Maternal Trypanosoma cruzi Infection Upregulates Capacity of Uninfected Neonate Cells To Produce Pro- and Anti-Inflammatory Cytokines

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The possibility of maternal in utero modulation of the innate and/or adaptive immune responses of uninfected newborns from Trypanosoma cruzi-infected mothers was investigated by studying the capacity of their whole blood cells to produce cytokines in response to T. cruzi lysate or lipopolysaccharide-plus-phytohemagglutinin (LPS-PHA) stimulation. Cells of such newborns occasionally released gamma interferon (IFN-γ) and no interleukin-2 (IL-2) and IL-4 upon specific stimulation, while their mothers responded by the production of IFN-γ, IL-2, and IL-4. Infection in mothers was also associated with a hyperactivation of maternal cells and also, strikingly, of cells of their uninfected neonates, since their release of proinflammatory (IL-1β, IL-6, and tumor necrosis factor alpha [TNF-α]) as well as of anti-inflammatory (IL-10 and soluble TNF receptor) cytokines or factors was upregulated in the presence of LPS-PHA and/or parasite lysate. These results show that T. cruzi infection in mothers induces profound perturbations in the cytokine response of their uninfected neonates. Such maternal influence on neonatal innate immunity might contribute to limit the occurrence and severity of congenital infection.

Maternal-fetal transmission of Trypanosoma cruzi, the protozoan parasite agent of Chagas’ disease in Latin America, occurs in 2 to 12% of pregnancy in chronically infected mothers, inducing severe disease and significant mortality (4, 7). The factors enabling the vertical transmission to occur, as well as those allowing the vast majority of babies of infected mothers to remain uninfected, are not entirely known. Maternal-fetal transfer of antigens might influence the capacity of the progeny to respond to infection through modulating the fetal immune system (11, 12, 19, 22, 28, 39). However, there is little information on innate immunity of neonates in the case of maternal infection, whereas monocyte activation plays a central role in controlling infection (20) as well as in maintaining maternal infection, whereas monocyte activation plays a central role in controlling infection (20) as well as in maintaining maternal-fetal transmission of T. cruzi.

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After 24 or 72 h of incubation at 37°C in a 5% CO₂ atmosphere, EASIA from Medgenix, BioSource Europe, bound TNF-α, IL-2, IFN-γ, and TNF-α from blood samples, the samples were centrifuged and the supernatants were incubated in polypropylene tubes (Falcon) either without stimulating agents or in the presence of either LPS (10 ng/ml) or mitogen (PHA 5 μg/ml) (A, C, E, and G). Number of individuals in each group ranged from 26 to 43 for uninfected mothers, 11 to 16 for infected mothers, 25 to 47 for neonates from uninfected mothers, and 7 to 13 for uninfected neonates from infected mothers. Results (mean ± SEM) are expressed as the differences between levels obtained for stimulated and unstimulated cells. The Mann-Whitney-Wilcoxon U test was used for statistical comparisons between infected and uninfected mothers and between their newborns (*, \( P < 0.05 \); **, \( P < 0.005 \)).

### Table 1: Production of Cytokines by WBC from T. cruzi-infected or Uninfected Patients

<table>
<thead>
<tr>
<th>Stimulus</th>
<th>Patient Group</th>
<th>Time (h)</th>
<th>Δ IFN-γ (pg/ml)</th>
<th>Δ IL-2 (pg/ml)</th>
<th>Δ IL-4 (pg/ml)</th>
<th>Δ IL-5 (pg/ml)</th>
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<tbody>
<tr>
<td>LPS-PHA</td>
<td>Mother</td>
<td>24</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>neonate</td>
<td>24</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>T. cruzi</td>
<td>Mother</td>
<td>24</td>
<td>**</td>
<td>-</td>
<td>*</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>neonate</td>
<td>24</td>
<td>-</td>
<td>-</td>
<td>**</td>
<td>-</td>
</tr>
</tbody>
</table>

**Fig. 1.** Production of type 1 and type 2 cytokines by WBC from T. cruzi-infected (■) or uninfected (□) mothers and their newborns. WBC were stimulated or not for 24 or 72 h with LPS (10 ng/ml) plus PHA (5 μg/ml) (A, C, E, and G) or a lysate of T. cruzi (10⁶ lysed parasites/ml) (B, D, F, and H). Results (mean ± SEM) are expressed as arithmetic means ± SEM of all individual patients tested in each group. The Mann-Whitney-Wilcoxon U test was used for comparison between groups.

