Prolactin Is Not Required for the Development of Severe Chronic Experimental Autoimmune Encephalomyelitis

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*J Immunol* published online 24 July 2013
http://www.jimmunol.org/content/early/2013/07/25/jimmunol.1301128

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Prolactin Is Not Required for the Development of Severe Chronic Experimental Autoimmune Encephalomyelitis

Massimo Costanza,* Silvia Musio,* Mhamad Abou-Hamdan,* Nadine Binart, and Rosetta Pedotti*

Predominance of multiple sclerosis (MS) in women, reductions of disease flares during pregnancy, and their increase in the postpartum period have suggested a hormonal influence on MS activity. The hormone prolactin (PRL) has long been debated as a potential immune-stimulating factor in several autoimmune disorders, including MS and its animal model experimental autoimmune encephalomyelitis (EAE). However, to date, no data clearly ascribe a pathogenic role to PRL in these diseases. Using PRL receptor–deficient (Prlr<sup>−/−</sup>) and PRL-deficient (Prl<sup>−/−</sup>) mice, we show that PRL plays a redundant role in the development of chronic EAE. In Prlr<sup>−/−</sup> and Prl<sup>−/−</sup> mice, EAE developed with a delayed onset compared with littermate control mice, but with full clinical severity. In line with the clinical outcome, T cell proliferation and production of IFN-γ, IL-17A, and IL-6 induced by myelin Ag were delayed in Prlr<sup>−/−</sup> and Prl<sup>−/−</sup> mice. Ag-specific IgG Ab responses were not affected by PRLR or PRL deficiency. We also show that mouse lymph node cells and purified CD4<sup>+</sup> T cells express transcript for Prl, but not for Prl. These results reveal that PRL does not play a central role in the development of chronic EAE and optimal Th1 and Th17 responses against myelin. Moreover, they also rule out a possible contribution of PRL secreted by immune cells to the modulation of autoreactive T cell response in this model. The Journal of Immunology, 2013, 191: 000–000.

Multiple sclerosis (MS) is an inflammatory demyelinating disorder of the CNS that affects 2.5 million people worldwide and represents the leading cause of neurologic disability in the young adult population (1). In MS, myelin-reactive CD4<sup>+</sup> Th1 and Th17 cells are generally believed to drive an immune-mediated attack against components of the myelin sheath, leading to demyelination and axonal damage (2). However, the pathologic mechanisms underlying the development of MS are still incompletely understood.

In recent years, several pieces of evidence have suggested that sex-related factors might influence both incidence and progression of MS (3). Epidemiologic studies have shown that MS affects more frequently women than men, with a female/male ratio ranging from 2:1 to 3:1, depending on geographic areas (3). Pregnancy also importantly affects the clinical course of MS. Relapse rate significantly declines during the third trimester of pregnancy but considerably increases in the first 3 mo after delivery, if compared with prepregnancy rates (4, 5). Similarly to human disease, pregnancy suppresses clinical symptoms of experimental autoimmune encephalomyelitis (EAE), an animal model for MS (6, 7), and induction of chronic EAE in the postpartum period results in enhanced mortality and slightly worsened severity (7). Among sex-related factors, hormones have been hypothesized to play an important role in regulating MS and EAE (3). Prolactin (PRL) is a 199-aa peptide hormone mainly secreted by lactotrophic cells of the anterior pituitary gland and by other sources including immune cells (8). The best established functions of PRL are related to mammary gland development and regulation of lactation and female reproduction (9). Mean PRL serum levels are slightly but significantly higher in women (~2–20 μg/l) than in men (~2–10 μg/l) (10). PRL secretion increases during pregnancy and peaks postpartum in association with breastfeeding. In parallel to its reproductive functions, a large body of literature has argued for a role of PRL in the regulation of both cell-mediated and humoral immune responses (11–13). PRL binds to a single-pass transmembrane receptor (PRLR), belonging to the class I cytokine receptor superfamily, which includes receptors for IL-2, IL-6, GM-CSF, and leptin (8). In vitro studies have shown that PRL sustains survival, proliferation, and differentiation of T cell precursors (14), and modulates CD4<sup>+</sup> T cell expression of T-bet, a key transcription factor for the differentiation of Th1 cells (15). PRL has also been reported to stimulate the maturation of monocyte-derived dendritic cells (16). In mouse models of systemic lupus erythematosus (SLE), a multiorgan Ab-dependent autoimmune disease, PRL administration increases autoreactive immune responses (17, 18), by breaking B cell tolerance and enhancing titers of autoreactive Abs (18). In human SLE, higher serum levels of PRL correlate with greater disease severity, and treatment of SLE patients with bromocriptine (BCR), a dopamine D2 agonist that inhibits PRL secretion, reduces disease activity (19).

