

# A Computational Immune Approach for Modeling Different Levels of Severity in COVID-19 Infections



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Matheus Ribeiro, Bárbara Quintela, **Ruy Freitas Reis**,  
Rodrigo dos Santos and Marcelo Lobosco

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Pós-Graduação em Modelagem Computacional  
Departamento de Ciência da Computação  
Universidade Federal de Juiz de Fora



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# Introduction

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- Group B Streptococcus (GBS) is a leading cause of neonatal mortality and morbidity.
  - 410,000 cases worldwide, leading to 147,000 stillbirths and infant deaths
- It can cause severe infections like sepsis, pneumonia, and meningitis in newborns.
- Current prevention relies on maternal screening and intrapartum antimicrobial prophylaxis (IAP).
- Maternal vaccination is a promising strategy, offering transplacental transfer of antibodies for protection.
- The Type V GBS-TT conjugate vaccine is a significant development.

- Computational models are valuable tools in vaccine research.
- They simulate disease dynamics, immune responses, and vaccine effects within a controlled virtual environment.
- Such models enable rapid exploration of scenarios, including variations in vaccine dosage and administration schedules.
- Ordinary differential equation (ODE) models offer a balance between interpretability and computational efficiency.
- In this study, we extend an established ODE model to evaluate the Type V GBS-TT conjugate vaccine.

# Background

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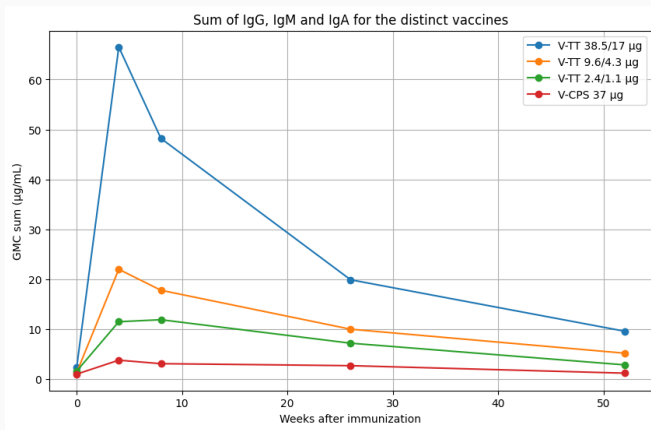
- GBS (*Streptococcus agalactiae*) is a common bacterium and a major cause of neonatal infections.
- The innate immune system acts as the first line of defense, involving cells such as neutrophils and macrophages.
- The adaptive immune system produces specific antibodies against GBS antigens, primarily targeting the polysaccharide capsule.
- Vaccines mimic natural infection to elicit memory immune responses without causing disease.
- The Type V GBS-TT conjugate vaccine uses capsular polysaccharides (CPS) conjugated with tetanus toxoid (TT) to enhance immunogenicity.

- A study by Baker *et al.*<sup>1</sup> evaluated the Type V GBS-TT conjugate vaccine at different dosages in healthy adults.
- The vaccine elicited a dose-dependent immune response, with higher doses inducing greater production of specific antibodies.

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<sup>1</sup>Baker *et al.*, Dose-response to type V group B streptococcal polysaccharide-tetanus toxoid conjugate vaccine in healthy adults. *Vaccine*, 25(1), pp. 55–63, Jan 2007.





**Figure 1:** Sum of IgG, IgM and IgA for the distinct vaccines. Cohort data from Baker *et al.*

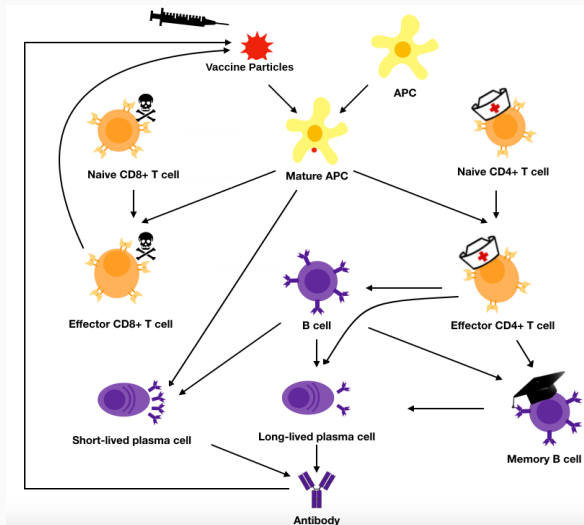
# Methods

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- The model is a system of ordinary differential equations (ODEs), adapted from Bonin *et al.* <sup>2</sup>
- It describes interactions among:
  - Vaccine particles (Vp),
  - Antigen-presenting cells (naive Ap, mature Apm),
  - Lymphocytes (Thn, The, Tkn, Tke, B, Bm, Ps, PI),
  - Antibodies (A).
- The model includes terms for vaccine elimination, cell maturation, activation, replication, differentiation, and decay.

