
347 have to be addressed to determine if breast milk was less nourishing/abundant. It is also  
348 possible that TCDD interfered with food intake (Tuomisto *et al.*, 1999). In addition, we found  
349 no alteration of the sex-ratio in agreement with recent studies (Rowlands *et al.*; 2006; Bell *et*  
350 *al.*, 2007a).

351 Maternal exposure to TCDD lead to controversial data regarding sperm reserves in the  
352 male offspring, as stated in the Introduction. One explanation for this debated question may  
353 reside in the use of different strains as it is known that rats may be differentially resistant to  
354 TCDD exposure (Simanainen *et al.*, 2004). In this study, we showed a significant decrease in  
355 caput and cauda sperm reserves of the TCDD-200 group at 67 days of age if data were  
356 expressed per rat. The origin of the reduced production of sperm cells in the young adult rats  
357 is presently unknown. Indeed, the decline was transitory, i.e. these parameters were in the  
358 normal range in 145-day old rats from TCDD-200 exposed dams. Gross histology of the testis  
359 and number of apoptotic germ cells, as well as intratesticular testosterone levels, and  
360 epididymal and testes weights, were all in the normal range compared with that of the  
361 controls. In addition, dams were dosed at embryonic day 15, at the onset of testicular  
362 testosterone production. Considering that TCDD half-life is close to 3 weeks in rat (Bell *et al.*,  
363 2007b), it implies that foetuses were maximally exposed in the first few days following  
364 dosing, i.e. during the early programming critical window for masculinization of the  
365 reproductive tracts in rat (Welsh *et al.*, 2008). Collectively, these observations would suggest  
366 that the androgenic signalling pathway was not targeted by a prenatal TCDD exposure in  
367 postnatal rats, which is consistent with previous studies (Gray *et al.*, 1995; Haavisto *et al.*,  
368 2006).

369 Gene expression profiles were used to select differentially expressed genes which  
370 could be regarded as markers of a dioxin exposure. We used 28 day-old rat testes because at



371 that age, spermatids massively populate the tubules and first elongated spermatids are  
372 differentiated at 28 days of age. Germ cells are not over-represented, thus allowing the  
373 identification of a potential defect in somatic cells. In addition, hepatic Cyp1a1 levels were  
374 highly induced at 28 days of age, indicating that at this age TCDD was still exerting a direct  
375 genomic action. Using RNAs extracted from testes of the TCDD-200 group, we selected a  
376 restricted number of genes with fold-changes  $\pm 1.40$ . Three genes were up-regulated and five  
377 genes were down-regulated. Four genes were further selected based on their identity and the  
378 presence of XRE in their flanking regions, indicating that they might represent direct target  
379 genes. The upregulated *Glipr1* gene has been found to exert tumour suppressor functions and  
380 is a p53 target gene (Li et al., 2008). In addition, it has previously been identified as a dioxin-  
381 sensitive gene in human subjects (McHale *et al.*, 2007). Further studies will be required to  
382 identify if its up-regulation in 28 and 67-day old rat testes from the TCDD-200 group could  
383 contribute to the decline in DSP and sperm reserves observed at 67 days of age.

384 *Insl3* is involved in testicular descent during embryo development (Nef & Parada,  
385 1999), and has been suggested to act as a pro-survival factor in germ cells of adult testes  
386 (Kawamura *et al.*, 2004). Therefore, it might be speculated that the up-regulation of *Insl3*  
387 would counterbalance deleterious effects induced by TCDD. However, expression levels were  
388 in the normal range in adult rats of exposed dams. In addition, expression levels at 5 days of  
389 age were very low, resulting in high variations in the Q-PCR dosage, and lack of significance.

390 The two other genes validated by quantitative PCR were the chemokines *Cxcl4* and  
391 *Ccl5/Rantes*. Chemokines have previously been identified as dioxin-sensitive genes in a  
392 microarray analysis of adipocytes treated with TCDD in vitro (Hanlon *et al.*, 2005). *Cxcl4*  
393 which was up-regulated at 28 days of age but not at the older ages investigated was not  
394 further studied. *Ccl5/Rantes* was expressed as a function of age and down-regulated in the  
395 testes of males from TCDD-200 dosed dams throughout development. It has previously been

396 reported in the testis (Le Goffic *et al.*, 2002), and we identified Leydig cells as the major site  
397 of Ccl5/Rantes expression. Leydig cells are also a target of the chemokine because specific  
398 receptors were detected through RT-PCR (DR, EC and BLMB, unpublished observations).

399 Rantes (for 'regulated upon activation normal T cell expressed and secreted') now  
400 given the immunologic designation Ccl5 was originally identified as a typical chemokine as it  
401 was able to recruit leukocytes to sites of inflammation. From its discovery, it was found that  
402 in addition to T-Cells, Ccl5/Rantes is produced by many other types of cells, including  
403 fibroblasts, endothelial and epithelial cells. Moreover, its activity is not merely restricted to  
404 chemotaxis. Beneficial activities have been described, including antimicrobial and antiviral as  
405 well as detrimental effects. For example, Ccl5/Rantes enhances inflammatory processes and  
406 has been associated with the induction or promotion of cancer (Appay & Rowland-Jones,  
407 2001; Levy, 2009). Interestingly, Ccl5/Rantes is present in both the male and female genital  
408 tract fluids and spermatozoa exhibit specific receptors for the chemokine. However,  
409 consistent with high levels found in diseases related to infertility including genital tract  
410 infections, Ccl5/Rantes has been shown to impact sperm fertilizing ability negatively  
411 (Barbonetti *et al.*, 2008). Therefore, the decrease in Ccl5/Rantes gene expression levels  
412 observed in this study in testes of rats born from exposed dams could be part of a protecting  
413 mechanism against TCDD impact. It remained to determine if (and to which extent) decreased  
414 Ccl5/Rantes gene expression levels contributed to the transitory sperm count decline. For  
415 example, sperm counts were normal in 145-day old rats, whereas Ccl5/Rantes gene  
416 expression levels were significantly lower than that of controls at that age. In addition, we  
417 may have bypassed important genes impacted as well by a TCDD exposure, and contributing  
418 with or independently of Ccl5/Rantes in decreasing sperm counts. A transcriptomic study  
419 using testes of 67-day old rats may be useful to answer this point.

420 Inhibition of *Ccl5/Rantes* gene expression levels exerted by dioxin was observed 20  
421 weeks after dams were given TCDD either 100 or 200 ng/kg bw, and 16 weeks after weaning  
422 if considering that the majority of TCDD in offspring of dosed dams has been shown to arise  
423 from lactational transfer of TCDD (Li *et al.*, 1995). As TCDD half-life is close to 3 weeks in  
424 rats (Bell *et al.*, 2007b), it is possible that increased transcriptional activity coupled to mRNA  
425 stability could account for the persisting decreased effects observed at 67 and 145 days of age.  
426 Further studies using primary cultures of Leydig cells are warranted to fuel this hypothesis.

