

Virus Versus Vaccine: The Mechanics of the Immune System

by

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Part I – Margaret’s First Symptoms

Margaret sat on her porch facing the pond. It was a cool, fresh autumn day, one of the last decent days of autumn before the upcoming winter. At 71, she cherished being outside and regularly walked with her children and grandchildren in the mornings and evenings. Her daughter was pregnant and due to give birth at any time soon. Margaret smiled at the thought of seeing her newborn grandson as she basked in the sun. Suddenly, she felt a shiver run down her spine. Margaret frowned, but she couldn’t shake the chills her body was feeling.

“Strange,” she muttered.

As the day drew to a close, the chills didn’t leave, and Margaret began to feel an ache in her muscles and joints. Having lived a long life, she knew this was a sign of sickness. Assuming it was a simple cold, she was afraid to spread it to her grandkids, so she canceled her visit the following day.

She called her daughter, “Hey Mary, we should cancel our visit tomorrow. I’m not feeling too good.” Margaret bundled up in bed early, hoping to sleep off the illness.

The next morning, Margaret awoke. Instead of feeling refreshed as she had hoped, Margaret felt even more drained. She pulled herself out of bed and into the kitchen. She made her usual breakfast, toast with jam and a cup of coffee. Taking a bite, she was surprised when she realized that it was bland. She took another bite and then sipped her coffee. Nothing; it might as well have been water for all she knew. Margaret was concerned.

After breakfast, she went to the bathroom and sprayed her favorite lavender air freshener. She couldn’t smell anything. Margaret was worried now and thought, *Something’s not right*.

Questions

1. List the symptoms Margaret is feeling.
2. The immune system helps to protect our body from pathogens. The immune system has two distinct branches: the innate and adaptive branches. Using the following table, compare these branches.

<i>Term</i>	<i>Innate Branch</i>	<i>Adaptive Branch</i>
Speed of response:		
Does this branch display specificity?	Yes or No	Yes or No
Cells/secreted products:		

3. What does it mean if an individual is “immune to disease” or has “developed immunity”? Which branch of the immune system provides immunity?

4. Margaret’s daughter is due to give birth soon. Would a newborn baby rely more on their innate or adaptive immune branch? Use the following terms in your response: *innate*, *adaptive immunity*, *memory*, *antigen*, and *sensitization*.

Part II – Breathing Troubles and Hospital Visit

Things only worsened for Margaret as the day progressed; her breathing became progressively more shallow, and she felt as if she couldn't catch her breath. Panic began to creep in, and she grabbed the phone and dialed her daughter.

An hour later, Margaret found herself sitting in the urgent care clinic, struggling to keep calm as the doctor listened to her lungs. He checked her throat and noticed that she had swollen lymphatic nodes, with the left side being bigger than her right.

The doctor said gently, "Margaret, I believe you have COVID-19 based on your symptoms. But to be sure, we will administer a rapid antigen test."



Watch the following video to learn how the rapid antigen test works and how to interpret its results:

- *How SARS-CoV2 Antigen Rapid Tests Work (Covid-19 Testing)*. Running time: 2: 43 min. Produced by Henrik's Lab, 2020. <<https://youtu.be/VmQmY-QYWss>>

Questions

5. You are a resident, and your attending physician turns to quiz you. The physician states, "Please explain to your patient how a rapid antigen test works." In your response, incorporate the following terminology: *antigen*, *control line*, *test line*, *primary antibody*, *secondary antibody*, *positive result*, and *negative result*.
6. Use Figure 1 below to identify the COVID-19 rapid antigen test results as either with positive, negative, or invalid. (Margaret's results are shown in Test 4.)

