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Immunotherapy of Tuberculosis with IgA and Cytokines

Rajko Reljic¹ and Juraj Ivanyi²

1 Clinical Sciences Division, St George’s, University of London, 2 Clinical and Diagnostic Sciences Department, Kings College London, Guy’s Campus of Kings College London, GB

1. Introduction

Immunotherapy of tuberculosis (TB) has long been considered to be a potential adjunct to chemotherapy, by targeting ‘persister’ organisms which are generated during chemotherapy. In this chapter, we briefly review the current immunotherapeutic approaches in TB and then focus in more detail on a novel form of combined immunotherapy (CIT), comprising an IgA monoclonal antibody (mAb) against the α-crystallin (Acr) antigen, IFN-γ and anti-IL-4 antibodies. CIT treatment significantly reduced new pulmonary infection and also the post-chemotherapy relapse in Mycobacterium tuberculosis infected BALB/c mice. Translation of this approach toward application in humans has been advanced by the development and characterization of a novel human IgA1 mAb which was generated by co-transfecting the V domains of the Acr-binding 2E9 scFv clone and IgA1 constant region domains into CHO-K1 cells. The monomeric 2E9IgA1 has strong binding affinities for Acr and for the human FcαRI/CD89 receptor. Intranasal inoculation of affinity purified 2E9IgA, and mouse IFN-γ inhibited M. tuberculosis pulmonary infection and granuloma formation in the lungs of CD89 transgenic, but not in littermate control mice. 2E9IgA1 also inhibited infection of human whole blood and monocyte cultures. Demonstration of the mandatory role of the FcαRI/CD89 receptor for passive protection is novel and important for the elucidation of mechanisms of IgA action. Further development of the described new human mAb is required for the translation of immunotherapy for the control of TB in humans.

2. Immunotherapy of TB

TB is a major killer, causing 1.5 million deaths annually, with the majority occurring in developing countries, also bearing the brunt of the rampant HIV epidemic. Although TB chemotherapy is highly effective, it is very protracted, lasting for six months or longer. This impacts negatively on completion rates, and defaulting leads to the emergence and spread of multi-drug resistant (MDR) strains of tubercle bacilli. Although new drugs have been proposed for treatment [1], the need for new therapies is of major concern in the fight against the MDR-TB. Arresting the global TB epidemic and also reducing the incidence of
MDR-TB could be achieved by shortening the duration of the treatment. Since combined drug and immunotherapy treatments probably carry the greatest potential, several immunotherapeutic approaches have been considered, with the three described below receiving most attention.

### 2.1 Immunotherapeutic vaccines

One of the first immunotherapeutic applications of vaccines to show some promise in a clinical trial was the heat-killed *Mycobacterium vaccae* [2]. Its mode of action has been proposed to be an enhancement of Th1 and down-regulation of Th2 cytokine expression. Multiple doses of vaccine are required to achieve faster bacteriological conversion, improved radiological picture and recovery of body weight. However, subsequent clinical trials with *M. vaccae* produced inconclusive (reviewed in [3]), or negative results [4, 5]. Plasmid DNA expressing mycobacterial antigens have also been evaluated for their therapeutic capacity. Thus, Hsp65-based DNA vaccine prevented the post-chemotherapy relapse in mice [6], while an Ag85-expressing DNA vaccine was effective in one [7], but not in another [8] study. A detoxified extract of *M. tuberculosis* in liposome form (termed RUTI), prevented post-chemotherapy relapse in the ‘Cornell model’, and was proposed for the immunoprophylactic treatment of latent tuberculous infection [9]; this vaccine has recently undergone a phase I clinical trial in Spain (Cardona-PJ, personal communication).