427 Several studies have provided evidence that endocrine disrupters might cause  
428 epigenetic alterations which could be transmitted to subsequent generations through the male  
429 germ line (Anway *et al.*, 2005) or the maternal lineage (Newbold *et al.*, 2006). We thus  
430 examined the reproductive performance of the F1 males from TCDD-200 dosed dams, and F3  
431 males were also generated using F2 males (not shown). Interestingly, we observed that sperm  
432 reserves, DSP, and testicular *Ccl5/Rantes* gene expression levels were in the normal range in  
433 the F2 and F3 (not shown) generations. However, because exposure was acute and performed  
434 at embryonic day 15 thus at the onset of a common programming window in which androgen  
435 action is essential for normal reproductive tract masculinization (Welsh *et al.*, 2008), but a  
436 few days after reprogramming of the germ line has occurred (Sasaki & Matsui, 2008; Trasler,  
437 2009), chronic dosing studies covering the whole developmental period should be carried out  
438 before one could conclude the lack of transgenerational effect of dioxin.

439 In conclusion, our data demonstrated that maternal exposure to TCDD at doses of 100  
440 and 200 ng/kg bw impacted the reproductive function of the F1 males. We propose that the  
441 chemokine *Ccl5/Rantes* might be regarded as a marker of TCDD exposure. Future studies will  
442 help to determine to which extent *Ccl5/Rantes* in Leydig cells may regulate spermatogenesis.  
443 In addition, given that TCDD has been shown to exhibit various endocrine disrupting effects  
444 both interacting with the estrogenic and androgenic pathways (Ohtake *et al.*, 2003), it would

445 be of interest to determine whether Ccl5/Rantes is modulated as well by chemicals with  
446 estrogenic and/or antiandrogenic activities.

447

448 Acknowledgment:

449 We are indebted to Drs Romain Guyot and Rosy El Ramy, and Marie-Pierre Monneret for  
450 their help with the animals. We thank Dr Romain Casey for helpful guidance in statistical  
451 analyses. This work was supported by Inserm, INRA, University of Lyon 1 and specific  
452 grants to BLMB from AFSSET (EST-2006/1/33) and ANR (ANR-06-PNRA-006-01). FO and  
453 AV were funded by MRT, FRM and Organon, respectively.

454 The authors declare they have no competing financial interests.

455

## 456 REFERENCES

- 457 Adamsson, A., Simanainen, U., Viluksela, M., Paranko, J. & Toppari, J. 9 July, 2008. The  
458 effects of 2,3,7,8-tetrachlorodibenzo-p-dioxin on foetal male rat steroidogenesis.  
459 *International Journal of Andrology* doi:10.1111/j.1365-2605.2008.00900.x
- 460 Anway, M.D., Cupp, A.S., Uzumcu, M. & Skinner, M.K. (2005) Epigenetic transgenerational  
461 actions of the endocrine disruptors and male fertility. *Science* 308, 1466-1469.
- 462 Appay, V. & Rowland-Jones, S.L. (2001) RANTES: a versatile and controversial chemokine.  
463 *TRENDS in Immunology* 22, 83-87.
- 464 Barouki, R., Coumoul, X. & Fernandez-Salguero, P.M. (2007) The aryl hydrocarbon receptor,  
465 more than a xenobiotic-interacting protein. *FEBS Letters* 581, 3608-3615.
- 466 Barbonetti, A., Vassallo, M.R.C., Antonangelo, C., Nuccetelli, V., D'Angeli, A., Pelliccione,  
467 F., Giorgi, M., Francavilla, F., & Francavilla, S. (2008) RANTES and human sperm  
468 fertilizing ability: effect on acrosome reaction and sperm/oocyte fusion. *Molecular*  
469 *Human Reproduction* 14, 387-391.
- 470 Bell, D.R., Clode, S., Fan, M.Q., Fernandes, A., Foster, P.M., Jiang, T., Loizou, G.,  
471 MacNicoll, A., Miller, B.G., Rose, M., Tran, L. & White, S. (2007a) Toxicity of  
472 2,3,7,8-tetrachlorodibenzo-p-dioxin in the developing male Wistar(Han) rat. I: no  
473 decrease in epididymal sperm count after a single acute dose. *Toxicological Sciences*  
474 99, 214-223.
- 475 Bell, D.R., Clode, S., Fan, M.Q., Fernandes, A., Foster, P.M.D., Jiang, T., Loizou, G.,  
476 MacNicoll; A., Miller, B.G., Rose, M., Tran, L. & White, S. (2007b). Relationships  
477 between tissue levels of 2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD), mRNAs, and  
478 toxicity in the developing male Wistar(Han) rat. *Toxicological Sciences* 99, 591-604.
- 479 Bilinska, B., Genissel, C. & Carreau, S. (1997) Paracrine effect of seminiferous tubule factors  
480 on rat leydig cell testosterone production: role of cytoskeleton. *Biology of the Cell* 89,  
481 435-442.

