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BCG: DO WE HAVE AN ALTERNATIVE*?

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Vaccination is generally used as a form of immunoprophylaxis, so that administration of the vaccine even a long time before exposure to the wild-type infectious organism should afford protection. Since effector T and B cells are short-lived; a prime requisite for a vaccine is to generate immunological memory[1]. In the case of organisms such as mycobacteria which are obligate intracellular pathogens and which elicit granulomatous tissue reactions, artificial immunisation with live bacteria is required to induce protection.[2,3] The only existing vaccine against tuberculosis is the BCG *(Bacille Calmette - Guerin),* an attenuated strain of *M. bovis,* and it is mandatory or officially recommended in 182 countries or territories. Under the Expanded Programme on Immunisation (EPI), started by the Government of India in 1978, BCG is recommended to be given to all infants 3-9 months after birth.[4]

HISTORY OF BCG VACCINE

The history of BCG vaccine and the trials conducted to assess its effectiveness in humans have been reviewed by many workers.[5-10] BCG, the bile-tolerant, attenuated strain of *M. bovis,* was isolated by Calmette and Guerin.[11] Ox-bile was originally added to these cultures to prevent clumping of bacilli. This led to the fortuitous observation that growth in the presence of bile also resulted in attenuation or gradual loss of virulence. Such attenuated organisms multiply only to a limited extent in the animal or human body and can bring about an increase in the resistance of the host to a subsequent fully virulent infection by the same or other antigenically closely related organisms. Calmette further attenuated this strain by cultivation of the organism on a potato-glycerol-bile medium for 230 serial transfers between the years 1908 and 1918.

The bacilli resulting from this attenuation have never been cloned. The original strain of BCG has been lost and has been replaced by a variant while it was being transferred serially on artificial culture media at the Pasteur Institute[12]. It has since been maintained by many different laboratories, using many different methods. As a result, the BCG strains used today are not bacteriologically identical.[13,14] In 1966, a WHO Expert Committee on Biological Standardisation adopted a series of recommendations for the production of BCG vaccine.[15] These recommendations stated that the vaccine should be freeze-dried, and that the vaccine strain should be maintained by the seed-lot-system whereby no vaccine is produced from a seed more than 12 passages removed from the primary freeze-dried lot. Such a method of maintenance was soon adopted by most laboratories and this eliminated the possibility of more attenuated variants in later BCG vaccine lots.[16]

BCG VACCINE PRODUCTION IN INDIA

In India, the BCG Vaccine Laboratory was started in Guindy, Madras in 1948 for the production of BCG vaccine for use in India and also for supply to some of the neighbouring countries. Since 1966, Danish strain 1331 is being used here for the preparation of both the liquid and the freeze-dried BCG vaccines, based on the seed-lot-system".

For preparing the liquid and freeze-dried vaccines, the BCG Laboratory, Madras, uses the method followed at the State Serum Institute, Copenhagen, but using Sauton potato medium for maintaining the BCG strain. The prepared vaccine is tested for purity by Ziehl Neelsen smear for acid fast bacilli, and by culture on nutrient broth, thioglycolate medium and Sabouraud's Agar

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medium. Total bacterial count and the number of culturable particles in the preparation are estimated. Biological tests are carried out in guinea pigs to estimate the degree of virulence of the BCG vaccine, allergenicity and safety. In addition to the above tests, in the case of the freeze-dried vaccine, tests are carried out to estimate residual moisture and heat stability. Both types of vaccines are to be stored at refrigeration temperature, protected from light. Under these conditions of storage, the liquid vaccine can be used for 4 weeks from the date of manufacture while the freeze-dried vaccine can be used for 3 months.

BCG can be administered intracutaneously, orally, by scarification or by multiple punctures. The most widely used method of administration is by intracutaneous injection. The dose is usually 0.1 ml and the site of injection is the upper arm. In the newborn, the dose used is 0.05 ml. The Madras liquid BCG vaccine administered by an intracutaneous injection of 0.1 ml of the vaccine contains 0.075 mg (moist weight) of BCG. The freeze-dried vaccine prepared there is reconstituted by the addition of sterile distilled water or sterile saline to contain 0.1 mg (moist weight) in 0.1 ml of vaccine which is given intracutaneously.

EFFICACY OF BCG -VACCINE

BCG was used successfully in humans for the first time in 1921 by Weil-Halle, a colleague of Calmette and Guerin.[18] Scepticism concerning the safety and efficacy of BCG vaccine, and the Lubeck disaster in which 72 of 240 children vaccinated with BCG died as a result of being fed a batch of vaccine containing virulent tubercle bacilli, delayed the acceptance of BCG. A series of controlled trials was begun in the 1930s. Despite inconsistent results from the trials, WHO encouraged widespread dissemination of BCG vaccines, starting in the 1950s.[7] By the 1970s BCG became the most widely used vaccine in the world. About 3 billion doses have been given in the last four decades, and more than 70 per cent of the world children now receive BCG.[5,19]

Between the years 1935 and 1955, at least eight controlled trials were conducted to assess the efficacy of BCG vaccine against tuberculosis.