### 2.2 Cytokine therapy

Cytokines are highly pleiotropic proteins that can promote host immune defence mechanisms. For effective treatment of mycobacterial infections, the administered cytokines must first reach their target cells, bind to the specific receptors and finally, activate an intact signal transduction pathway to elicit a cellular response. Due to their pleiotropic activities, the dose and route of administration must be carefully considered, in order to avoid the risk of toxicity and other unwanted pharmacological effects. Several cytokines have been considered for treatment of mycobacterial infections, including IFN-γ, IL-2, IL-12, GM-CSF (granulocyte-macrophage colony-stimulating factor) and G-CSF (granulocyte colony-stimulating factor). In TB patients, Th1 cytokines are produced at high levels at the site of infection, but the systemic response is characterised by high levels of Th2 and reduced levels of Th1 cytokines [10, 11]. Given the established protective role of Th1 immunity to intracellular pathogens, this provides a strong rationale for using these cytokines as immunotherapeutic adjunct treatment for TB. Two small clinical trials utilising recombinant IL-2 reported a definitive benefit in TB patients [12, 13]. However, a subsequent large-scale randomized IL-2 trial of HIV-negative TB patients yielded disappointingly negative results. Paradoxically, it even appeared that IL-2 had a detrimental effect on bacillary clearance, probably due to IL-2-mediated induction of CD25⁺ regulatory T cells [14]. These studies show that although the cytokines carry a significant therapeutic potential, their application for treatment of TB is yet to be fully explored.

### 2.3 Monoclonal antibodies

Historically, the view that protective immunity against TB is imparted exclusively by T cells, but not by antibodies has been influenced by the assumption that antibodies cannot reach
the bacilli which shelter within the phagosomes of infected macrophages. However, a review of the early literature on passive ‘serum therapy’ indicates both positive and negative results[15], with the one consistent theme being that such treatments appeared more effective in patients with early and localised TB rather than long-standing, chronic cases. With the development of modern approaches and tools, most notably the monoclonal antibody technology, it became possible to address the role of antibodies in intracellular infections in a far more controlled, reproducible fashion. Thus, significant new evidence emerged that antibodies can play a role in suppressing intracellular infections, including those caused by *Cryptococcus neoformans* [16], *Listeria monocytogenes* [17] and *Erlichia chaffensis* [18]. This led to a reappraisal of the role of antibodies in TB, which has recently been reviewed by us [19] and others [15, 20]. However, this approach still remains contentious, and further work is clearly needed to address the role of antibodies and their potential therapeutic application in TB and other intracellular infections.

3. Evidence for a therapeutic potential of antibodies in TB

The possible protective role of antibodies in *M. tuberculosis* infection has been indicated by clinical studies, showing that antibody titres to LAM [21] or Ag85 antigens [22] were higher in patients with milder forms of active TB. Support for a protective role comes also from animal experiments showing higher level of infection in mice genetically depleted of B cells (μ-chain knock-out)[23] or defective for IgA production [24].

Recently, a significant 100-fold reduction of the postchemotherapy relapse of pulmonary infection in SCID mice was reported following intraperitoneal inoculation of mouse antiserum containing predominantly IgG antibodies [25]. These antibodies were stimulated by *M. tuberculosis* infection, chemotherapy and immunization of DBA/2 mice with a detoxified *M. tuberculosis* extract. In addition, intraperitoneal administration of a standard preparation of human gamma globulin from normal donors, reduced bacterial loads in the spleen and lungs of intravenously infected mice [26]. Antibodies could have played a role, since normal human sera contain high antibody titres for LAM and mycobacterial heat shock proteins [27].

Passive inoculation of mouse monoclonal antibodies (mAb) against a number of antigens was reported to be protective in mouse models of TB infection, but the mechanisms involved differed. Thus, pre-opsonization of intratracheally administered tubercle bacilli with IgG3 against LAM antigen [28] enhanced the granulomatous infiltration and prolonged the survival of mice, without affecting the bacterial load in the lungs, while an intravenously administered IgG1 against the same antigen decreased the bacterial load, and also prolonged survival [29]. The authors of both these studies suggested that antibody action involved blocking of the LAM-mediated uptake of bacilli by macrophages.