(i) Cells of T. cruzi-infected mothers produce IFN-γ, IL-2, and IL-4 in response to parasite stimulation, whereas neonatal cells occasionally release IFN-γ. Whatever the patient group (infected or uninfected mothers and their neonates), IFN-γ, IL-2, IL-4, and IL-5 were not spontaneously released by blood cells or were released only at similar background levels in all patient groups. Mitogenic stimulation with LPS-PHA showed that maternal and neonatal cells were able to produce the type 1 cytokines IL-2 and IFN-γ, with no significant differences according to maternal infection status (Fig. 1A and C). Though neonates are generally considered poor IFN-γ producers (45), in this study newborn WBC were as able as WBC from the mothers to produce significant amounts of IFN-γ and IL-2, although with slightly different kinetics: newborns were more prone to produce IL-2 at 24 h than their mothers, whereas IFN-γ release was delayed. By contrast, but in agreement with previous work (46), the type 2 cytokines IL-4 and IL-5 were not produced by neonates from both groups in the presence of mitogens, whereas their mothers did produce these cytokines (Fig. 1E and G).

As expected, mothers chronically infected with T. cruzi harbored parasite-specific memory T cells, since their WBC released lymphocyte-derived cytokines (IFN-γ, IL-2, and IL-4 but not IL-5 [Fig. 1B, D, F, and H]) when incubated with T. cruzi antigens. Moreover, the production of both type 1 and type 2 cytokines suggests that the adaptive response to the parasite in mothers is not polarized, in agreement with previous reports on human and experimental Chagas’ disease (17, 47). Since maternal-fetal transfer of parasite antigens, present in maternal blood (1) or released from parasites present in the placenta (unpublished data), is likely in the case of maternal T. cruzi infection and could lead to lymphocyte priming (29), we also investigated the production of lymphocytic cytokines in uninfected neonates from infected mothers upon specific stim-

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ulation of WBC with *T. cruzi* lysate. However, except for significant IFN-γ production by one neonate at 24 h (100 pg/ml) and another at 72 h (170 pg/ml), no type 1 or 2 cytokines were detected (Fig. 1B, D, F, and H). This could be related to (i) a low release of such cytokines and/or cytokine consumption by cell receptors, thereby preventing their detection in ELISA (5); (ii) the presence of parasite-specific antibodies, transferred from mother into fetal blood, disturbing antigen binding to antigen-presenting cells and the subsequent response by newborn T cells (40); or (iii) immunosuppression and/or apoptosis of lymphocytes induced by the parasitic molecules added in the WBC culture (25, 30).

(ii) Maternal *T. cruzi* infection upregulates the capacity of maternal and neonate cells to produce proinflammatory cytokines. In contrast to lymphocytic cytokines, IL-1β, IL-6, and TNF-α were spontaneously released by blood cells from mothers as well as their neonates (data not shown), likely reflecting the monocytic activation normally associated with pregnancy and delivery (3, 37). As shown in Fig. 2A, C, and E, such spontaneous inflammatory cytokine release was enhanced in mothers and neonates upon in vitro stimulation with LPS-PHA (except for IL-6 in neonates of uninfected mothers). Moreover, IL-6, and to a lesser extent IL-1β, levels were still higher in infected mothers and also, surprisingly, in their uninfected newborns. The parasite lysate strongly stimulated the production of TNF-α and IL-6, and slightly that of IL-1β, in both chagasic mothers and their neonates (Fig. 2B, D, and F). A detailed analysis of individual results indicated that a simultaneous higher production of these cytokines was observed in 58% of newborns. *T. cruzi* infection in mothers could easily explain their higher capacity to produce inflammatory cytokines. Indeed, although PHA-activated lymphocytes could be the source of IL-6, the simultaneous overproduction of three inflammatory cytokines suggests a monocytic origin. Different mechanisms could account for monocytic activation in infected mothers: (i) in vivo monocyte priming, known to occur during *T. cruzi* infection (8), strengthening the direct effect of parasite molecules supporting proinflammatory activities (2, 10, 21, 35) and present in the parasite lysate used to activate cells; (ii) monocytic activation due to IFN-γ released in vitro by specific lymphocytes after recognition of *T. cruzi* antigens; or (iv) proinflammatory cytokine release resulting from a cross-linking of FcR on monocytes and/or NK cells (6, 14, 27) by immune complexes formed by the *T. cruzi*-specific antibodies present in the blood of infected mothers and the parasite lysate added in vitro.