- 482 Carreau, S., Papadopoulos, V. & Drosowsky, M.A. (1988) Stimulation of adult rat Leydig  
483 cell aromatase activity by a Sertoli cell factor. *Endocrinology* 122, 1103-1109.
- 484 Churchill, G.A. (2002) Fundamentals of experimental design for cDNA microarrays. *Nature*  
485 *Genetics* 32, Suppl: 490-495.
- 486 Cozzone, D., Debard, C., Dif, N., Ricard, N., Disse, E., Vouillarmet, J., Rabasa-Lhoret, R.,  
487 Laville, M., Pruneau, D., Rieusset, J., Lefai, E. & Vidal, H. (2006) Activation of liver  
488 X receptors promotes lipid accumulation but does not alter insulin action in human  
489 skeletal muscle cells. *Diabetologia* 49, 990-999.
- 490 Cooke, G.M., Price, C.A. & Oko, R.J. (1998) Effects of in utero and lactational exposure to  
491 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) on serum androgens and steroidogenic  
492 enzyme activities in the male reproductive tract. *The Journal of Steroid Biochemistry*  
493 *and Molecular Biology* 67, 347-354.
- 494 Diamanti-Kandarakis, E., Bourguignon, J.P., Giudice, L.C., Hauser, R., Prins, G.S., Soto,  
495 A.M., Zoeller, T. & Gore, A.C. (2009) Endocrine-disrupting chemicals: an endocrine  
496 society scientific statement. *Endocrine Reviews* 30, 293-342.
- 497 Faqi, A.S., Dalsenter, P.R., Merker, H.J. & Chahoud, I. (1998) Reproductive toxicity and  
498 tissue concentrations of low doses of 2,3,7,8-tetrachlorodibenzo-p-dioxin in male  
499 offspring rats exposed throughout pregnancy and lactation. *Toxicology and Applied*  
500 *Pharmacology* 150, 383-392.
- 501 Fisher, J.S., Macpherson, S., Marchetti, N. & Sharpe, R.M. (2003) Human “testicular  
502 dysgenesis syndrome”: a possible model using in-utero exposure of the rat to dibutyl  
503 phthalate. *Human Reproduction* 18, 1383-1394.
- 504 Fletcher, N., Wahlström, D., Lundberg, R., Nilsson, C.B., Nilsson, K.C., Stockling, K.,  
505 Hellmold, H. & Håkansson, H. (2005) 2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD)  
506 alters the mRNA expression of critical genes associated with cholesterol metabolism,  
507 bile acid biosynthesis, and bile transport in rat liver: a microarray study. *Toxicology*  
508 *and Applied Pharmacology* 207:1-24
- 509 Gies, A., Neumeier, G., Rappolder, M. & Konietzka, R. (2007) Risk assessment of dioxins  
510 and dioxin-like PCBs in food. Comments by the German Federal Environmental  
511 Agency. *Chemosphere* 67, S344-349.
- 512 Gray, L.E. Jr, Kelce, W.R., Monosson, E., Ostby, J.S. & Birnbaum, L.S. (1995) Exposure to  
513 TCDD during development permanently alters reproductive function in male Long  
514 Evans and hamsters: reduced ejaculated and epididymal sperm numbers and sex  
515 accessory gland weights in offspring with normal androgenic status. *Toxicology and*  
516 *Applied Pharmacology* 131, 108-118.
- 517 Haavisto, T.E., Myllymaki, S.A., Adamsson, N.A., Brokken, L.J., Viluksela, M., Toppari, J.  
518 & Paranko, J. (2006) The effects of maternal exposure to 2,3,7,8-tetrachlorodibenzo-  
519 p-dioxin on testicular steroidogenesis in infantile male rats. *International Journal of*  
520 *Andrology* 29, 313-322.
- 521 Hanlon, P.R., Cimafranca, M.A., Liu, X., Cho, Y.C. & Jefcoate, C.R. (2005) Microarray  
522 analysis of early adipogenesis in C3H10T1/2 cells: cooperative inhibitory effects of  
523 growth factors and 2,3,7,8-tetrachlorodibenzo-p-dioxin. *Toxicology and Applied*  
524 *Pharmacology* 207, 39-58.
- 525 Hotchkiss, A.K., Rider, C.V., Blystone, C.R., Wilson, V.S., Hartig, P.C., Ankley, G.T.,  
526 Foster, P.M., Gray, C.L. & Gray, L.E. (2008) Fifteen years after “Wingspread”-  
527 Environmental endocrine disrupters and human and wildlife health: Where we are  
528 today and where we need to go? *Toxicological Sciences* 105, 235-259.
- 529 Ikeda, M., Tamura, M., Yamashita, J, Susuki, C. & Tomita, T. (2005) Repeated in utero and  
530 lactational 2,3,7,8-tetrachlorodibenzo-p-dioxin exposure affects male gonads in

- 531 offspring leading to sex ratio changes in F2-progeny. *Toxicology and Applied*  
532 *Pharmacology* 206, 351-355.
- 533 Kawamura, K., Kumagai, J., Sudo, S., Chun, S.Y., Pisarska, M., Morita, H., Toppari, J., Fu,  
534 P., Wade, J.D., Bathgate, R.A. & Hsueh, A.J. (2004) Paracrine regulation of  
535 mammalian oocyte maturation and male germ cell survival. *Proceedings of the*  
536 *National Academy of Sciences U. S. A.* 101, 7323-7328.
- 537 Kuroda, M., Oikawa, K., Ohbayashi, T., Yoshida, K., Yamada, K., Mimura, J., Matsuda, Y.,  
538 Fujii-Kuriyama, Y. & Mukai, K. (2005) A dioxin sensitive gene, mammalian WAPL,  
539 is implicated in spermatogenesis. *FEBS Letters* 579, 167-172.
- 540 Le Goffic, R., Mouchel, T., Aubry, F., Patard, J.J., Ruffault, A., Jégou, B. & Samson, M.  
541 (2002) Production of the chemokines monocyte chemoattractant protein-1, regulated on  
542 activation normal T cell expressed and secreted protein, growth-related oncogene, and  
543 interferon-gamma-inducible protein-10 is induced by the Sendai virus in human and  
544 rat testicular cells. *Endocrinology* 143, 1434-1440.
- 545 Le Magueresse-Battistoni, B., Wolff, J., Morera, A.M. & Benahmed, M. (1994) Fibroblast  
546 growth factor receptor type 1 expression during rat testicular development and its  
547 regulation in cultured Sertoli cells. *Endocrinology* 135, 2404-2411.
- 548 Le Magueresse-Battistoni, B., Pernod, G., Sigillo, F., Kolodjé, L. & Benahmed, M. (1998)  
549 Plasminogen activator inhibitor 1 is expressed in cultured rat Sertoli cells. *Biology of*  
550 *Reproduction* 59, 591-598.
- 551 Levy, J.A. (2009) The unexpected pleiotropic activities of RANTES. *The Journal of*  
552 *Immunology* 182, 3945-3946.
- 553 Li, L., Abdel Fattah, E., Cao, G., Ren, C., Yang, G., Goltsov, A.A., Chinault, A.C., Cai,  
554 W.W., Timme, T.L. & Thompson, T.C. (2008) Glioma pathogenesis-related protein 1  
555 exerts tumor suppressor activities through proapoptotic reactive oxygen species-c-Jun-  
556 NH2 kinase signaling. *Cancer Research* 88, 163-172.
- 557 Li, X., Weber, L.W. & Rozman, K.K. (1995) Toxicokinetics of 2,3,7,8-tetrachlorodibenzo-p-  
558 dioxin in female Sprague-Dawley rats including placental and lactational transfer to  
559 fetuses and neonates. *Fundamental and Applied Toxicology* 27, 70-76.
- 560 Longin, J., Guillaumot, P., Chauvin, M.A., Morera, A.M. & Le Magueresse-Battistoni, B.  
561 (2001) MT1-MMP in rat testicular development and the control of Sertoli cell pro-  
562 MMP2 activation. *Journal of Cell Sciences* 114, 2125-2134.
- 563 Lundqvist, C., Zuurbier, M., Leijts, M., Johansson, C., Ceccatelli, S., Saunders, M., Schoeters,  
564 G., ten Tusscher, G. & Koppe, J.G. (2006) The effects of PCBs and dioxins on child  
565 health. *Acta Paediatrica* 95, 55-64.
- 566 Mably, T.A., Bjerke, D.L., Moore, R.W., Gendron-Fitzpatrick, A. & Peterson, R.E. (1992) In  
567 utero and lactational exposure of male rats to 2,3,7,8-tetrachlorodibenzo-p-  
568 dioxin. 3. Effects of spermatogenesis and reproductive capability. *Toxicology and*  
569 *Applied Pharmacology* 114, 118-126.
- 570 Mazaud Guittot, S., Vérot, A., Odet, F., Chauvin, M.A. & Le Magueresse-Battistoni, B.  
571 (2008) A comprehensive survey of the laminins and collagens type IV expressed in  
572 mouse Leydig cells and their regulation by LH/hCG. *Reproduction* 135, 479-488.
- 573 McHale, C.M., Zhang, L., Hubbard, A.E., Zhao, X., Baccarelli, A., Pesatori, A.C., Smith,  
574 M.T. & Landi, M.T. (2007) Microarray analysis of gene expression in peripheral  
575 blood mononuclear cells from dioxin-exposed human subjects. *Toxicology* 229, 101-  
576 113.
- 577 Mimura, J. & Fujii-Kuriyama, Y. (2003) Functional role of AhR in the expression of toxic  
578 effects by TCDD. *Biochimica et Biophysica Acta* 1619, 263-268.