Test 1: _____ Test 2: _____ Test 3: _____ Test 4: _____

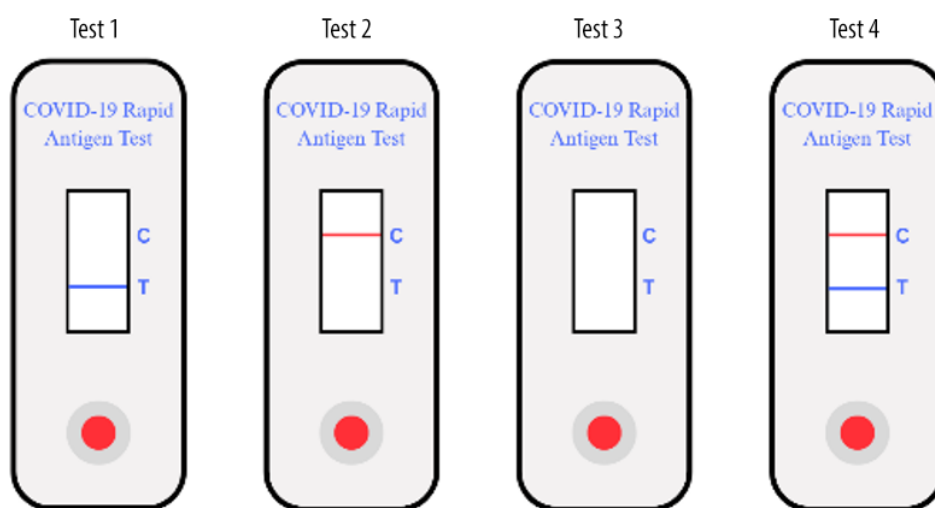


Figure 1. Interpretation of COVID-19 rapid antigen test results.

7. The chances of getting a false negative on rapid antigen tests are 30.7%.
 - a. What is a false negative?
 - b. From a public health perspective (spreading of disease), which is more concerning, a false positive or a false negative?

Part III – Innate Immunity and the Inflammatory Response

Margaret's rapid antigen test results came back positive for COVID-19. As the doctor broke the news to Margaret, she started to feel light-headed and tear up. The doctor explained that her body had been constantly trying to defend itself against the virus and was utilizing its mechanisms to minimize the damage it caused.

"What exactly do you mean that my body is trying to defend itself? Is it not enough to protect me from COVID-19?" Margaret asked.

The doctor pulled up a chair, ready to clarify how the virus worked inside her body.

"When the COVID-19 virus enters your body, it latches on to the cells of your respiratory tract and lungs. Your body's first line of defense, the innate immune branch, responds immediately with general responses, such as fever and inflammation."

Margaret nodded slowly, absorbing the explanation. "So my fever and chills were my body fighting back?"

"Exactly."

Margaret had another question. "So if my immune system is fighting for me, why am I feeling this out of breath?"

"Sometimes, COVID-19 can cause excessive inflammation, which can lead to complications such as difficulty breathing."



Inflammation is a normal response to tissue injury or infection, serving to remove dead cells and debris. Acute (short-term) inflammation is protective and beneficial, but chronic (long-term) inflammation can damage tissues. Answer the following questions to review your knowledge of inflammation.

Questions

8. Tissue damage causes the release of chemical mediators that lead to vasodilation, increased capillary permeability, chemotaxis, and leukocytosis. Match each component of inflammation to its function in the context of immunity.

Component of Inflammation

Function

- | | |
|------------------------------------|---|
| a. Vasodilation | _____ Chemical messengers that coordinate inflammation and immune cell communication. |
| b. Increased vascular permeability | _____ Immune cells, such as neutrophils and macrophages, move toward the site of infection to engulf pathogens. |
| c. Phagocyte migration | _____ Increases blood flow, bringing immune cells and nutrients to the site of infection. |
| d. Cytokine release | _____ Allows immune cells and proteins to move from blood vessels into infected tissue. |

9. The cardinal (classic) signs of inflammation are heat, redness, swelling, and pain. For each sign, explain the underlying physiological mechanisms that cause it and describe how each contributes to the healing process.

a. Heat and redness:

b. Swelling and pain:

10. What is the difference between acute and chronic inflammation as an immune response to a viral infection, and how can an overactive immune response be dangerous?
11. Interferons are part of the body's innate immune response to viral infections, but COVID-19 attempts to block their production early in infection. What are interferons, and why would the virus try to suppress them during the early stages of infection?