In MS, hyperprolactinemia has been largely debated (20). Early studies in rat EAE showed that serum PRL levels increase during the induction phase of disease (21), and treatment with BCR improves clinical signs of EAE (21, 22), suggesting a detrimental role for PRL in EAE. However, stimulation of D2 dopaminergic receptors on immune cells can modulate their functions, and BCR has been shown to directly suppress human T cell proliferation.
EAE in PRLR- and PRL-deficient mice

Mice

Prlr−/− mice were backcrossed for >12 generations into 129P2/Ola background (24). Prl−/− bred to C57BL/6 mice backcrossed for 10 generations into C57BL/6 background were purchased from Jackson Laboratories (25). Heterozygous pairs of each strain were bred to obtain Prl−/− and Prlr−/− or Prl−/− and Prl+/− mice. Genotyping was performed by PCR in Prl−/− and Prlr−/− as previously described (24) and in Prl−/− and Prl+/− as recommended by the vendor. C57BL/6 mice were from Charles River. Mice were bred and maintained under pathogen-free conditions at the animal facility of the Foundazione Istituto Neurologico Carlo Besta. Age-matched female 8- to 12-wk-old mice were used in all EAE experiments. Both knockout strains bear an H-2b haplotype, which confers susceptibility to MOG 35–55–induced EAE. However, Prl−/− mice were backcrossed into C57BL/6 background, which is known to be more susceptible to EAE development than the 129 background, into which Prlr−/− mice were backcrossed (26, 27). All procedures involving animals were approved by the Instituto Éthical Committee and performed in accordance to institutional guidelines and national law (DL116/92), and carried out according to the Principles of Laboratory Animal Care (European Communities Council Directive 86/609/EEC).

Peptide synthesis and EAE induction

MOG35–55 (MEVGWYRSPFSRSHYLYRNGK) and control peptide (rat PrP, DGDFAIKFKTVKLLVDGTHY) were synthesized using a standard 9-fluorenylmethoxycarbonyl chemistry on a 433A automated peptide synthesizer (Applied Biosystems) and purified by HPLC. The purity of each peptide was >95% as assessed by analytical reverse-phase HPLC. EAE was induced as previously described (28). In brief, 96-well plates (Immunol; Thermo Labsystems) were coated overnight at 4°C with 0.1 ml MOG35–55 diluted in 0.1 M NaHCO3 buffer (pH 9.5) at a concentration of 0.010 mg/ml. The plates were blocked with 10% FCS (blocking buffer) for 2 h. Samples were diluted in blocking buffer at 1/100, and Ab binding was tested by the addition of peroxidase-conjugated monoclonal goat anti-mouse IgG, IgG1, IgG2a, and IgG3 (Southern Biotechnology Associates), each at a 1:5000 dilution in blocking buffer. Enzyme substrate was added, and plates were read at 450 nm on a microplate reader.