- 579 Mutoh, J., Taketoh, J., Okamura, K., Kagawa, T., Ishida, T., Ishii, Y. & Yamada, H. (2006)  
580 Fetal pituitary gonadotropin as an initial target of dioxin in its impairment of  
581 cholesterol transportation and steroidogenesis in rats. *Endocrinology* 147, 927-936.
- 582 Nef, S., and Parada, L.F. (1999) Cryptorchidism in mice mutant for Ins13. *Nature Genetics* 22,  
583 295-299.
- 584 Newbold, R.R., Padilla-Banks, E. & Jefferson, W.N. (2006) Adverse effects of the model  
585 environmental estrogen diethylstilbestrol are transmitted to subsequent generations.  
586 *Endocrinology* 147, S11-S17.
- 587 Ohsako, S., Miyabara, Y., Sakaue, M., Ishimura, R., Kakeyama, M., Izumi, H., Yonemoto, J.  
588 & Tohyama, C. (2002) Developmental stage-specific effects of perinatal 2,3,7,8-  
589 tetrachlorodibenzo-p-dioxin exposure on reproductive organs of male rat offspring.  
590 *Toxicological Sciences* 66, 283-292.
- 591 Ohsako, S., Miyabara, Y., Nishimura, N., Kurosawa, S., Sakaue, M., Ishimura, R., Sato, M.,  
592 Takeda, K., Aoki, Y., Sone, H., Tohyama, C. & Yonemoto, J. (2001) Maternal  
593 exposure to low dose of 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) suppressed the  
594 development of reproductive organs of male rats: dose-dependent increase of mRNA  
595 levels of 5 $\alpha$ -reductase type 2 in contrast to decrease of androgen receptor in the  
596 pubertal ventral prostate. *Toxicological Sciences* 60, 132-143.
- 597 Ohtake, F., Takeyama, K., Matsumoto, T., Kitagawa, H., Yamamoto, Y., Nohara, K.,  
598 Tohyama, C., Krust, A., Mimura, J., Chambon, P., Yanagisawa, J., Fujii-Kuriyama, Y.  
599 & Kato, S. (2003) Modulation of oestrogen receptor signalling by association with the  
600 activated dioxin receptor. *Nature* 423, 545-50.
- 601 Rinaldi, S., Déchaud, H., Biessy, C., Morin-Raverot, V., Toniolo, P., Zeleniuch-Jacquotte, A.,  
602 Akhmedkhanov, A., Shore, R.E., Secreto, G., Ciampi, A., Riboli, E. & Kaaks, R.  
603 (2001) Reliability and validity of commercially available, direct radioimmunoassays  
604 for measurement of blood androgens and estrogens in postmenopausal women.  
605 *Cancer Epidemiology, Biomarkers and Prevention*. 7, 757-65.
- 606 Robb, G.W., Amann, R.P. & Killian, G.J. (1978) Daily sperm production and epididymal  
607 sperm reserves of pubertal and adult rats. *Journal of Reproduction and Fertility* 54,  
608 103-107.
- 609 Rowlands, J.C., Budinsky, R.A., Aylward, L.L., Faqi, A.S. & Carney, E.W. (2006) Sex ratio  
610 of the offspring of the Sprague-Dawley rats exposed to 2,3,7,8-tetrachlorodibenzo-p-  
611 dioxin (TCDD) in utero and lactationally in a three-generation study. *Toxicology and*  
612 *Applied Pharmacology* 216, 29-33.
- 613 Sasaki, H. & Matsui, Y. (2008) Epigenetic events in mammalian germ-cell development:  
614 reprogramming and beyond. *Nature Reviews* 9, 129-140.
- 615 Sato, S., Shirakawa, H., Tomita, S., Ohsaki, Y., Haketa, K., Tooi, O., Santo, N., Tohkin, M.,  
616 Furukawa, Y., Gonzalez, F.J. & Komai, M. (2008) Low-dose dioxins alter gene  
617 expression related to cholesterol biosynthesis, lipogenesis, and glucose metabolism  
618 through the aryl hydrocarbon receptor-mediated pathway in mouse liver. *Toxicology*  
619 *and Applied Pharmacology* 229, 10-19.
- 620 Sharpe, R.M. & Skakkebaek, N.E. (2008) Testicular dysgenesis syndrome: mechanistic  
621 insights and potential new downstream effects. *Fertility and Sterility* 89, e33-38.
- 622 Simanainen, U., Adamsson, A., Tuomisto, J.T., Miettinen, H.M., Toppari, J., Tuomisto, J. &  
623 Viluksela, M. (2004) Adult 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) exposure and  
624 effects on male reproductive organs in three differentially TCDD-susceptible rat lines.  
625 *Toxicological Sciences* 2, 401-407.