Table: **Protective efficacy of BCG vaccine against tuberculosis (trials between 1935 to 1955)**

Population group	Period of intake	Protective efficacy (%)
North American Indians	1935-1938	80
Chicago infants	1937-1948	75
Georgia school children	1947	0
Illinois children	1947-1948	0
Puerto Rico population	1949-1951	31
Georgia and Alabama population	1950	14
British children	1950-1952	78
South Indian rural population	1950-1955	31

The protective efficacy results obtained ranged from 0 to 80 per cent (Table).[8]

THE SOUTH INDIAN TRIAL

A new study was started in Chingleput, south India, in 1968 in an attempt to avoid the methodological errors that might have affected previous trials.[10,20,21] This south Indian BCG trial was organised by the Indian Council of Medical Research (ICMR) in collaboration with the WHO and Centres for Disease Control (CDC), US Public Health Services. The intake for the study started in 1968 and was completed in 1971, including about 2,60,000 participants out of a population of 3,60,000. The entire population of all ages was eligible and tuberculin reactors were not excluded, in contrast with previous trials. Two BCG strains, Copenhagen and Paris, were tested at two doses, 0.1 mg and 0.01 mg. Neither of the vaccines, whether in full or reduced dosage, gave any protection against the bacillary form of pulmonary tuberculosis, as assessed over a 7.5 year follow up period. No data were available from the study to evaluate protection in children. Very little disease was observed in the period immediately after infection.[22] Incidence peaks were absent in young children and in young adults but the incidence increased logarithmically with age.

The findings of the south Indian trial were disappointing. The ICMR convened an expert

committee meeting to scrutinise the trial methodology, wherein it was agreed that no errors in the conduct of the field operations or in the data processing could have been SO serious as to invalidate the results.[10] In the first meeting of the ICMR/WHO Scientific Group[23] it was stated that be data obtained in this trial were unique and of great importance for tropical countries, and should be considered as the starting point for further intensive investigations into the epidemiological, bacteriological and immunological problems related to BCG vaccine and tuberculosis, as well as studies to test certain hypotheses, e.g, that the immune response of the population was unusual, that the vaccines were inadequate to confer immunity, that the south Indian variant of *M. tuberculosis* acted as an attenuated immunising agent, and that mycobacteria other than *M. tuberculosis* may have partially immunised the study population.

EXPLANATIONS FOR VARYING EFFICACY OF BCG

The explanations and hypotheses for the varying efficacy of BCG have been discussed in detail[5,7]. BCG's varying efficacy due to interactions with the immune responses to other mycobacterial infections still remains one of the most popular explanations. Palmer and associates[24,25] showed in animal experiments, and in studies of US navy personnel, that infections with certain non-tuberculous mycobacteria could impart some protection against infection with the tubercle bacillus and such naturally acquired protection could mask any protection due to BCG vaccination, partially or totally. This explanation was criticised by Hart[26] as being inadequate to explain all the differences between the various BCG vaccine trials. Comstock et al[27] also could not find any evidence for lowered protection by BCG in those with intermediate levels of tuberculin reactivity, and this was thought to be due to non-tuberculous mycobacterial infection, in the Puerto Rico trial.

In the 1980s, Rook, Stanford and associates[28-30] proposed that exposure to non-tuberculous mycobacteria (NTM) can result in two types of cell-mediated responses, the 'Listeria type' and the 'Koch type'. Which of these two types of responses is evoked depended, among other factors, on the mycobacterial species inducing the response and the immunomodulating cells and the pathway brought into play. They further proposed that the 'Listeria type' of response enhances the protective effect of subsequent vaccination with BCG while the 'Koch type' response opposes the protective effect of BCG. Once Koch-like responsiveness is present, this blocks subsequent recognition of further species by Listeria-like responses. BCG vaccination of a person with a pre-existing Koch-like response will temporarily boost this response, but completely fail to reconvert to Listeria-like responsiveness or induce protection from pathogenic challenge. According to them, this is likely to have been the situation in the south Indian trial.[31,32]

Investigations carried out since then have been able to produce some evidence supporting the hypothesis that infection with NTM induces a protective response and does not interfere with the immunity produced by BCG. Attempts to demonstrate that prior infection with any of the mycobacteria induced a suppressive effect against BCG have failed.[33-36]