Real-time PCR

Gene expression analysis was performed ex vivo on LNCs or magnetically purified CD4+ T cells (purity >95% by flow cytometry; CD4+ T cell isolation Kit II, Miltenyi) from LNCs of naive or immunized C57BL/6 mice 7 d after immunization, and on in vitro–stimulated CD4+ T cells from naive mice. Total RNA was extracted with RNeasy Mini Kit (Qiagen) and reverse transcribed with Quantitect Reverse Transcription Kit (Qiagen) according to manufacturer’s guidelines. Real-time PCR was performed on 7500 Fast Real-time PCR system (Applied Biosystems). Prl detection was performed with Fast Universal Master Mix (Applied Biosystems) and the following primer/probe sets (Applied Biosystems): Prl, Mm00499949_m1; Gapdh, Mm03928990_g1; Prl detection was performed with Fast SYBR Green Master Mix (Applied Biosystems) and the following primers (synthesized by Integrated DNA Technologies): Prl forward: 5′-TTGACATACGCAAAAGAGGAGAGAAGA-3′; Prl reverse: 5′-TGCTTGTCAAAGAAAGCAAGATTTG-3′; Gapdh forward: 5′-TGGCACCACACTGCTTGA-3′; Gapdh reverse: 5′-GGATGACGGAGGATGTGC-3′ (29). Prl primer pairs have been designed to amplify exons 4–5, which are common to the four described isoforms of PRLR. Expression of target genes was quantified by the comparative threshold cycle method, and Gapdh was used as housekeeping gene. Data are presented as percentage of the housekeeping gene Gapdh ± SD.

Measurement of PRL in supernatants and sera

PRL was measured in supernatants of cultured CD4+ T cells and sera of naive or immunized C57BL/6 mice by ELISA (Mouse Prolactin Duoset; R&D Systems), according to manufacturer’s instructions. Serum PRL concentrations were tested during priming (i.e., day 7 p.i.), onset, and acute phases of MOG35–55–induced EAE. Sera collected from naive Prl−/− mice, which display hyperprolactinemia (9), and naive Prl−/− mice were used as positive and negative controls, respectively.

Statistical analysis

For clinical data, Mann–Whitney test was used to compare results between two groups. For all other analyses, unpaired Student t test, two tailed, was used to compare results between two groups. Analysis was performed by SPSS software. In all tests, *p < 0.05 was considered statistically significant.

Results

EAE develops with delayed onset but full clinical severity in absence of PRLR or PRL

To investigate the role of PRL in CNS autoimmunity, we induced EAE in female PRLR-deficient (Prlr−/−) mice and WT littermates (Prl−/−) by immunization with MOG35–55 in CFA. Prl−/− mice developed EAE with delayed onset but similar
clinical severity as compared with Prlr⁺/⁺ controls (Fig. 1A, Table I). As previously reported (9), Prlr⁻/⁻ mice are hyperprolactinemic (data not shown). Moreover, in recent years, an N-terminal 16-kDa fragment of full-length 23-kDa PRL has been described that might not bind the classical PRLR, but a yet unidentified receptor (9). To evaluate any possible PRLR-independent effect of PRL on CNS autoimmunity, we next induced EAE in PRL-deficient (Prl⁻/⁻) and WT littermate (Prl⁺/⁺) (H-2b haplotype) female mice. In line with the results obtained in absence of PRLR, Prl⁻/⁻ mice developed EAE with a mild but significantly delayed onset, and with a severity indistinguishable from that of WT littermates (Fig. 1B, Table I).

Th1 and Th17 autoimmune responses are delayed in absence of PRLR or PRL.