- 626 Skakkebaek, N.E., Rajpert-De-Meyts, E. & Main, K.M. (2001) Testicular dysgenesis  
627 syndrome: an increasingly common developmental disorder with environmental  
628 aspects. *Human Reproduction* 5, 972-978.
- 629 Sommer, R.J., Ippolito, D.L. & Peterson, R.E. (1996) In utero and lactational exposure of the  
630 male Holtzman rat to 2,3,7,8-tetrachlorodibenzo-p-dioxin: decreased epididymal and  
631 ejaculated sperm numbers without alteration in sperm transit rate. *Toxicology and  
632 Applied Pharmacology* 140, 146-153.
- 633 Theobald, H.M. & Peterson, R.E. (1997) In utero and lactational exposure to 2,3,7,8-  
634 tetrachlorodibenzo-rho-dioxin: effects on development of the male and female  
635 reproductive system of the mouse. *Toxicology and Applied Pharmacology* 1, 124-135.
- 636 Tuomisto, J.T., Pohjanvirta, R., Unkila, M. & Tuomisto, J. (1999) TCDD-induced anorexia  
637 and wasting syndrome in rats: effects of diet-induced obesity and nutrition.  
638 *Pharmacology Biochemistry and Behavior* 62, 735-742.
- 639 Tusher, V.G., Tibshirani, R. & Chu, G. (2001) Significance analysis of microarrays applied to  
640 the ionizing radiation response. *Proceedings of the National Academy of Sciences U.  
641 S. A.* 98, 5116-5121.
- 642 Trasler, J.M. (2009) Epigenetics in spermatogenesis. *Molecular and Cellular Endocrinology*  
643 306, 33-36.
- 644 Van de Berg, M., Birnbaum, L.S., Denison, M., De Vito, M., Farland, W., Feeley, M.,  
645 Fiedler, H., Hakansson, H., Hanberg, A., Haws, L., Rose, M., Safe, S., Schrenk, D.,  
646 Tohyama, C., Tritscher, A., Tuomisto, J., Tysklind, M., Walker, N., Peterson, R.E.  
647 (2006) The 2005 World Health Organization reevaluation of human and mammalian  
648 toxic equivalency factors for dioxins and dioxin-like compounds. *Toxicological  
649 Sciences* 93, 223-241.
- 650 Vanden Heuvel, J.P., Clark, G.C., Kohn, M.C., Tritscher, A.M., Greenlee, W.F., Lucier, G.W.  
651 & Bell, D.A. (1994) Dioxin-responsive genes – Examination of dose-response  
652 relationships using quantitative reverse transcriptase-polymerase chain-reaction.  
653 *Cancer Research* 54, 62-68.
- 654 Wang, E., Miller, L.D., Ohnmacht, G.A., Liu, E.T. & Marincola, F.M. (2000) High-fidelity  
655 mRNA amplification for gene profiling. *Nature Biotechnology* 18, 457-459.
- 656 Welsh, M., Saunders, P.T., Fiskens, M., Scott, H.M., Hutchison, G.R., Smith, L.B., and  
657 Sharpe, R.M. (2008) Identification in rats of a programming window for reproductive  
658 tract masculinization, disruption of which leads to hypospadias and cryptorchidism.  
659 *Journal of Clinical Investigation* 118, 1479-1490.
- 660 Wilker, C., Johnson, L. & Safe, S. (1996) Effects of developmental exposure to indole-3-  
661 carbinol or 2,3,7,8-tetrachlorodibenzo-p-dioxin on reproductive potential of male rat  
662 offspring. *Toxicology and Applied Pharmacology* 141, 68-75.
- 663 Yamano, Y., Ohyama, K., Ohta, M., Sano, T., Ritani, A., Shimada, J., Ashida, N., Yoshida,  
664 E., Ikehara, K. & Morishima, I. (2005) A novel spermatogenesis related factor-2  
665 (SRF-2) gene expression affected by TCDD treatment. *Endocrine Journal* 52, 75-81.  
666
- 667  
668



669 **FIGURE LEGENDS**

670 **Figure 1:** Relative expression of *Cyp1a1* assessed by Q-PCR analysis in the livers of TCDD-  
671 200 male rats of the F1 generation at 5 and 28 days of age. The *Gusb* levels-normalized  
672 values are the mean  $\pm$  S.E.M. of n=3-4 different animals from 3-4 different litters. a,  $p<0.05$   
673 as compared to age-matched controls.

674  
675 **Figure 2:** Relative expression of *Ccl5/Rantes* assessed by Q-PCR analysis in the testes of  
676 TCDD-200 and control rats of 5 to 145 days of age. Testes of TCDD-10 and TCDD-100 rats  
677 were studied at 67 and 145 days of age. The *Rpl19* levels-normalized values are the mean  $\pm$   
678 S.E.M. of n= of 3 to 5 animals from 3 to 5 different litters. a,  $p<0.05$  as compared to controls.

679  
680 **Figure 3:** Identification of the testicular source of *Ccl5/Rantes*. (A) Total RNA was extracted  
681 from 6-day old cultured peritubular cells (Pc) or Sertoli cells (Sc) recovered from 20-day old  
682 rat testes; from a fraction enriched in Leydig cells (Lc), a crude fraction of germ cells (TGc)  
683 elutriated fractions enriched in spermatids (Stids) or in pachytene spermatocytes (Scytes) (all  
684 from adult rat testes). RT-PCR analysis was conducted on 4 independent series of samples,  
685 and one representative series is shown. *Rpl19* was used to roughly estimate differences of  
686 expression between samples. (B) Immunohistochemical localization of *Ccl5/Rantes* (red  
687 labeling) on testis paraffin sections. Staining for  $3\beta$ -HSD (red labeling) was used to identify  
688 Leydig cells in the interstitium. Leydig cells were strongly labeled for *Ccl5/Rantes* by contrast  
689 to seminiferous tubules which were weakly labeled. Nuclei are blue-labeled (DAPI staining).  
690 Arrowheads point to Leydig cells. Control (-) for *Ccl5/Rantes* indicates that the primary  
691 antibody against *Ccl5/Rantes* was omitted. Bar: 100  $\mu$ m.

692  
693  
694  
695  
696

697  
698

**Table 1: List and sequence of primers used for PCR analysis**

Gene Symbol	Accession #	Forward 5' to 3'	Reverse 5' to 3'	Size (bp)	Topt
Ccl5/Rantes (a)	NM_031116	CTTGCAAGTCGTCCTTTGTCAC	GACTAGAGCAAGCAATGACAG	158	58
Ccl5/Rantes (b)	NM_031116	ACCTTGCAAGTCGTCCTTTGTC	ATCTATGCCCTCCCAGGAATG	224	55
Cyp1a1	NM_012540	CAAGAGCTGCTCAGCATAGTC	GCTCAATGAGGCTGTCTGTG	229	58
Glipr1	NM_001011987	TCTCTGCACTAACCCACAACG	GGAGAAGTACTTAGCGATG	124	58
Gusb	NM_017015	CTTCATGACGAACCAGTCAC	GCAATCCTCCAGTATCTCTC	117	58
Insl3	NM_053680	CTGTCTCACTGGCTGCACC	GGGTGTTTCATTGGCACAG	119	58
Pf4	NM_001007729	TTCTTCTGGGTCTGCTGTTG	ATTCTTCAGCGTGGCTATG	197	55
Rpl19	NM_031103	CTGAAGGTCAAAGGGAATGTG	GGACAGAGTCTTGATGATCTC	195	58
Sycp1	NM_012810	TTGGGAGAGGTTGAGAAAGC	CCTTTGCTGAAGACTGTTCC	205	58

699  
700  
701  
702  
703  
704

The size of the expected PCR fragment in base pairs (bp) and the optimal temperature (Topt) for annealing are reported. Two reference genes were used, Gusb (Glucuronidase Beta) and Rpl19 (Ribosomal protein L19). Two couples were used for Ccl5/Rantes, Ccl5/Rantes (a) for RT-PCR and Ccl5/Rantes (b) for RT-Q-PCR.