Another study, utilising an antibody against heparin-binding hemagglutinin (HBHA) glycoprotein, showed impaired bacterial dissemination from the lungs, due to the antibody inhibiting HBHA interaction with epithelial cells [30]. In addition to the above quoted passive protection studies, *in vitro* coating of *M. tuberculosis* bacilli with monoclonal anti-lipomannan IgG3 [28] or anti-MPB83 surface glycoprotein IgG1 [31] prolonged the survival (but not the infection of lungs) of infected mice.
Taken together, these studies have clearly demonstrated that antibodies can influence *M. tuberculosis* infection, despite the intracellular location, by probably interacting with the bacilli during the extracellular phase following the initial inhalation, or the release from apoptotic macrophages. No clinical trials have been conducted as yet, but they seem justified, subject to development and evaluation of ‘humanised’ mAbs.

### 4. Immunotherapy of TB with mouse IgA mAb TBA61

IgA is the most abundant antibody class in mucosal fluids, where it plays important antimicrobial roles involving several different mechanisms of action. The majority of the IgA found in mucosal fluids is secretory IgA (sIgA), which is formed when polymeric IgA binds to the poly-immunoglobulin receptor (PIGR), expressed on the basolateral side of epithelial membranes. While retaining a portion of PIGR, the antibody is then translocated into the mucosal lumen, where it can bind to invading pathogens, leading to their neutralisation or ‘exclusion’ of infection. sIgA can also intercept viruses infecting epithelial cells, during the process of antibody transcytosis [32]. These important functions of sIgA, coupled with its increased stability in harsh mucosal environment, make this form of IgA antibody particularly suitable for therapeutic purposes. Unfortunately, sIgA is difficult to make in recombinant form, though advances in expression technology have been made [33]. Therefore, most of the passive protection studies have been conducted with the serum forms of monomeric IgA.

IgA can bind to a number of different cellular receptors. In addition to the already mentioned PIGR on epithelial cells, the main Fc receptor of mononuclear cells for human IgA is CD89, though its mouse equivalent has not been identified. Other known IgA receptors include the asialoglycoprotein receptor, which plays a role in IgA catabolism by hepatocytes [34], the transferrin receptor, which binds IgA1 but not IgA2 [35] and the IgA/IgM receptor (Fca/μR), which is expressed on B cells and monocytes [36].

IgA was reported to be protective against pathogenic bacteria in a number of studies, although the mechanisms of action appear different. For example, immune exclusion was reported as the key protective mechanism against *Salmonella typhimurium* [37] and *Vibrio cholera* [38], while agglutination was shown to play a role in inhibition of *Chlamydia trachomatis* genital infection [39]. In addition, binding to a defined virulence factor and neutralisation, were the mechanisms of inhibition of *Helicobacter felis* gastric infection [40], while multiple mechanisms were suggested for IgA-mediated inhibition of *Shigella flexneri* infection [41].

Transmission of mAbs against mycobacterial antigens into the lungs following intranasal (i.n.) or parenteral administration [42] was more efficient for IgA, than for IgG mAbs. When comparing these mAbs for their protective capacity in BALB/c mouse model of *M. tuberculosis* infection, the IgA mAb TBA61, which is specific for the a-crystallin (Acr, 16 kDa) antigen, was superior to both an IgG1 of the same antigen and epitope specificity, and also to another IgA mAb, specific for the PstS1 (38 kDa) antigen [43]. Both monomeric and polymeric form of IgA were found to be protective, inducing an approximately 10-fold reduction of the bacterial load in infected animals. Interestingly, both pre- and post-challenge mAb inoculations were required for optimal protection and the Acr antigen specificity and IgA isotype were both important for the observed inhibitory effect [43].
Acr is a small heat shock protein of *M. tuberculosis* which is expressed at particularly high levels during conditions of anoxia and stress during growth in macrophages [44, 45]. Although the protein is largely expressed in the cytosol, an increased association with the bacterial cell wall is observed under the conditions of stress and low oxygen concentration [46]. These conditions are present during the stationary phase of growth *in vitro* and also during the intracellular phase of infection. The recent evidence suggests that *M. tuberculosis* clinical strains recovered from the sputum of TB patients have a changed phenotype consistent with stationary, rather than actively dividing organisms [47], lending further support to the importance of the Acr antigens as the antibody target. Evidence from the guinea pig model of *M. tuberculosis* infection indicates that the majority of residual ‘persister’ bacilli following short-term drug treatment are extracellular [48]. Most likely, such non-dividing organisms would express high levels of cell wall associated Acr, making them a suitable target for anti-Acr IgA mAbs.