Because Th1 and Th17 responses play a key role in CNS inflammation of EAE, we wanted to explore whether peripheral T cell responses against myelin were affected by PRLR deficiency. For this purpose, we isolated draining LNs from Prlr⁺/⁺ and Prlr⁻/⁻ mice during the priming phase of EAE, and examined in vitro the proliferative recall response and cytokine production in response to MOG₃₅₋₅₅ stimulation. LNCs from Prlr⁻/⁻ mice harvested 7 d after the induction of EAE displayed a significantly reduced proliferation in response to peptide stimulation if compared with Prlr⁺/⁺ littersmates (Fig. 2A). Moreover, we found a significantly decreased production of IFN-γ, IL-17A, IL-6, and IL-10 in peptide-stimulated LNCs of Prlr⁻/⁻ as compared with Prlr⁺/⁺ littersmates (Fig. 2A). These findings could reflect a decreased frequency of MOG₃₅₋₅₅-reactive T cells in LNs of Prlr⁻/⁻ mice compared with Prlr⁺/⁺ mice, and/or a reduced potential of autoreactive cells from Prlr⁻/⁻ mice to proliferate and secrete proinflammatory cytokines in response to MOG₃₅₋₅₅. Because we observed that in absence of PRLR the onset of EAE was delayed, we performed the same analysis at a later time point during EAE priming (day 10 p.i.), when Prlr⁺/⁺ control mice displayed first clinical symptoms of disease, whereas Prlr⁻/⁻ mice were still disease free. At this time point, we observed that LNCs from Prlr⁻/⁻ mice were fully responsive to MOG₃₅₋₅₅, showing even higher proliferation and increased production of IFN-γ, IL-17A, IL-6, and IL-10 (Fig. 2B) as compared with Prlr⁺/⁺ control mice.

In line with data obtained with PRLR-deficient strain, LNCs from Prl⁻/⁻ mice displayed significantly reduced proliferation (Fig. 3A) and production of IFN-γ, IL-17A, IL-6, and IL-10 (Fig. 3B) in response to MOG₃₅₋₅₅ as compared with WT controls at day 7, but not at day 10 after EAE induction.

These results reveal that the absence of PRLR or PRL does not impair the development of Th1 and Th17 responses against MOG₃₅₋₅₅, but induces a delay in the generation of these responses. This delay appears consistent with the delayed appearance of clinical symptoms of EAE observed in Prlr⁻/⁻ and Prl⁻/⁻ mice.

Several lines of evidence have suggested that PRL might importantly modulate B cell functions. In a mouse model of SLE, PRL has been shown to increase serum titers of anti-DNA Abs and IgG deposits in glomeruli (18). We therefore evaluated in our models whether PRL had any impact on the production of autoantibodies. In a mouse model of SLE, PRL has been shown to increase serum titers of anti-DNA Abs and IgG deposits in glomeruli (18). We therefore evaluated in our models whether PRL had any impact on the production of autoantibodies. In a mouse model of SLE, PRL has been shown to increase serum titers of anti-DNA Abs and IgG deposits in glomeruli (18). We therefore evaluated in our models whether PRL had any impact on the production of autoantibodies. In a mouse model of SLE, PRL has been shown to increase serum titers of anti-DNA Abs and IgG deposits in glomeruli (18). We therefore evaluated in our models whether PRL had any impact on the production of autoantibodies.

### Table I. EAE in Prlr⁻/⁻ and Prl⁻/⁻ mice

<table>
<thead>
<tr>
<th>Strain</th>
<th>Incidence (%)</th>
<th>EAE Onset (d)</th>
<th>Peak Disease Severity</th>
<th>Cumulative Disease Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prlr⁺/⁺</td>
<td>100 (29/29)</td>
<td>12.5 ± 0.7</td>
<td>3.7 ± 0.2</td>
<td>59.8 ± 6.0</td>
</tr>
<tr>
<td>Prlr⁻/⁻</td>
<td>100 (14/14)</td>
<td>15.1 ± 1.2*</td>
<td>3.6 ± 0.3</td>
<td>60.7 ± 10.3</td>
</tr>
<tr>
<td>Prl⁺/⁺</td>
<td>100 (27/27)</td>
<td>11.0 ± 0.4</td>
<td>4.5 ± 0.1</td>
<td>89.5 ± 3.5</td>
</tr>
<tr>
<td>Prl⁻/⁻</td>
<td>100 (15/15)</td>
<td>13.5 ± 1.4**</td>
<td>4.2 ± 0.3</td>
<td>82.5 ± 7.6</td>
</tr>
</tbody>
</table>

Data are shown as mean ± SEM.