705  
706  
707  
708

**Table 2: F1 pups and weight of the offspring**

2.3.7.8 TCDD (ng/kg)	0	10	100	200	
<b>Mean number of pups/dam</b>	12.5±2.7 (9)	11.7±1.5 (3)	13.7±2.5 (3)	10.91±2.9 (9)	
<b>Mean % of males/litter</b>	47.6±19 (9)	62.4±19.2 (3)	59.2±10.1 (3)	48.4±13 (9)	
<b>Male pup weight (g) from 5 to 14 postnatal days</b>					
	<b>5</b>	14.3±2.4 (5)	13.7±1.3 (3)	13.3 ± 1.3 (3)	12.9±1.6 (5)
		13.7±1.7 [32]	13.7±1.3 [17]	13.3± 1.3 [21]	12.6± 1.7 [26] <sup>a</sup>
	<b>7</b>	20.4±3.2 (5)	18.8±1.8 (3)	18.0±1.4 (3)	17.7±2.9 (5)
		19.5±2.2 [28]	18.7±1.8 [19]	17.9±1.4 [22]	17.2±3.0 [22] <sup>a</sup>
	<b>10</b>	28.1±4.0 (5)	26.5±1.6 (3)	26.3±0.8 (3)	25.4±4.1 (5)
		26.9±3.0 [28]	26.4±2.0 [18]	26.3±1.1 [22]	24.7± 4.3 [22] <sup>a</sup>
	<b>12</b>	34.9±5.5 (5)	33.7±1.3 (3)	32.7±1.0 (3)	31.9±4.5 (5)
		33.4±4.1 [28]	33.7±1.7 [18]	32.6± 1.4 [22]	31.0±4.6 [22] <sup>a</sup>
	<b>14</b>	42.0±5.6 (5)	40.6±2.4 (3)	39.9±1.1 (3)	38.5±5.4 (5)
		40.3±4.5 [28]	40.2±2.6 [18]	39.8±1.5 [22]	37.5± 5.6 [22] <sup>a</sup>

723  
724  
725  
726  
727  
728  
729  
730  
731  
732  
733  
734  
735  
736  
737  
738  
739  
740  
741  
742  
743  
744  
745  
746

The number of dams studied is indicated in parentheses. The total number of pups weighed is indicated in brackets. Male pups were regularly weighed during the first two weeks. Values are mean ± SEM of (n) litter. For pup weight values are mean ± SD of (n) litter or [n] pups. Statistical analysis was performed using ANOVA followed by the multiple comparisons Dunett's test. No significance was observed if data were expressed per litter; a, p<0.05 as compared to time-matched controls if considering data expressed per male pup.

747 **Table 3: Epididymal sperm reserves and daily sperm production (DSP) in 67-day old rats of the**  
 748 **TCDD-10, TCDD-100, TCDD-200 and control groups.**

2,3,7,8 TCDD (ng/kg bw)		0	10	100	200
<b>Epididymal Sperm Reserves (10<sup>6</sup>)</b>					
Caput	(litter)	48.8±0.65 (9)	46.9±2.3 (3)	42.4±2.6 (3)	39.9±4.3 (9) P=0.06
	(rat)	48.5±2 (12)	47.2±1.6 (7)	42.1±1.5 (8)	39.5±3.6 (10) P=0.013
Corpus	(litter)	7.6±0.52 (9)	8.8±1.7 (3)	6.8±1.1 (3)	8.6±1.9 (9)
	(rat)	7.4±0.72 (12)	8.4±1.3 (7)	6.9±0.7 (8)	8.3±1.6 (10)
Cauda	(litter)	59.9±3.2 (9)	67.7±1.3 (3)	59.4±1.1 (3)	46.5±3.4 (9) P=0.056
	(rat)	62.4±3.3 (12)	70.5±7.1(7)	59.9±6.4 (8)	45.9±3.1(10) P=0.021
<b>Daily Sperm Production (10<sup>6</sup>)</b>					
	(litter)	25.9±0.9 (9)	25.2±3 (3)	25.7±1.8 (3)	22.5±1 (9) P=0.052
	(rat)	26.3±1.04 (12)	25.3±1.9 (7)	25.5±6.4 (8)	22.4±0.9 (10) P=0.06

774 Values are mean ± SEM and are expressed per litter (3 to 9) and per rat (7 to 12). Statistical analysis  
 775 was performed using ANOVA followed by the multiple comparisons Dunett's test, and the *p* value is  
 776 reported for the TCDD-200 group as compared to the control group.

781 **Table 4: List of genes up and down regulated in 28 day-old rat testes from the TCDD-200 group**

Gene symbol and known function or localization	Accession number	Micro Array Fold Change	Q PCR Fold Change (n=3)	Number of 5' flanking XRE in mouse orthologous genes
Insl3 Leydig cells	NM_053680	1.49	1.41 ± 0.10	6
Glipr1 Tumor suppressor	NM_001011987	1.45	1.65 ± 0.10	1
Cxcl4 Chemokine	NM_001007729	1.39	1.66 ± 0.24	2
Q4V7D5	XM_576624	-1.48	nd	nd
RGD1561017	XM_577094	-1.53	nd	nd
RT1-CE5 variant 1, variant 2	NM_001008843, NM_001033986	-1.53	nd	nd
LOC679900	XM_574899	-1.83	nd	nd
Ccl5/Rantes Chemokine	NM_031116	-1.86	-2.70 ± 0.05	3

782 Data for Q PCR are mean ± SEM of 3 testis samples from 3 different litters. nd, not defined.

793  
794  
795  
796  
797  
798  
799  
800  
801  
802  
803  
804  
805  
806  
807  
808  
809  
810  
811  
812  
813  
814  
815  
816  
817  
818  
819  
820  
821  
822  
823  
824

**Table 5: Generation of F2 males raw data of end-points surveyed**

<b>End-points surveyed</b>		<b>Control</b>	<b>TCDD 200 ng/kg bw</b>
<b>Number of males</b>		8	7
<b>Number of dams</b>		16	14
<b>Mean number of pups/dam</b>		13.19±3 (16)	12.64±3 (16)
<b>Mean % of males/litter</b>		51.6±12.2 (16)	47.2±13 (16)
<b>Male pup weight (g)</b>	<b>5 days</b>	12.7±1.1 (8)	13.9±2.2 (7)
		12.6± 1.4 [51]	13.2± 1.9 [30]
	<b>8 days</b>	19.9±1.7 (8)	20.2±3.9 (7)
		19.7± 2.4 [51]	19.2±3.7 [30]
<b>Q PCR data (relative expression)</b>			
<b>Hepatic cyp1a1 levels</b>	<b>20 days</b>	2.7±3.2 (3)	1.6±1.9 (3)
<b>Testicular Ccl5/Rantes levels</b>	<b>67 days</b>	0.84±0.09 (4)	1.06±0.45 (3)
	<b>145 days</b>	1.05±0.13 (4)	1.31±0.23 (3)
<b>Daily Sperm Production (10<sup>6</sup>)</b>	<b>67 days</b>	22.7±1.02 (4)	25.3±4.1 (3)
	<b>145 days</b>	31.3±3.4 (4)	31.4±1.3 (3)
<b>Epididymal Sperm Reserves (10<sup>6</sup>)</b>	<b>67 days</b>	73.5±9.7 (4)	95.5±9.8 (3)
	<b>145 days</b>	244.9±29.2 (4)	261.5±12.9 (3)

The number of dams studied is indicated in parentheses. The total number of pups weighed is indicated in brackets. Values for pup weight are the mean ± SD of (n) litters or [n] pups. Data were not significant. Q PCR data, DSP and sperm reserves were expressed as mean ± SEM of (n) samples, each sample originated from a different litter.

