Covid-19 Vaccine Efficacy Explained

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1 What you see in the media

News media and blogs abound with articles reporting on the latest developments in the production of vaccines targeting the SARS-Cov-2 virus, which is responsible for the Covid-19 pandemic. In those reports, it's quite common [2, 3, 4, 5], to see efficacy [1] numbers displayed like Figure 1.

Figure 1: Typical media display of vaccine efficacies

For our purposes, efficacies for the vaccines currently being distributed in the USA are collected in Table 1. Flu vaccine efficacy, which is usually omitted, is included for comparison.

Table 1: Nominal vaccine efficacies

Pharma	Efficacy (%)	Dosage	My remarks
Pfizer	95	2	Requires dry ice storage (-70^oC) and transport.
Moderna	94	2	Refrigerated storage and transport (-20^oC).
AstraZ	76	2	Not approved in USA. Possible thrombotic side effects.
J&J	72	1	Efficacy from USA clinical trials.
Flu shot	40–50	1	Multiple corona viruses mutate rapidly every year.

Based on these numbers, people naturally want to rank them in order of decreasing efficacy [6], which leads to the obvious conclusion that Pfizer is best, J&J is worst, and

seasonal flu shots are a complete waste of time and money. Nothing could be further from the truth.

Remark 1 (Percentage of what?)**.** *Whenever you see a percentage value, you have to ask yourself, "Percentage of what?" A percentage, after all, is just a fraction (expressed as a ratio of 100). So, "Fraction of what?" People seeing the percentages in Table 1 assume it means some kind of coverage or protection, e.g., Pfizer offers 95% protection. But, 95% is a fraction of what? 95% of your body? That doesn't make sense.*

As the subsequent sections will demonstrate, such ranking vaccines on the basis of their reported efficacy gives a false impression that is ultimately counterproductive. In fact, it would be better if the media did not confuse the public with these efficacy numbers at all.

2 How efficacy is measured

All efficacy numbers are based on clinical trials that are defined by each pharma company. There are certain FDA standards that have to be met but quite a lot of them have been relaxed to enable "fast tracking" in view of the urgency of getting control over the world-wide pandemic crisis. Primarily, this has meant the size of the trials have been limited to a smaller number of volunteers than would normally have been the case. Also, other considerations such as, whether or not the vaccines reduce transmissibility, remain unknown. There simply has not been enough time (usually years) to collect the right kind of data.

In a clinical trial the total number of volunteers (or other participants) is split evenly into two groups: the control group and the target group.

Table 2: Example from Pfizer trials

Group	Infected	Healthy	Total
Placebo	162	21,838	22,000
Vaccine	8	21,992	22,000
Total	170	43,830	44,000

The first row in Table 2 (the *Placebo* group) is the control group against which everything else is compared. Those volunteers represent that part of the USA population that has not received any kind of treatment for Covid-19. In particular, they could not have received any vaccine since it's not yet available to the general population at this phase of the trial. The other group now receives the trial vaccine. Both groups are then monitored for some period following administration of the vaccine.

Remark 2 (Double blind trial)**.** *In order that all the volunteers remain unaware of which group they belong to (so as not to biased the final results), the Placebo group get a vaccine shot but it contains only salt water or a similar inert substance: anything that will not cause them to exhibit an immune response. Similarly, the clinicians running the trial do not know what they are administering in each shot they give.*

Here, monitoring means checking for one or more symptoms that are associated with Covid-19, e.g., cough, fever, aches, etc. The actual monitored symptoms has differed across the different pharma companies. This has mostly been due to the way in which clinical data could be collected expeditiously, given the urgency of producing an efficacious vaccine.

In the first row of Table 2, we see that 162 people in the Placebo group of 22,000 participants, exhibited symptoms that were classed as being due to Covid-19. They were therefore classed as "infected" by Covid-19. In the Vaccinated group (second row), only 8 people of those other 22,000 participants exhibited the defined symptoms of Covid-19 infection.

3 How efficacy is calculated

The way I like to think about this, is as follows. The Placebo group sets our expectations as to what the Covid-19 infection rate looks like. Out of 22,000 people in the general USA population, we expect to see about162 infections. Put another way, there is a $162/22,00$ chance, (or less than a one percent chance) of getting infected with Covid-19.