* *p = 0.035 versus Prlr⁺/⁺ WT mice by Mann–Whitney U test.

** *p = 0.045 versus Prlr⁺/⁺ WT mice by Mann–Whitney U test.
with MOG35–55 and measured serum PRL concentrations. In contrast with a previous study reporting an increase in serum PRL levels in rat EAE (21), we observed a reduction of serum PRL concentrations in mice with EAE compared with naive mice (Fig. 5). Although PRL is mainly secreted centrally by the pituitary, PRL has been suggested to be secreted also peripherally in lymphoid organs (30). However, previous work has failed to detect mRNA for Prl in mouse spleen, thymus, LN, and bone marrow (31). More recent work reported Prl mRNA expression in mouse thymocytes and in freshly isolated or mitogen-stimulated splenocytes (30). Moreover, immunoreactivity for PRL in some splenic CD4+ T cells has been described (32), although this work did not clarify whether CD4+ cells were the sources of PRL or were binding PRL deriving from other sources. To evaluate any possible contribution of PRL produced and secreted locally in secondary lymphoid organs to the development of autoreactive T cell responses, we first harvested LNs from naive C57BL/6 mice (H-2b haplotype) and assessed ex vivo by real-time PCR the expression of Prl transcript in total LNCs and in magnetically purried CD4+ T cells. We did not find expression of Prl mRNA in either LNCs or CD4+ T cells of these mice (Fig. 6A). Next, to evaluate the possibility that the transcription of Prl gene is

**FIGURE 2.** Delayed Th1 and Th17 responses against myelin in PRLR-deficient mice. LNCs were isolated from draining (axillary and inguinal) LNs of Prl+/- and Prl-/- mice at day 7 (A) or 10 (B) after EAE induction and stimulated in vitro with MOG35–55 or medium alone. Proliferation rate was assessed by [3H]thymidine incorporation after 48 h of culture. Data represent the mean cpm ± SEM of triplicate cultures of cells pooled from three to four mice per group. Cytokine production was determined in supernatants of parallel cultures by ELISA (means ± SEM, from duplicate wells). Data are representative of two independent experiments that gave similar results, each including three to four mice per group. *p < 0.05 by Student t test.

**FIGURE 3.** PRL-deficient mice display delayed Th1 and Th17 responses against myelin. LNCs were isolated from draining (axillary and inguinal) LNs of Prl+/- and Prl-/- mice at day 7 (A) or 10 (B) after EAE induction and stimulated in vitro with MOG35–55 or medium alone. Proliferation rate was assessed by [3H]thymidine incorporation after 48 h of culture. Data represent the mean cpm ± SEM of triplicate cultures of cells pooled from three to four mice per group. Cytokine production was determined in supernatants of parallel cultures by ELISA (mean ± SEM, from duplicate wells). Results are representative of two independent experiments each including three to four mice per group. *p < 0.05 by Student t test.
induced in immune cells during EAE, we repeated the analysis in LNCs and purified CD4+ T cells harvested from C57BL/6 mice during the priming phase of MOG35–55–induced EAE. We failed to detect Prl transcript also in these in vivo activated cells (Fig. 6A). To further test the hypothesis of an induction of Prl gene transcription upon immune stimulation, we activated in vitro CD4+ T cells purified from naive C57BL/6 mice with anti-CD3 and anti-CD28 Abs, and analyzed mRNA expression of Prl by real-time PCR and PRL protein secretion in culture supernatants by ELISA. PRL was undetectable at both transcript (Fig. 6C) and protein levels (data not shown) also after stimulation. These data are consistent with results reported by Clevenger and colleagues (33) showing that a murine Th cell line, either resting or stimulated with IL-2 or Con A, does not express PRL at either mRNA or protein level. Taken together, our findings indicate that PRL concentrations do not increase during EAE, and that neither T cells nor LNCs express and secrete PRL, thus ruling out CD4+ T cells as a possible source of local PRL that could contribute to the development of autoreactive T cell responses in EAE. Conversely, in line with previous findings (8), we found expression of Prlr mRNA in both LNCs and purified CD4+ T cells isolated from C57BL/6 naive mice or mice with EAE. Interestingly, we observed a reduction of Prlr transcript during the priming phase of EAE (Fig. 6B). CD4+ T cells activated in vitro with anti-CD3 and anti-CD28 Abs displayed a downregulation of Prlr mRNA 48 h after stimulation in comparison with unstimulated cells (Fig. 6C). It must be taken into consideration that expression of Prlr gene at the mRNA level might be different from that of PRLR at the protein level, because of complex regulatory processes controlling the final expression of protein in a cell. Nevertheless, given the observed downregulation of Prlr mRNA in CD4+ T cells after in vitro stimulation, it is possible that downregulation of Prlr transcript in mice immunized for EAE reflects the activation state of CD4+ T cells during the disease.