Part IV – T Cell Maturation and Activation

Later, the doctor reviews Margaret's case with his resident. Imagine you are the resident as the doctor begins quizzing you on immune system physiology and assigns you the following tasks.

Questions

12. List the antigen-presenting cells in the human body.

13. Before being seeded into secondary lymphoid tissues, T cells must mature in the thymus. Maturation includes learning to recognize self-MHC, displaying self-tolerance (not reacting to self-peptides), and immunocompetence. Watch the video listed below to review T-cell maturation, then answer the associated questions below:
 - *T Cell Development and Maturation - T Cells Are COOL!* Running time: 5:48 min. Produced by Interactive Biology, 2022. <<https://youtu.be/3IQT9KsrO6M>>
 - a. Create a flowchart outlining the process of CD4⁺ T cell maturation. The flow chart should include the following terms: *antigen-presenting cell, double-negative T cell, double-positive T cell, naive CD4⁺ T cell, negative selection, positive selection, self-MHC II, and thymic epithelial cell.*

 - b. Create a flowchart outlining the process of CD8⁺ T cell maturation. The flow chart should include the following terms: *antigen-presenting cell, double-negative T cell, double-positive T cell, naive CD8⁺ T cell, negative selection, positive selection, self-MHC I, and thymic epithelial cell.*

- c. For each of the following statements, decide whether they are true of negative selection, positive selection, or neither. For statements true of negative selection, write “Negative” on the line; for statements true of positive selection, write “Positive”; for statements true for both, write “Both”; for statements true of neither, write “Neither.”

_____ Occurs in the red bone marrow.
 _____ Occurs in the cortex of thymus.
 _____ Determines if the T cell can recognize self-MHC.
 _____ Antigen presenting cell (APC) displays antigen to naïve T cell.
 _____ T cell receptor binds to MHC of a thymic epithelial cell.
 _____ T cell receptor binds to MCH of an antigen presenting cell.

14. Autoimmune diseases result from the immune system incorrectly targeting and destroying one’s own (self = auto) tissue. What kind of selection protects against autoimmunity, positive or negative?
15. Using the diagram below, write a description for steps 1–6 in the process of CD4⁺ T cell activation. Include the following terms: *antigen-presenting cell*, *viral antigen*, *MHC II*, *naïve CD4⁺ T cell*, *co-stimulatory signal*, *CD4⁺ helper T cell*, *CD4⁺ memory T cell*, *B cell*, *memory B cell*, *plasma cell*, and *antibodies*.