The study population in the south Indian BCG trial was characterised by a very high prevalence of nonspecific sensitivity.[37] Further, nearly 20 per cent of the NTM obtained from sputum samples of subjects in this area belonged to the *Mycobacterium avium-intracellulare-scrofulaceum* (MAIS) complex.[38] And a recent study on the isolation profiles of environmental mycobacteria present in soil, water and dust samples, and sputum samples of symptomatics in this area has shown that isolates belonging to the MAIS complex are predominant in water, dust and sputum samples while organisms of the *M. fortuitum* complex are predominant in soil samples.[39]

The hypothesis that oral immunisation with *M. avium intracellulare* complex might induce tolerance which might interfere with the immune response to subsequent BCG immunisation was studied at the Tuberculosis Research Centre (TRC)[40] in guinea pigs challenged with *M. tuberculosis*, and it was found that there was no interference with the protective immunity induced by BCG. A later study using intradermal route

showed that while there was no interference with the immunity due to BCG by prior exposure to NTM on the early course of challenge infection, modulation could be taking place during the later course.[41]

The variation in the efficacy of BCG has also been attributed to the differences between the BCG preparations[42,43]. Another view is that BCG is more effective in stopping haematogenous spread of the bacteria as occurring in primary progressive disease and endogenous reactivation compared with exogenous reinfections.[44] Other explanations include the genetic or physiological differences between the trial populations.

More recently, another explanation for the varying efficacy of BCG has been proposed based on the observation that a subgroup of the population may actually be adversely affected by vaccination.[45] Several trials included many subjects with weak initial tuberculin sensitivity, due either to environmental mycobacterial infection or to infection with *M. tuberculosis.* While it is accepted that vaccine efficacy may be moderately reduced in the former subgroup, it has been postulated that the latter subgroup may be at risk of reactivation of tuberculosis soon after vaccination perhaps from focal reactions due to enhancement of their weak sensitivity. The low levels of efficacy in several trials, and the early adverse effect in the south Indian trial are broadly consistent with this hypothesis.

In the search for identifying the correlates of vaccine-induced protective immunity, more than 70,000 subjects in northern Malawi were skin tested with soluble antigens of the tubercle and leprosy bacilli, and then followed up for 5 years for tuberculosis and leprosy incidence. Incidence rate ratios were calculated to compare subjects with different levels of prior skin test sensitivity.[46] It was found that the delayed type hyper-sensitivity to mycobacterial antigens has different implications for tuberculosis and leprosy: low level hypersensitivity, probably attributable to environmental mycobacteria, was associated with protection, but persistent vaccine-associated hypersensitivity to mycobacterial antigens was not a correlate of vaccine-derived protection against mycobacterial diseases.

BCG VACCINATION AND HIV INFECTION

With regard to BCG vaccination in NIV infected individuals, there are reports of BCG abscesses in HIV seropositives, and of disseminated infection due to BCG in at least one case given BCG.[47] However, in all these cases, the resulting infection could be successfully treated. Since the risks and known consequences of natural infection with tubercle bacilli are likely to be more serious than the risks associated with live attenuated vaccines, the WHO has recommended that all asymptomatic HIV infected children should receive the standard vaccines, both live and inactivated, and those with symptoms of AIDS Related Complex (ARC)/AIDS should receive all the vaccines but BCG. However, in developing countries like India, where extensive HIV testing is not possible, the WHO Expert Group has recommended that all infants should continue to receive immunisation against all the major preventable diseases.[48]

There is no evidence that BCG activates HIV infection.[49] Further, it has been observed that the incidence of disease due to *M. avium intracellulare* (MAI) in AIDS patients varies from region to region and it has been postulated that this difference is the result of a protective effect of neonatal BCG vaccination.[50] In the USA, 30 per cent of patients with AIDS develop MAI disease in contrast to only 10 per cent of AIDS patients in Sweden. This difference in incidence between the two countries could be due to BCG vaccination: most Swedish patients with AIDS would have received BCG in infancy while those in the USA would be unvaccinated. This is further supported by the fact that over 50 per cent of AIDS patients in Netherlands, where BCG vaccination is not given, developed disease due to MAI or *M. Scrofulaceum* Also, in a limited follow up of HIV infected individuals at the TRC, Madras, it has been found that while a few HIV infected individuals developed disease due to *M. tuberculosis,* no case has been encountered so far with disease due to MAI (Tuberculosis Research Centre - unpublished observations). It has been suggested that MAI disease in AIDS is not due to direct infection but that it arises from long standing silent foci of MAI in the lymphatic

tissue of the patient.[51] It is possible that neonatal BCG vaccination prevents overt infection by MAI and may, therefore, prevent inapparent persisting infection of lymphoid tissue, thus removing the internal reservoir of these bacilli from which AIDS-related MAI disease may arise later in life.[52]