**Discussion**

Collectively, this study provides evidence that PRL plays a redundant role in the development of chronic EAE, and that PRL
locally produced in lymphoid organs is unlikely to exert an immune-modulating effect on immune cells during EAE in this model. Even though we observed a delay in the onset of EAE symptoms, which was associated with a delay in the establishment of anti-MOG peptide Th1 and Th17 responses in LNs, the overall severity of EAE was indistinguishable between Prl−/− and Prl+/+ mice and corresponding WT littermates. This finding suggests that the PRL/PRLR axis can be readily compensated by other factors in the development of chronic EAE. The results obtained in Prl−/− and Prl+/− mice are in contrast with earlier studies proposing that PRL exerts a detrimental effect in CNS autoimmunity (21, 22). However, in these previous studies, PRL functions were evaluated in rat EAE by the use of BCR, whose immune-modulating effects are not solely related to PRL depletion (23), whereas our results were obtained in Prl−/− and Prl+/− mice. Importantly, Prl−/− mice display a normal composition of lymphocyte subsets in primary and secondary lymphoid organs (34). Similarly, Prl−/− mice have normal myelopoiesis and primary lymphopoiesis (25). Our findings are consistent with the study of Bouchard and colleagues (34) showing that Prl−/− mice mount an effective immune response to several types of stimuli, such as infection with an intracellular pathogen (i.e., Listeria monocytogenes) and infection with an allogeneic tumor cell line. In this work, it was also demonstrated that Prl−/− mice develop a normal specific Ig response after immunization with a non-self Ag (34). In line with these results, we show that IgG response against the self-Ag MOG35-55 was not affected by PRLR or PRL deficiency.

In the MS field, PRL has gained renewed interest in recent years, because two studies showed that exclusive breastfeeding (a hyperprolactinemic physiologic condition) reduces the risk for postpartum relapses (35, 36), albeit other articles reported discordant results (5, 37, 38). Further, another article has demonstrated that PRLR-deficient mice have normal myelopoiesis and primary lymphopoiesis (25). The authors have no financial conflicts of interest.

References

11. Ormanody, C. J., A. Camus, J. Barra, D. Damotte, B. Lucas, H. Buteau, M. Edery, H. Buteau, M. Edery, and J. Barra. 2005. Prolactin exerts a detrimental effect in CNS autoimmunity (21, 22). However, in these previous studies, PRL functions were evaluated in rat EAE by the use of BCR, whose immune-modulating effects are not solely related to PRL depletion (23), whereas our results were obtained in Prl−/− and Prl+/− mice. Importantly, Prl−/− mice display a normal composition of lymphocyte subsets in primary and secondary lymphoid organs (34). Similarly, Prl−/− mice have normal myelopoiesis and primary lymphopoiesis (25).

Disclosures

The authors have no financial conflicts of interest.

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References