The IgA-mediated inhibition of the early *M. tuberculosis* infection in mice was transient, and therefore we explored the possibilities for extending and further enhancing the observed therapeutic effect. Cytokines play crucial roles in modulating immune responses to infection, and therefore, could be harnessed to aid therapeutic treatments. We considered the immune-stimulating cytokine IFN-\(\gamma\), and the suppression/removal of Th2 cytokine IL-4, that can undermine protective immunity in TB. The rationale for inclusion of IFN-\(\gamma\) and also the neutralising anti-IL-4 antibodies, as well as the effect of combined immunotherapy is described in the following section.

### 5. Combined immunotherapy for TB with IgA, IFN-\(\gamma\) and anti-IL-4

#### 5.1 Rationale for IFN-\(\gamma\)

IFN-\(\gamma\) has many important activities, such as activation of phagocytes, stimulation of antigen presentation, induction of cell proliferation and cell adhesion, and regulation of apoptosis. These important roles of IFN-\(\gamma\) for the immune responses to pathogens are best described in the context of the so-called Th1/Th2 paradigm. IL-12, another important cytokine, directly induces IFN-\(\gamma\) gene transcription and secretion in antigen-stimulated naive CD4\(^+\) cells [49], while in turn, IFN-\(\gamma\) induces IL-12 expression in macrophages and monocytes [50], thus creating a positive feedback loop. This leads against a Th1 type immune response to an intracellular infection. In contrast, Th2 cytokines IL-4, IL-13 and IL-10 suppress production of IL-12 by monocytes, and consequently also inhibit effector functions of IFN-\(\gamma\), notably, the expression of inducible nitric oxide synthase [51, 52] and the respiratory burst [53].

The critical role of IFN-\(\gamma\) in the immunity to mycobacterial infections was confirmed in IFN-\(\gamma\) deficient mice, when two groups showed independently [54, 55] that mice with a disrupted IFN-\(\gamma\) gene were unable to control *M. tuberculosis* infection. The lack of protective immunity in IFN-\(\gamma\) deficient mice could be attributed exclusively to their inability to activate macrophages, since these mice otherwise developed antigen specific T cell responses, albeit more rapidly than the control mice [56]. Humans with a mutation in the IFN-\(\gamma\) receptor show enhanced susceptibility to TB [57] and the results of a first small scale clinical trial for treatment of MDR-TB with aerosolised IFN-\(\gamma\) [58] indicated a short-term treatment benefit. Therefore, IFN-\(\gamma\) may have a therapeutic potential for treatment of TB, although additional components may be required to achieve a more robust therapeutic effect [59].
5.2 Rationale for Th2-suppressing agents

The regulatory and potentially detrimental role of Th2 cytokines in TB has recently attracted considerable research interest, in relation to studies of both immunopathogenesis of TB and vaccine development. TB develops only in a small proportion (5-10%) of the exposed immunocompetent individuals. It is tempting to speculate that these individuals could have the normally protective innate and acquired immunity ‘dis-regulated’ by Th2 cell mediated inhibitory immune mechanisms. It has been proposed that IL-4 in particular, could downregulate the protective Th1 cytokine IFN-\(\gamma\) and lead to mediated toxicity and fibrosis [60].