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<sup>2</sup>Bonin *et al.*, Validation of a yellow fever vaccine model using data from primary vaccination in children and adults, revaccination and dose-response in adults, and studies with immunocompromised individuals. *BMC Bioinformatics*, 21(S17), Dec 2020.

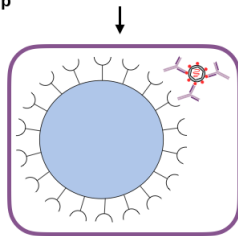


$$\frac{d}{dt}V_p = - \frac{c_{v1}V_p}{c_{v2} + V_p} - k_{v1}V_pA - k_{v2}V_pT_E$$



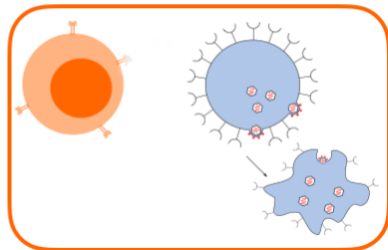
**Innate system action**

$$\frac{d}{dt}V_p = -\frac{c_{v1}V_p}{c_{v2} + V_p} - \boxed{k_{v1}V_pA} - k_{v2}V_pT_E$$



**Neutralization by antibodies**

$$\frac{d}{dt}V_p = -\frac{c_{v1}V_p}{c_{v2} + V_p} - k_{v1}V_pA - \boxed{k_{v2}V_pT_E}$$



**Elimination by T killer cells**

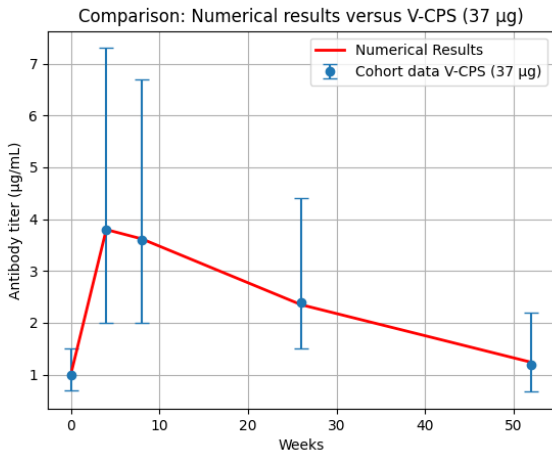
- Cohort data were extracted from a phase 1 trial comparing the Type V GBS-TT conjugate vaccine (V-TT) with an unconjugated Type V capsular polysaccharide (V-CPS) vaccine.
- Healthy adults (aged 18–50 years) were assigned to four vaccine groups.
- Blood samples were collected at baseline and at 4, 8, 26, and 52 weeks post-vaccination.



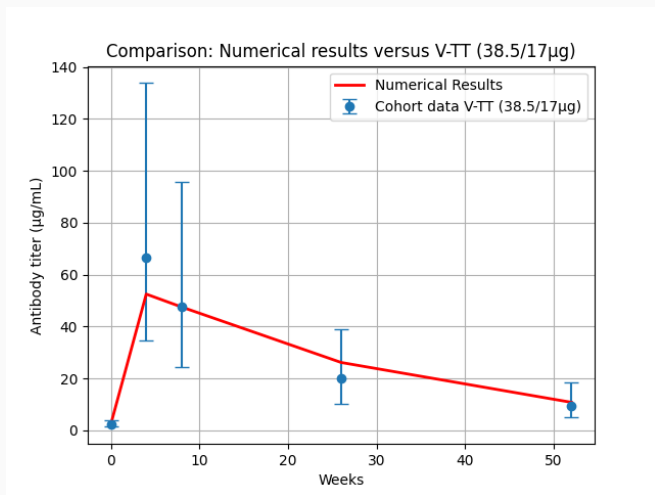
- Type V CPS-specific antibodies (IgG, IgA, and IgM) were quantified using ELISA.
- Differential Evolution (DE) was employed to calibrate seven key model parameters.
- The objective function minimized the  $L_2$  norm of the relative error between observed and simulated antibody levels.