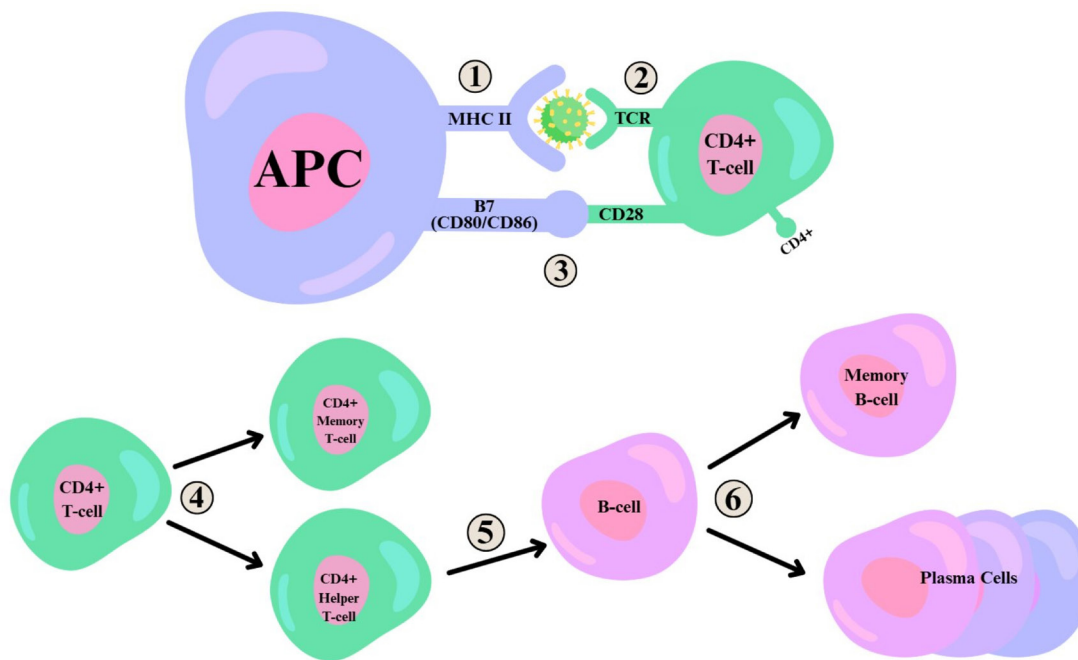


Figure 2. T-cell activation and maturation.

16. Complete the table below to summarize the characteristics of CD4⁺ and CD8⁺ T cells.

<i>Characteristics</i>	<i>CD4⁺ T Cells</i>	<i>CD8⁺ T Cells</i>
<i>MHC Recognition:</i> Does the cell recognize MHC I or II?		
<i>Antigen Presentation:</i> Which cell(s) present antigens to these cells? What is the source of these antigens (e.g., intracellular)?		
<i>Effector Cells:</i> What effector cells are associated with each of these cell types? What is their function?		

Part V – Preventive Measures

Wanting to get better as soon as possible to make it to her grandson's birth, Margaret asked, "I've heard of a vaccine for COVID-19. Would it help me get better faster?"

The doctor replied, "Unfortunately, no. Vaccines serve a preventative function. Think of it as practice for your immune system. Many vaccines work by imitating an infection to engage the body's immune system ahead of time by exposing it to harmless pieces of the virus. Your immune system builds memory cells, so when the real virus comes, it can respond more quickly rather than taking days to learn how to fight back. But since you're already infected, your body is now in real combat, not training."

Margaret sighed. "So, I'll just have to wait it out?"

"No, but we have another option. Margaret, I'm going to prescribe Paxlovid®, an antiviral medication. This medication limits your body's ability to replicate the virus."



Paxlovid is a prescription containing two separate medications: nirmatrelvir and ritonavir. Nirmatrelvir inhibits a key enzyme involved in viral assembly, whereas ritonavir slows the liver's metabolism of nirmatrelvir, increasing its length in circulation. Paxlovid must be given within five days of symptom onset.

Questions

17. While many people receive immunity through artificial means (a vaccine), Margaret has acquired natural immunity through her body's response to her illness. Immunity can be gained through natural or artificial means, and passively or actively. Determine the classification of each of the following.

Table 3. Classification of immunity types by case examples.

<i>Case</i>	<i>Type of Immunity</i>
Margaret's grandson is receiving IgG antibodies through his mother's placenta.	Passive or active? Natural or artificial?
A farmer receives an antibody serum after being bitten by a rabid raccoon.	Passive or active? Natural or artificial?
A person receives a flu shot (e.g., influenza vaccine).	Passive or active? Natural or artificial?
A person who has already been exposed to COVID-19 gets infected again and recovers more quickly.	Passive or active? Natural or artificial?
A person receives antivenom after a snake bite.	Passive or active? Natural or artificial?

18. Why is it important for vaccines to activate both B and T cells, not just one or the other? Explain what would happen if one were activated and not the other.
19. Even though Margaret never got the vaccine, are her chances of getting COVID-19 again the same, higher, or lower? Explain your answer.

20. Margaret's daughter is strongly against vaccines. Her husband received the vaccine and still contracted COVID-19 and nearly died. She believes this proves that vaccines are ineffective. What does Figure 3 below suggest about the relationship between vaccination status and the number of COVID-19-related deaths? Support your answer with specific data from the diagram.