However, the exact mechanism of the negative IL-4 effect on the course of mycobacterial infection is not fully understood. One possibility is that IL-4 inhibits the expression of nitric oxide synthase [61, 62] and since nitric oxide is a mandatory mediator of macrophage activation mediated killing of tubercle bacilli, its decreased levels could delay the clearance of mycobacterial infection [52].

Additional circumstantial evidence from experimental studies also points to a possible negative role of IL-4 in TB. Thus, \(\beta\)-glucan mediated inhibition of TGF-\(\beta\), resulted in upregulated expression of IFN-\(\gamma\) and IL-2 and downregulated production of IL-4, leading to a significant reduction in bacterial counts in the absence of chemotherapy [63]. This was unfortunately associated with an increased risk of inflammation in the lungs, which required anti-inflammatory treatment for optimal anti-tuberculous effect.

Similarly, immunisation of \(M.\) \(tuberculosis\) infected mice with heat-killed \(M.\) \(vaccæ\) resulted in decrease of bacterial burden in the lungs, which was correlated by decrease in IL-4 expression [64]. Two other immunotherapeutic vaccines have been proposed (though not tested in clinical trials), both interfering with Th2 cytokine expression levels. A DNA vaccine incorporating mycobacterial heat shock protein 65 (HSP65) was shown to be protective in mice [6] and the protection was clearly correlated with down-regulation of IL-4 production. More recently, a fragmented and detoxified \(M.\) \(tuberculosis\) based vaccine termed RUTI, was shown to be protective when given to chemotherapy-treated mice [9], and this effect was at least in part mediated by suppression of Th2 cytokine activity. Therefore, therapeutic approaches targeting Th2 cytokines could potentially be utilised for adjunctive treatment of TB.

6. Development and testing of CIT

IgA-mediated protection against early \(M.\) \(tuberculosis\) in mice could be further extended by co-inoculation with IFN-\(\gamma\) [65, 66]. IFN-\(\gamma\) was inoculated to mice i.n., 3 days before aerosol \(M.\) \(tuberculosis\) challenge, and then again together with IgA mAb, on the day of the infection and 2 days later. Co-administration of IgA and IFN-\(\gamma\) synergistically prolonged and enhanced the CFU-inhibitory effect of IgA alone and also reduced lung pathology [65].

IL-4 depleted or genetically deficient IL-4\(-/-\) mice are more resistant to \(M.\) \(tuberculosis\) infection; this could be reversed by reconstitution of mice with recombinant IL-4 [67, 68]. Combined treatment of mice with a neutralizing anti-IL-4 antibody, anti-\(\alpha\)-crystallin IgA mAb and IFN-\(\gamma\) reduced lung infection with \(M.\) \(tuberculosis\) profoundly more than individual treatment regimens. Most importantly, however, this combined triple treatment with anti-IL-4 mAb, IgA and IFN-\(\gamma\), prevented post-chemotherapy relapse of the infection in
three different strains of mice [69], suggesting that CIT has the therapeutic potential for adjunctive application with standard TB treatment.

Multiple mechanisms are likely to be involved in protection against *M. tuberculosis* conferred by CIT. Some of them may operate on a cellular level (for example, stimulation of phagocytosis by IgA and IFN-γ), while others may involve more complex interactions within the immune system, resulting in modulation of the early response to *M. tuberculosis* infection. A schematic representation of some of the potential mechanisms of CIT action is depicted in Fig.1.

**Fig. 1.** Proposed mechanisms of action of combined immunotherapy (CIT) in *M. tuberculosis* infected hosts. Antibody could target extracellular bacteria and following their phagocytosis via IgA-receptor (indicated is human FcαR, though the mouse equivalent is not known), the bacilli are destroyed in phagolysosome. IFN-γ activates non-infected monocytes/macrophages, thus enhancing their bactericidal activity towards incipient infection. IL-4 could induce alternative activation of macrophages that does not lead to killing of intracellular organisms; in addition, it could also negatively modulate the early immune response to *M. tuberculosis*, by undermining the Th1 type response. Other, unknown mechanisms might also be involved, possibly including cytotoxicity of lymphocytes and granuloma formation.