BCG AS AN IMMUNOPOTENTIATING AGENT

The widespread use of BCG has demonstrated its safety and its potent immunogenicity. This has also led to its suggested use as a carrier to vaccination against other diseases.[53-54] BCG and other mycobacteria are highly effective adjuvants. It is one of the few vaccines that can be given at birth, and with a single dose it induces long-lasting immune responses. Till now, nearly 3 billion vaccinations have been carried out using BCG with a long record of safe use. There is also a worldwide distribution network with experience in BCG vaccination. The adjuvant properties of BCG and its cell wall components have previously been made use of in experimental vaccines. Mixtures of BCG and schistosomal antigens have been used successfully to protect mice in a model of schistosomiasis.[55] Mixture of muramyl dipeptide, which is one of the mycobacterial ceil wall components that contributes to the adjuvant properties, and killed simian immunodeficiency virus (SIV) has been shown to provide partial protection against SIV infection in monkeys.[56] Mixtures of BCG and killed *M. leprae* have been used in large scale trials to assess the efficacy Of this leprosy vaccine candidate.[57]

RECOMBINANT BCG AND BCG AS A MULTIPLE VACCINE VEHICLE

Recently developed genetic engineering techniques for mycobacteria have provided the means for the introduction and expression of foreign genes in BCG.[53-58] Recombinant BCG vaccine vehicles can induce immune responses to foreign proteins produced by the bacillus, indicating that BCG can act simultaneously as an adjuvant and as a vehicle to produce and deliver specific antigens to the immune system. A BCG recombinant may provide a longer lasting immunity to a pathogen than a simple mixture of BCG and the antigen because the antigen continues to be produced by BCG multiplying in the host.

There is no ready answer to the question whether there is an alternative to BCG vaccine for protection against tuberculosis. It is possible to improve the protective efficacy of the existing BCG vaccine against tuberculosis by using the tools of genetic engineering even though very little has been achieved in this direction to date. Such an approach requires a full understanding of the important factors in the virulence of *M. tuberculosis*, pathogenesis of tuberculosis, and protective response against tuberculosis. Genetic deletion or modification of mycobacterial virulence factors or the addition of appropriate mycobacterial antigens, important for protection, might improve the effectiveness of BCG as an antituberculosis vaccine.

CONCLUSION

Fine and Rodrigues[7] state that several factors, especially the differences in BCG strains and regional differences in mycobacterial ecology in addition to differences in trial methods, have all contributed to the observed variation in BCG's efficacy. They conclude that despite our inability to predict its precise effect, BCG is still judged worthwhile in many countries because there is a possibility that the vaccine might provide reasonable levels of protection against childhood forms of the disease in most populations.[7] Recent retrospective studies of BCG vaccine efficacy among newborns and children have reported a protective effect against all forms of tuberculosis ranging from. 17 to 90 per cent. And protection against tuberculous meningitis and cavitary, miliary and bone and joint tuberculosis has been estimated to be 75 per cent or greater.[59-61] BCG vaccination, when effective, does not prevent infection but interferes with the haematogenous spread of tubercle bacilli, thus reducing the risk of severe primary disease and its complications.[60] A meta-analysis of 14 trials and 12 case-control studies showed that the protective effect of BCG against tuberculosis was 51 and 50 per cent respectively.[62] Combining data from 7 trials reporting on deaths from tuberculosis, the relative risk for death

among the vaccinated was 0.29 (71% protective effect). Five case-control studies reporting on tuberculous meningitis showed a 64 per cent protective effect, and 3 case-control studies reporting efficacy of BCG in preventing disseminated tuberculosis showed a 78 per cent protective effect. **The conclusion was that BCG reduces the risk of active tuberculosis on an average by 50 per cent, and the risk of tuberculosis death, meningitis and disseminated tuberculosis.** The fact that BCG provides variable though significant protection against leprosy increases its value in countries with high prevalence of leprosy.[63]

BCG vaccination alone, at least with the the present vaccine, cannot substantially influence the epidemiological situation but should still' be continued for children because its use is justified.[64] BCG vaccination of the newborns protects against the serious forms of tuberculosis, is safe and cheap, and should be used in developing countries, including India, where tuberculosis is more prevalent. However, in such highly endemic areas, due to the frequent occurrence of exogenous reinfection and also due to the waning of protective effect over the years after vaccination, BCG vaccination of the newborns may not offer protection in the later years of life when revaccination, perhaps at the school going age, may have to be considered. In developed countries with low prevalence of tuberculosis, BCG should be given to high risk groups such as immigrants, their newborns, contacts of patients with tuberculosis and hospital staff.[65]

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