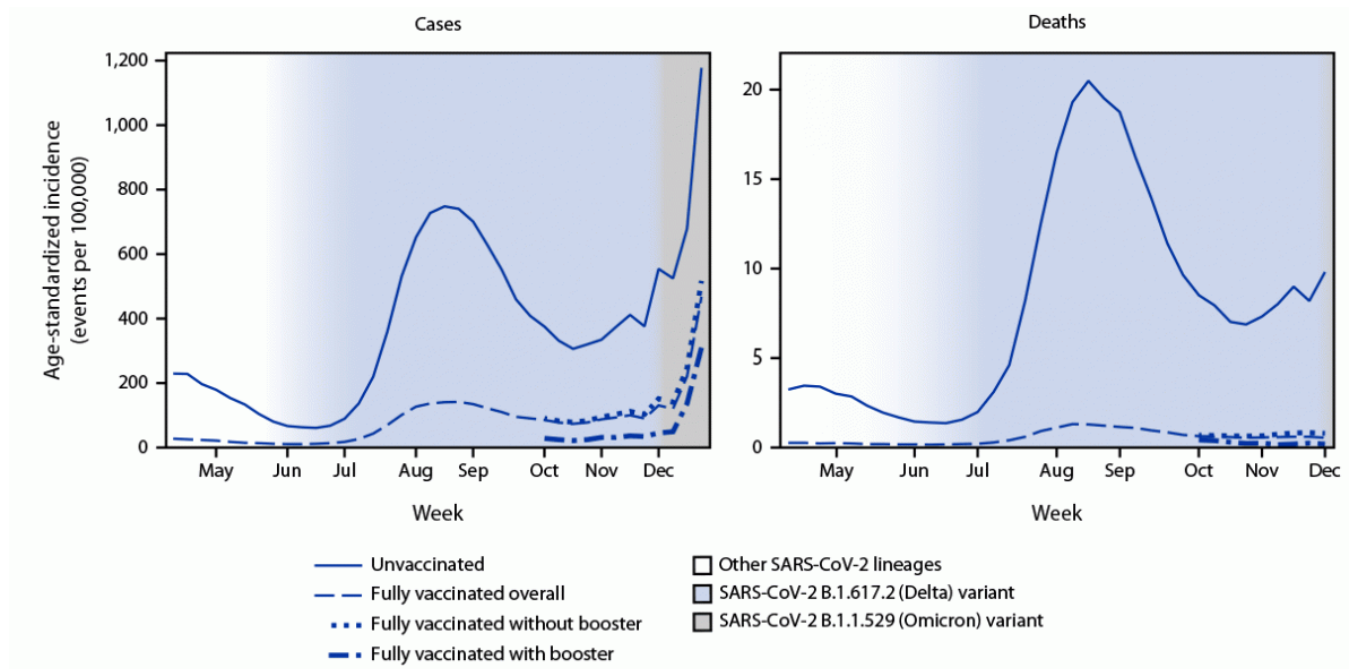


Figure 3. Weekly trends in age-standardized incidence of COVID-19 cases and deaths for unvaccinated compared with fully vaccinated persons and by booster dose. *Source:* Johnson et al., 2022.

21. Why do patients often experience soreness and inflammation at the injection site after receiving a vaccine? Some people take ibuprofen after booster shots to reduce inflammation, but this is no longer recommended. Explain why reducing inflammation with ibuprofen can lower the effectiveness of the vaccine.

Epilogue

Fortunately, Margret sought care early in her infection and the physician was able to provide her with Paxlovid. The anti-viral medication prevented her from developing severe illness.

A year later at her annual physical, her physician recommended she receive a COVID-19 vaccine. “Margret, would you like to receive a COVID-19 vaccine at your appointment today?”

Margret hesitated, replying, “I felt awful last year when I had COVID. I don’t want to experience that again! But aren’t I immune now?”

The doctor gently explained, “Immunity to COVID-19 can wane over time and the virus frequently mutates.” Additionally, the physician compassionately communicated that as an elderly individual, her immune system is not as effective as it once was and that the mortality rate for elderly individuals is significantly higher than younger individuals.