### 7. Translational studies with human IgA

In order to further develop the combined TB immunotherapy for potential application in humans, a human IgA antibody specific for Acr antigen has been generated. As mentioned
earlier, the human and mouse IgA systems differ significantly, both in terms of IgA structure and also the availability of IgA Fc receptors. Thus, IgA exists in two forms in humans, IgA1 and IgA2, while the mouse IgA exists in a single form, corresponding to IgA1. The most significant difference, however, is that there is a well characterised IgA-Fc receptor on human myeloid cells, CD89, which is responsible for much of the IgA-mediated antimicrobial activity [70-72], while an equivalent receptor in mice has not been identified. Therefore, it is an important consideration that therapeutic recombinant IgA antibodies should bind efficiently not only to the target antigen, but also to CD89 on monocytes/macrophages, the target cell population for immunotherapy.

A single chain Fv fragment (scFv) specific for Acr was generated using a human phage library and then expressed in CHO cells as a human IgA1 molecule with ‘grafted’ scFv epitope binding site [73]. The expressed 170 kDa recombinant IgA was purified by affinity chromatography and found to be glycosylated, with both N- and O-linked sugars present. The purified human antibody, termed 2E9IgA1, bound to both Acr (7.0 x 10^{-8}) and CD89 (2.9 x 10^{-6}), with both the affinity constants being well within the range for antibody-antigen and antibody-receptor type interactions, respectively.

The effect of 2E9IgA1 on M. tuberculosis infection was tested in mice transgenic for the human IgA receptor. Antibody was administered at the time of infection and again, at either 1 or 21 day after infection. Separate groups of mice were inoculated with IFN-γ or with both IFN-γ and IgA. The bacterial load in the lungs and spleen, as well as the immunopathology of the lungs were analysed four weeks later. Both 2E9IgA1 and IFN-γ caused partial reduction in bacterial load, but the greatest therapeutic effect was observed when the two were co-administered together, with the difference between treated and untreated animals being statistically highly significant [73]. Early and late treatment applications following challenge of mice with M. tuberculosis produced a similar therapeutic effect. Importantly though, the treatment had no significant effect on the infection in non-transgenic littermate controls, suggesting a mandatory role for CD89 in the observed reduction of infection. In agreement with decreased bacterial load in the lungs, the treated animals showed also reduced granulomatous infiltration of their lungs.

Studies on whole human blood cultures infected with M. tuberculosis showed that 2E9IgA1 reduced the infection at least in some donors. This effect required a relatively high concentration of the antibody (100 μg/ml) and the inhibition was apparent only when the ratio of bacteria:cell was 10 or less [73]. Interestingly, IFN-γ did not enhance the bactericidal effect of 2E9IgA in whole blood cultures although it did so in purified human monocytes infected with M. tuberculosis. The outcome of the in vitro studies is generally consistent with the finding using mouse IgA, that the therapeutic effect in vivo was greater than the inhibition of infection in vitro, hence suggesting the involvement of complex in vivo mechanisms of antibody action.