825 Supplemental Data: Description of the 2 preliminary experiments settled up to determine the  
826 dose-range of TCDD

827

828 Experiment 1: Four groups of five dams each were orally treated with 0, 27, 140 or  
829 270 ng/kg bw. Timing of dosing was Embryonic Day 11. Animals were killed at different  
830 developmental ages. Intra-testicular content of testosterone and 4-androstenedione were  
831 performed in samples collected at different periods of development. We also performed  
832 histological analysis and fertility tests. Sperm reserves were counted in animals aged of 159  
833 days. No treatment-related differences were noted with regard to the outcome of gestation, the  
834 litter size, the sex-ratio or the body weights of fetuses from females that were dosed with the  
835 two lower doses of TCDD. However, one dam had aborted and a second one gave birth to 10  
836 dead fetuses in the group administered the highest dose. We did not collect samples from the  
837 dead fetuses, and the origin of their death has not been investigated. The gross histology of  
838 the in utero exposed rat testes of the different TCDD dosed groups including the highest  
839 dosed-group was comparable to the control group. Intra-testicular hormone levels in the  
840 treated animals were also in the normal range. Animals could reproduce and sperm reserves  
841 assessed at 159 days of age were in the normal range.

842

843 Experiment 2: A unique dose of TCDD of 1000 ng/kg bw was administered at  
844 Embryonic Day 15 to mimic the design of previous experiments leading to a spectrum of  
845 effects in the reproductive system of the male offspring (Ref. in Introduction). Two groups of  
846 5 dams each were handled. The five control dams had normal gestation, normal litter size and  
847 sex-ratio. In the TCDD-dosed dams group, one dam died before giving birth, 2 dams had  
848 eaten their fetuses soon after delivery, one dam gave birth to one male, and one dam gave  
849 birth to one male and two females. The four pups died a few days after birth. The three  
850 surviving dams were killed showing apathy and stuck and bristly hair.

851

852 Aliquots containing various doses of dioxins were assayed by Dioxlab (Dioxlab,  
853 94417 Saint-Maurice) to ascertain doses given to the animals. Therefore, maternal and foetal  
854 toxicity were observed in our hands at the dose of 270 ng/kg bw, and death of dams occurred  
855 at the dose of 1000 ng/kg bw.

856

857

Figure 1:

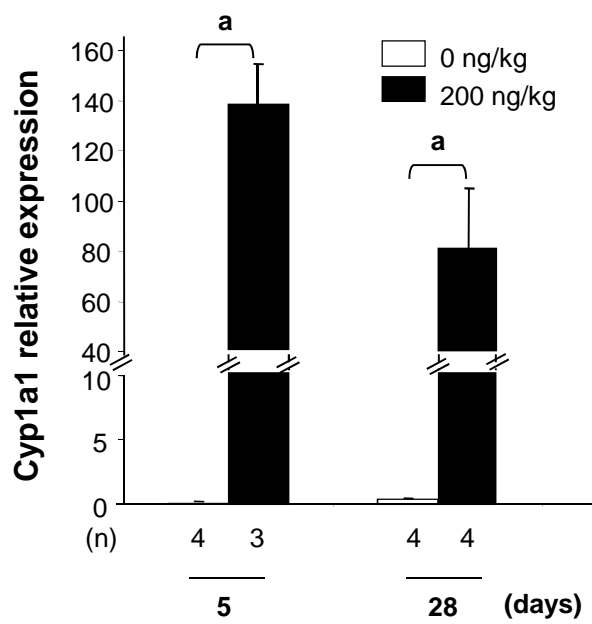


Figure 2:

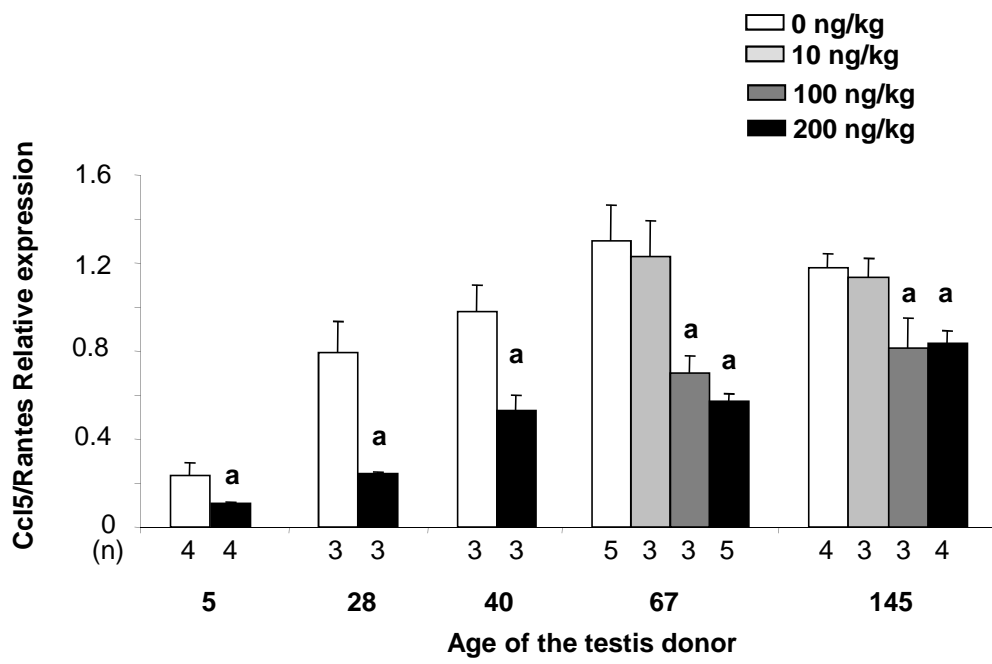
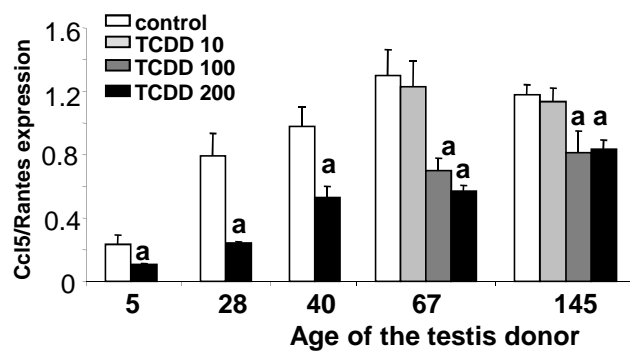
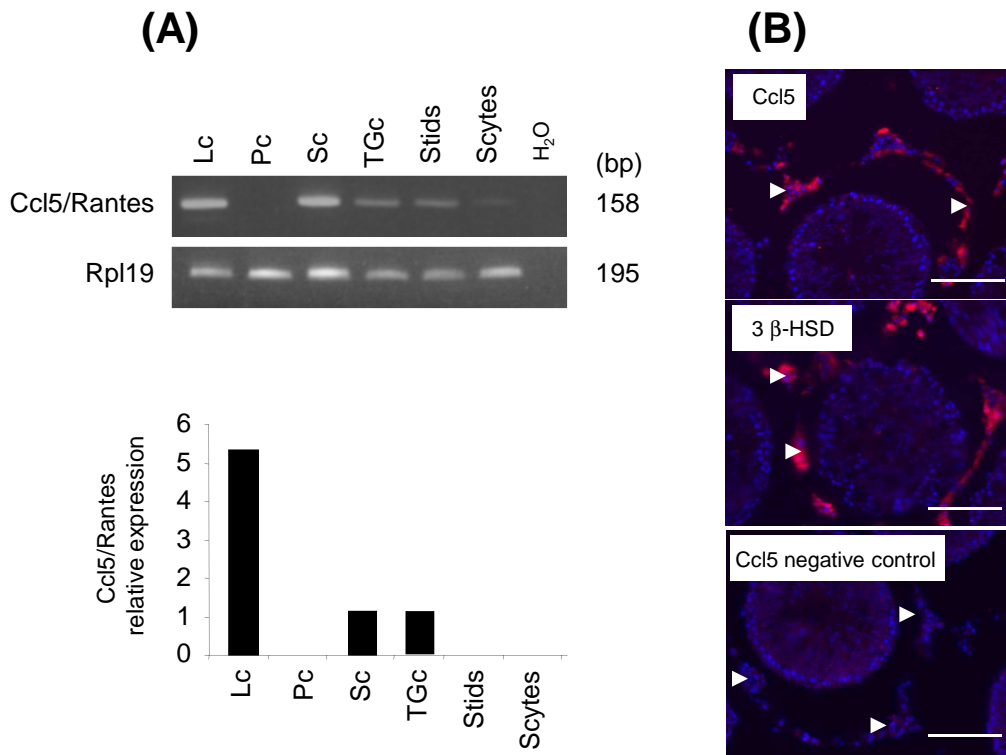