That likelihood may seem small but, if you're over 65 years of age, there's a very high chance you will end up needing to be hospitalized or dead.

The next step is to compare our expectations with what actually happened to those who did receive the real vaccine: the actuals. Out of the 22,000 vaccinated people, only 8 of them became infected (according to the Pfizer monitoring criteria). Clearly, that number of much smaller than the expected value of 162 unvaccinated people.

To summarize this effect, we use a relative effect measure, which I'll call E and define as:

$$E = \frac{\text{expected} - \text{actual}}{\text{expected}} \tag{1}$$

In other words, it's the difference between the **expected** number of infections (based on the Placebo group data) and the **actual** number of infections (based on the Vaccinated group data), normalized (scaled) by the expected value.

Remark 3. *The relative effect defined by equation (1) can only have numerical values between 0 (i.e., no effect) and 1 (i.e., maximal effect).*

No effect: *If the actual number of infections is the same as the expected number of infections, then expected−expected = 0, and therefore $E = 0$, which means there is no effect. Expressed in terms of percentages, this is the same as writing $E = 0\%$.*

Maximal effect: *Conversely, if there are no infections at all in the Vaccination group, the actual value will be zero, and equation (1) reduces to just expected/expected = 1, and therefore $E = 1$. Expressed in terms of percentages, this is the same as writing $E = 100\%$.*

Using the numbers in Table 2, equation (1) becomes

$$E = \frac{162 - 8}{162}$$

It's easier to appreciate this equation if we write it as

$$E = 1 - \frac{8}{162}$$

Since $8/162$ is very close to $8/160$, we can replace it with $1/20$.

$$E = 1 - \frac{1}{20}$$

But, $1/20 = 0.05$ as a decimal fraction and we end up with

$$E = 1 - 0.05 = 0.95 \tag{2}$$

Recall that I mentioned fractions in Section 1. See Remark 1. We can change that decimal fraction in equation (2) to a percentage (i.e., a fraction of 100) by simply multiplying it by 100 to produce 95%. And there it is, the efficacy percentage in Table 1 as reported by Pfizer.

We could calculate the other efficacies in the same way (assuming the same controls):

$$E_{\text{pfizer}} = 1 - \frac{8}{162} \simeq 0.95 = 95\%$$
$$E_{\text{astra}} = 1 - \frac{40}{162} \simeq 0.75 = 75\%$$
$$E_{\text{flushot}} = 1 - \frac{80}{162} \simeq 0.50 = 50\%$$

Remark 4 (All the lonely people)**.** *Notice that the number of participants (none of whom ostensibly know about each other) in the Pfizer clinical trial, i.e., the 44,000 people in Table 2, does not appear in the calculation of E. Why not? Ideally, the result $E = 95\%$ is independent of the test population size, i.e., it should hold for any scale of clinical trial. Statistically speaking, the bigger the trial group, the more reliable E is expected to be. In the Pfizer case, 44,000 subjects is more than 10 times larger than required by the FDA for a standard Phase III trial [8]. This is an unprecedented level of accuracy for such a short development period of less than 12 months.*

4 How to say it

It's important to be able to state the meaning of E in the correct way.

Pfizer Covid-19 Efficacy

Relative to the number of people in the Pfizer control group who became infected (i.e., 162), only 5% of that expected number (viz., 8) actually became infected after those non-control participants received the Pfizer `BNT162B2` vaccine.
The fractional reduction in Covid-19 symptoms, relative to the Pfizer control group, was 95%.

So, the efficacy (E) is a measure of the relative reduction in the infection rate within the context of a clinical trial.

Depending on the country (USA, UK, Brazil, India, etc.), differences in demographics from the USA trials, presence of different Covid-19 mutations [9], as well as other effects, the reported efficacy number can vary.

Overall, each of the vaccines in Table 1 is equally effective at eliminating severe consequences of Covid-19 that would otherwise require hospitalization. None of these vaccines guarantees that you will not get infected by the SARS-CoV-2 virus.

References

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