These studies showed that the therapeutic potentials of 2E9IgA1 human mAb for tuberculosis deserve further evaluation in the form of CIT for treatment. The history of the past advances using IgA based CIT are summarised in Table 1.
<table>
<thead>
<tr>
<th>Year</th>
<th>Stage of development</th>
<th>Reference</th>
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<tbody>
<tr>
<td>2000</td>
<td>TBA61 anti-Acr mAb generated and shown to be superior to IgG for transmission to lungs</td>
<td>[42]</td>
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<tr>
<td>2004</td>
<td>TBA61 IgA induced a 10-fold inhibition of early M. tuberculosis infection in BALB/c mice; however, inhibition was transient</td>
<td>[43]</td>
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<td>2006</td>
<td>Co-administration of IgA and IFN-γ extended the duration of inhibition compared to IgA alone</td>
<td>[65]</td>
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<tr>
<td>2007</td>
<td>Addition of anti-IL-4 antibody profoundly enhanced the therapeutic effect of IgA and IFN-γ</td>
<td>[67]</td>
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<tr>
<td>2009</td>
<td>CIT (IgA, IFN-γ and anti-IL4) reduced significantly postchemotherapy relapse of M. tuberculosis infection in mice</td>
<td>[69]</td>
</tr>
<tr>
<td>2011</td>
<td>Human 2E9IgA1 anti-Acr mAb generated and shown to be protective, when co-administered with IFN-γ, in human IgA-receptor transgenic mice</td>
<td>[73]</td>
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<tr>
<td>Future research</td>
<td>Testing of 2E9IgA1-based CIT in non-human primates and subsequently, phase I human clinical trials</td>
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Table 1. Key stages of development of CIT based on IgA, IFN-γ and anti-IL-4

8. Targets for future research, development and clinical evaluation

There is scope for future research on the following different aspects of the combined immunotherapy:

1. *Mechanisms of IgA action.* We proposed previously that binding of mouse IgA to the intracellular lectin galectin 3 [74], which accumulates in phagosomes [75], could ‘unblock’ the *M. tuberculosis* induced inhibition of phagosome maturation [19]. In principle, galectin 3 could act as a mediator of the intracellular actions of IgA, considering that it has structural homology with TRIM21, which mediates the virus neutralizing activity of IgG antibodies [76].

2. *Studies in CD89 transgenic mice.* There is a need to demonstrate: i) if there is synergy between the actions of the 2E9IgA human antibody and anti-IL-4 antibodies or IL-4 antagonists; ii) if 2E9IgA based CIT can reduce the relapse of infection following short-term chemotherapy to an extent, which had been reported for the mouse TBA61-based CIT; iii) if CIT can reduce the MDR-TB infection.

3. *Development of 2E9IgA production.* It is necessary to modify the plastic adherent CHO-K1 transfectant cell line into a suspension growing variant [77], in order to increase the yield of IgA production. This is a prerequisite for producing the GMP-grade antibody in quantities required for evaluation in clinical trials.

4. *Evaluation of 2E9IgA based CIT in non-human monkey models of TB.* Macaques are eminently suitable, since they express the IgA/CD89 receptor [78] that can bind human IgA [79]. A suitable technique for aerosol delivery of IgA would need to be developed.
using the approaches for the inhaled therapy with various agents [80]. Demonstrating protection against aerosol *M. tuberculosis* infection and pathology in the macaque model of infection would justify further evaluation in human clinical trials.

5. **Evaluation in HIV-positive, low CD4+ cell patients.** They develop active TB at a high rate and need an alternative to the current combined chemotherapy for HIV and TB [81], because it associates with drug-drug interactions and toxicity.

6. **Evaluation in patients with drug-susceptible TB, as an adjunct to chemotherapy.** The potential benefit to the widest range of patients would be to shorten the duration of treatment. This would in turn lead to higher completion rates, reduced risk of relapse and MDR-TB. The rationale of this approach has recently been strengthened by the finding, that chemotherapy generated ‘persister’ bacilli are extracellular [48]; this makes them a suitable target for IgA-based CIT.

7. **Evaluation in MDR-TB and XDR-TB patients.** Existing difficulties in developing effective new drugs justify evaluation of CIT as a possible alternative approach.

9. **References**


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Mycobacterium tuberculosis in an attempt to understand the extent to which the bacilli has adapted itself to the host and to its final target. On the other hand, there is a section in which other specialists discuss how to manipulate this immune response to obtain innovative prophylactic and therapeutic approaches to truncate the intimal co-evolution between Mycobacterium tuberculosis and the Homo sapiens.

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