## Results and Discussion

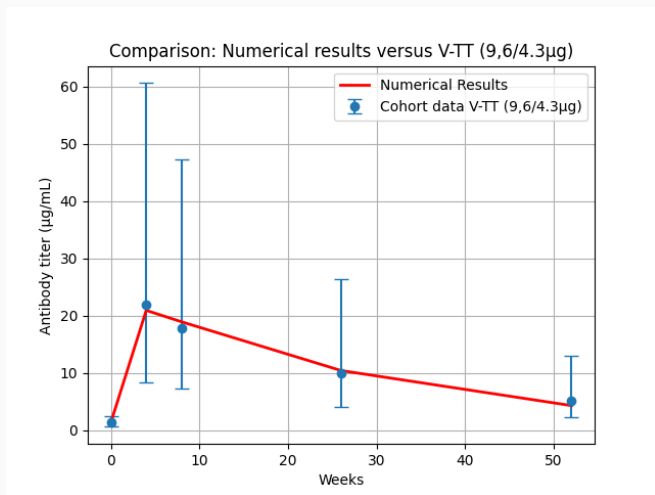
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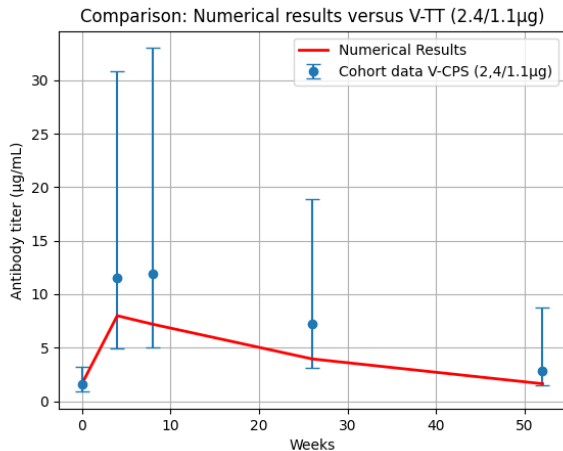
**Figure 2:** Unconjugated CPS: 37  $\mu$ g



**Figure 3:** V-TT: 38.5 $\mu$ g CPS/17.0 $\mu$ g TT



**Figure 4:** V-TT: 9.6 $\mu$ g CPS/4.3 $\mu$ g TT



**Figure 5:** V-TT: 2.4 $\mu$ g CPS/1.1 $\mu$ g TT

- The model accurately reproduced the dose-dependent antibody response observed in the clinical trial.
- Higher CPS doses elicited stronger and more sustained antibody levels.
- The highest V-TT dose ( $38.5 \mu\text{g}$  CPS /  $17.0 \mu\text{g}$  TT) showed near-perfect alignment with cohort data.
- Lower doses ( $2.4 \mu\text{g}$  CPS /  $1.1 \mu\text{g}$  TT) exhibited greater discrepancies, with simulated titers consistently falling below the geometric mean titer (GMT).
- These deviations suggest opportunities for model refinement.

- The DE algorithm successfully calibrated seven key parameters to fit the model to cohort data for both unconjugated CPS and conjugated V-TT vaccines.
- Significant differences were observed between the two vaccine formulations, reflecting distinct immunological mechanisms.
- For the V-TT vaccine, the antigen-presenting cell maturation rate ( $\beta_{ap}$ ) was 93 times higher than for the unconjugated vaccine.
  - This supports the adjuvant effect of tetanus toxoid.



- The antibody-mediated vaccine clearance rate ( $k_{v1}$ ) was approximately 1,700 times higher for the conjugated vaccine, suggesting more effective neutralization of vaccine particles.
- The short-lived plasmocyte decay rate ( $\delta_{ps}$ ) remained consistent across formulations.
- The antibody decay rate ( $\delta_A$ ) was slightly higher for the V-TT conjugate vaccine.

## Conclusion and Future Work

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- Developed a computational model to simulate the immune response to the Type V GBS-TT conjugate vaccine.
- Successfully reproduced clinical trial data across multiple dosage groups.
- Calibration using Differential Evolution provided mechanistic insights into dose-dependent efficacy.
- The conjugated V-TT vaccine elicited a more robust and sustained antibody response than the unconjugated CPS formulation.
- Enhanced APC maturation and accelerated antibody-mediated clearance emerged as key contributors to the superior immune response.

- Incorporate additional parameters into the calibration process to improve model precision.
- Explore uncertainty quantification to assess confidence in model predictions.
- Integrate patient-specific immune profiles to enable personalized dosing strategies, especially for high-risk populations.

Obrigado!  
Thanks!