It is puzzling to observe such overproduction of inflammatory cytokines also in uninfected neonates from infected mothers. This did not result from an increase of monocyte concentration, since we have verified that their numbers are similar in both groups of neonates (202 ± 42 and 230 ± 23 monocytes/mm³ for newborn of infected and uninfected mothers, respectively), strongly suggesting that their monocytes are hyperactivated as in their mothers. Although the monocytic origin of proinflammatory cytokines has still to be confirmed, this is, as far as we know, the first indication of a maternal modulation of neonatal innate immunity in human infection. This agrees with our previous observations regarding experimental Chagas disease showing that both fetuses and offspring of infected mice display increased TNF-α gene transcription and/or production (34). The origin of neonatal (and probably fetal) monocytic hyperactivation remains unknown. Mechanisms similar to those mentioned above for mothers might also function in neonates, following maternal-fetal transfer of shed *T. cruzi* molecules or antibodies. In vivo IFN-γ-dependent monocytic activation seems unlikely since this cytokine was hardly detectable in the supernatants of neonate cells. The maternal induction of such neonatal cell activation raises the question of its contribution in the control of congenital infection, since the neonates displaying such activation were uninfected (as verified by parasitological, PCR, and antibody detection). It is tempting to hypothesize that such newborns could be protected against an eventual vertical transmission of parasites, by a synergy between maternally transferred antibodies and acti-
vated monocytes, previously shown to be effective in the in vitro and in vivo killing of parasites (32, 33, 44).

(iii) Maternal T. cruzi infection upregulates the capacity of maternal and newborn cells to produce anti-inflammatory factors. The effect of maternal infection on proinflammatory cytokines prompted us to also investigate the production of the potent anti-inflammatory factor IL-10 (41), as well as the stTNFR1 and stTNFR2, previously shown to play an essential role in modulating TNF bioactivity (31), particularly in experimental Chagas’ disease (43). Though only traces of IL-10 could be found in supernatants of unstimulated cells from newborns and mothers (data not shown), LPS-PHA stimulated IL-10 production by WBC from all patient groups (Fig. 3A), whatever the maternal infection status. By contrast, maternal infection was associated with a higher reactivity of both mother and newborn WBC to parasite lysate, which produced two- to threefold more IL-10 after 24 h of culture than the control couples (Fig. 3B). Infection status did not modify the WBC release of both stTNFRs, either spontaneously (data not shown) or after incubation with LPS-PHA (Fig. 3C and E). By contrast, T. cruzi components induced a higher release of both stTNFRs in infected mothers and their newborns (Fig. 3D and F). The overproduction of IL-10 and stTNF by cells incubated with the parasite lysate was observed in the same newborns from infected mothers as those who responded upon proinflammatory cytokine production.

The in vivo triggering of anti-inflammatory factors might protect fetal or neonatal tissues against the harmful effects generated by the intense inflammatory reaction that would occur in the case of congenital infection. Such homeostatic regulation might also contribute to avoidance of the fetal growth retardation associated with overproduction of TNF (24). Indeed, stTNFR/TNF molar ratios (calculated as previously described [43]) were similar in neonates of infected and uninfected mothers (data not shown). This suggests that TNF bioactivity remains similar in control and infected groups of mothers or neonates and could explain why neonates from infected mothers displayed normal birth weights (3,438 ± 154 and 3,293 ± 48 g for newborns from infected and uninfected mothers, respectively).

In conclusion, a potent state of cell activation is induced in uninfected neonates (and probably fetuses) from T. cruzi-infected mothers, leading to the simultaneous production of pro- and anti-inflammatory factors in the presence of parasite antigens. Such maternal influence on neonatal innate immunity might have protective effects, limiting the occurrence and outcome of congenital infections.

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