Figure 2:





**Figure 3:**



2,3,7,8 TCDD (ng/kg bw)		0	10	100	200
<b>Epididymal Sperm Reserves (10<sup>6</sup>)</b>					
Caput	(litter)	48.8±0.65 (9)	46.9±2.3 (3)	42.4±2.6 (3)	39.9±4.3 (9) P=0.06
	(rat)	48.5±2 (12)	47.2±1.6 (7)	42.1±1.5 (8)	39.5±3.6 (10) P=0.013
Corpus	(litter)	7.6±0.52 (9)	8.8±1.7 (3)	6.8±1.1 (3)	8.6±1.9 (9)
	(rat)	7.4±0.72 (12)	8.4±1.3 (7)	6.9±0.7 (8)	8.3±1.6 (10)
Cauda	(litter)	59.9±3.2 (9)	67.7±1.3 (3)	59.4±1.1 (3)	46.5±3.4 (9) P=0.056
	(rat)	62.4±3.3 (12)	70.5±7.1(7)	59.9±6.4 (8)	45.9±3.1(10) P=0.021
<b>Daily Sperm Production (10<sup>6</sup>)</b>					
	(litter)	25.9±0.9 (9)	25.2±3 (3)	25.7±1.8 (3)	22.5±1 (9) P=0.052
	(rat)	26.3±1.04 (12)	25.3±1.9 (7)	25.5±6.4 (8)	22.4±0.9 (10) P=0.06

±sem

Table 2: F1 pups and weight of the offspring

2.3.7.8 TCDD (ng/kg)	0	10	100	200
<b>Mean number of pups/dam</b>	12.5±2.7 (9)	11.7±1.5 (3)	13.7±2.5 (3)	10.91±2.9 (9)
<b>Mean % of males/litter</b>	47.6±19 (9)	62.4±19.2 (3)	59.2±10.1 (3)	48.4±13 (9)
<b>Male pup weight (g) from 5 to 14 postnatal days</b>				
	<b>5</b>			
	14.3±2.4 (5)	13.7±1.3 (3)	13.3 ± 1.3 (3)	12.9±1.6 (5)
	13.7±1.7 [32]	13.7±1.3 [17]	13.3± 1.3 [21]	12.6± 1.7 [26] <sup>a</sup>
	<b>7</b>			
	20.4±3.2 (5)	18.8±1.8 (3)	18.0±1.4 (3)	17.7±2.9 (5)
	19.5±2.2 [28]	18.7±1.8 [19]	17.9±1.4 [22]	17.2±3.0 [22] <sup>a</sup>
	<b>10</b>			
	28.1±4.0 (5)	26.5±1.6 (3)	26.3±0.8 (3)	25.4±4.1 (5)
	26.9±3.0 [28]	26.4±2.0 [18]	26.3±1.1 [22]	24.7± 4.3 [22] <sup>a</sup>
	<b>12</b>			
	34.9±5.5 (5)	33.7±1.3 (3)	32.7±1.0 (3)	31.9±4.5 (5)
	33.4±4.1 [28]	33.7±1.7 [18]	32.6± 1.4 [22]	31.0±4.6 [22] <sup>a</sup>
	<b>14</b>			
	42.0±5.6 (5)	40.6±2.4 (3)	39.9±1.1 (3)	38.5±5.4 (5)
	40.3±4.5 [28]	40.2±2.6 [18]	39.8±1.5 [22]	37.5± 5.6 [22] <sup>a</sup>

Male pups were regularly weighed during the first two weeks. Values are the mean ± SD of (n) litter. The number of total pups weighed is reported in [] and statistical analysis was performed using ANOVA followed by the multiple comparison Dunnett's test. <sup>a</sup> p<0.05 as compared to time matched controls.

Table 5: Generation of F2 males raw data of end-points surveyed

End-points surveyed		Control	TCDD 200 ng/kg bw
Number of males		8	7
Number of dams		16	14
Mean number of pups/dam		13.19±3 (16)	12.64±3 (16)
Mean % of males/litter		51.6±12.2 (16)	47.2±13 (16)
Male pup weight (g)	5 days	12.7±1.1 (8)	13.9±2.2 (7)
		12.6± 1.4 [51]	13.2± 1.9 [30]
	8 days	19.9±1.7 (8)	20.2±3.9 (7)
		19.7± 2.4 [51]	19.2±3.7 [30]
<b>Q PCR data (relative expression)</b>			
Hepatic cyp1a1 levels	20 days	2.7±3.2 (3)	1.6±1.9 (3)
Testicular Ccl5/Rantes levels	67 days	0.84±0.09 (4)	1.06±0.45 (3)
	145 days	1.05±0.13 (4)	1.31±0.23 (3)
Daily Sperm Production (10 <sup>6</sup> )	67 days	22.7±1.02 (4)	25.3±4.1 (3)
	145 days	31.3±3.4 (4)	31.4±1.3 (3)
Epididymal Sperm Reserves (10 <sup>6</sup> )	67 days	73.5±9.7 (4)	95.5±9.8 (3)
	145 days	244.9±29.2 (4)	261.5±12.9 (3)

Data are mean ±SD of (n) litter for pups weight and ±SEM for QPCR, DSP and sperm reserves. The number of rats for male pup weight is indicated in [].