The physician listened to and answered Margret’s remaining questions. Feeling that her questions has been answered, Margret concluded, “The vaccine sounds like a good insurance plan. It might not be perfect, but it greatly reduces my risk of contracting COVID. Even if I do get sick, I’m more likely to stay out of the hospital!”



References

- 5MinuteSchool. (2018). B cells vs T cells. [Video]. Running time: 5:00 min. YouTube. <<https://youtu.be/NMOHWry8EDc>>
- Ada's Medical Knowledge Team. (2025). COVID-19: swollen lymph nodes. [Webpage]. ADA Health GmbH. <<https://ada.com/covid/covid-19-swollen-lymph-nodes/>>
- Aurora Biomed. (n.d.). How to interpret COVID-19 antigen rapid test results. [Webpage]. Aurora Biomed Inc. <<https://www.aurorabiomed.com/interpret-results-covid-19-rapid-antigen-test/>>
- Cascella, M., M. Rajnik, A. Aleem, S.C. Dulebohn, & R. Di Napoli. (2023). Features, evaluation, and treatment of coronavirus (COVID-19). In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing. <<https://www.ncbi.nlm.nih.gov/books/NBK554776/>>
- CDC. (2026). Types of COVID-19 treatment. [Webpage]. Centers for Disease Control and Prevention. <<https://www.cdc.gov/covid/treatment/index.html>>
- Clebak, K.T., J. Snyder, & T.M. Felix. (2023). Accuracy of point-of-care rapid antigen tests for diagnosis of COVID-19. *American Family Physician* 107(4): 354–5. <<https://www.aafp.org/afp/2023/0400/cochrane-poc-rapid-antigen-tests-for-diagnosis-of-covid-19>>
- Fraser, S. (2022). How do rapid antigen tests work? [Webpage]. Today's Clinical Lab. <<https://www.clinicallab.com/how-do-rapid-antigen-tests-work-26279>>
- Ikeokwu, A.E., R. Lawrence, E.D. Osieme, K.M. Gidado, C. Guy, & O. Dolapo. (2023). Unveiling the impact COVID-19 vaccines: a meta-analysis of survival rates among patients in the United States based on vaccination status. *Cureus* 15(8), e43282. <<https://doi.org/10.7759/cureus.43282>>
- Johnson, A.G., A.B. Amin, A.R. Ali, et al. (2022). COVID-19 incidence and death rates among unvaccinated and fully vaccinated adults with and without booster doses during periods of delta and omicron variant emergence: 25 U.S. jurisdictions, April 4–December 25, 2021. *Morbidity and Mortality Weekly Report*, 71(4). <<https://doi.org/10.15585/mmwr.mm7104e2>>
- Sabir, S., & A. Jan. (2025). Physiology, immune response. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing. <<https://www.ncbi.nlm.nih.gov/books/NBK539801/>>
- Samuel, C. E. (2023). Interferon at the crossroads of SARS-CoV-2 infection and COVID-19 disease. *The Journal of Biological Chemistry* 299(8), 104960. <<https://doi.org/10.1016/j.jbc.2023.104960>>
- Self, W. H., M.W. Tenforde, J.P. Rhoads, et al. (2021). Comparative effectiveness of Moderna, Pfizer-BioNTech, and Janssen (Johnson & Johnson) vaccines in preventing COVID-19 hospitalizations among adults without immunocompromising conditions — United States, March–August 2021. *Morbidity and Mortality Weekly Report*, 70(38): 1337–43. <<https://doi.org/10.15585/mmwr.mm7038e1>>
- Zieneldien, T., J. Kim, J. Cao, & C. Cao. (2021). COVID-19 vaccines: current conditions and future prospects. *Biology* 10(10), 960. <<https://doi.org/10.3390/biology10100960>>
- Zhu, Y., L. Sharma, & D. Chang. (2023). Pathophysiology and clinical management of coronavirus disease (COVID-19): a mini-review. *Frontiers in Immunology* 14, 1116131. <<https://doi.org/10.3389/fimmu.2023.1116131>>

Internet references accessible as of October 12, 2026.

