

# A statistical sceptic's view of personalised medicine

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# Acknowledgements

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# A former captain of industry speaks

It will soon be possible for patients in clinical trials to undergo genetic tests to identify those individuals who will respond favourably to the drug candidate, based on their genotype.... This will translate into smaller, more effective clinical trials with corresponding cost savings and ultimately better treatment in general practice. ... individual patients will be targeted with specific treatment and personalised dosing regimens to maximise efficacy and minimise pharmacokinetic problems and other side-effects.

Sir Richard Sykes, FRS, 1997

My emphasis

# A leading researcher speaks

Not only will genetic tests predict responsiveness to drugs on the market today, but also genetic approaches to disease prevention and treatment will include an expanding array of gene products for use in developing tomorrow's drug therapies.

Francis S Collins, *NEJM*, 1999

# The editor of a leading journal speaks

*Anybody familiar with the notion of “number needed to treat” (NNT) knows that it's usually necessary to treat many patients in order for one to benefit. NNTs under 5 are unusual, whereas NNTs over 20 are common.*

Richard Smith, *BMJ*, 13 December 2003

(Richard Smith was the editor of the *BMJ* for many years and remains a very interesting commentator of medicine and health.)

*Significance gets in on the act*

# Statistics and the medicine of the future

New drugs that are effective and safe for all become harder and harder to find. Individuals react differently to different medications. **Chris Harbron** points to a future where drugs will be better targeted. With the help of statisticians we will each have our own designer drugs, no longer off-the-shelf but tailored exactly to suit our own individual genome.

June 2006

# A previous Prime Minister of the UK speaks

This agreement will see the UK lead the world in genetic research within years. I am determined to do all I can to support the health and scientific sector to unlock the power of DNA, turning an important scientific breakthrough into something that will help deliver better tests, better drugs and above all better care for patients....

David Cameron, August 2014 (my emphasis)

# The world's leading regulatory agency speaks

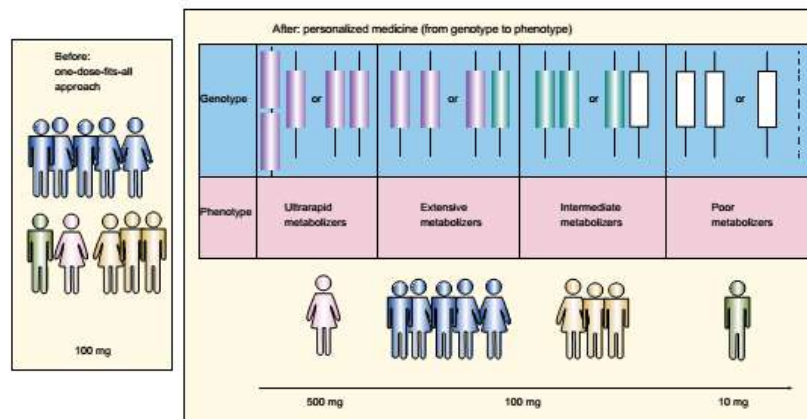


Figure 1. Representation of the trial-and-error or one-dose-fits-all approach versus personalized medicine. The left panel shows a situation in which everyone gets the same dose of a drug, regardless of genotype. The right panel shows a personalized medicine approach in which the dose of the drug is selected based upon genotypical, and therefore phenotypical, variability of the metabolizing enzyme. (Source: Xie, H., Frueh, F.W., (2005). Pharmacogenomics steps toward personalized medicine. *Personalized Medicine*, 2(4), 333.)



# The leading evidence based medicine organisation speaks



Following

Featured review: Only 10% people with tension-type headaches get a benefit from paracetamol

[uk.cochrane.org/news/featured- ...](http://uk.cochrane.org/news/featured-...)



RETWEETS 20 LIKES 3



59% had no or at worst mild headache **after 2 hours** when treated with paracetamol

49% had no or at worst mild headache **after 2 hours** when treated with placebo

$59\% - 49\% = 10\%$

Therefore 10% benefitted

The number needed to treat (NNT) for one extra patient to have a benefit is 10

Based on a review of 23 studies and 6000 patients

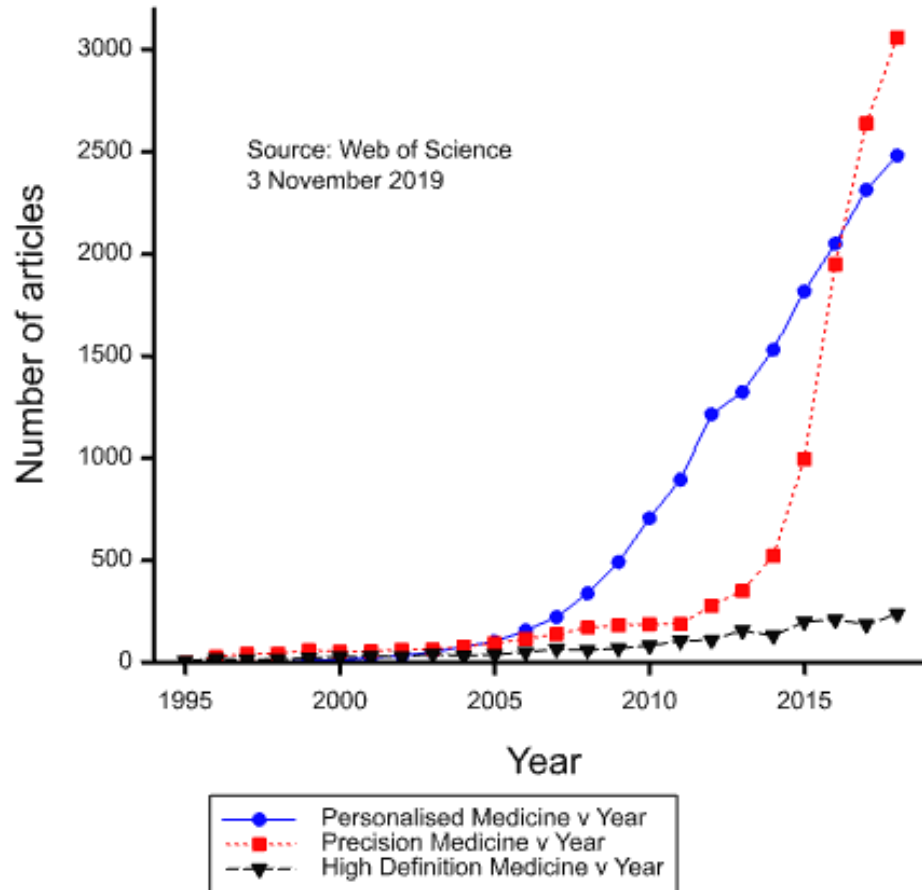
# The financial press gets in on the act



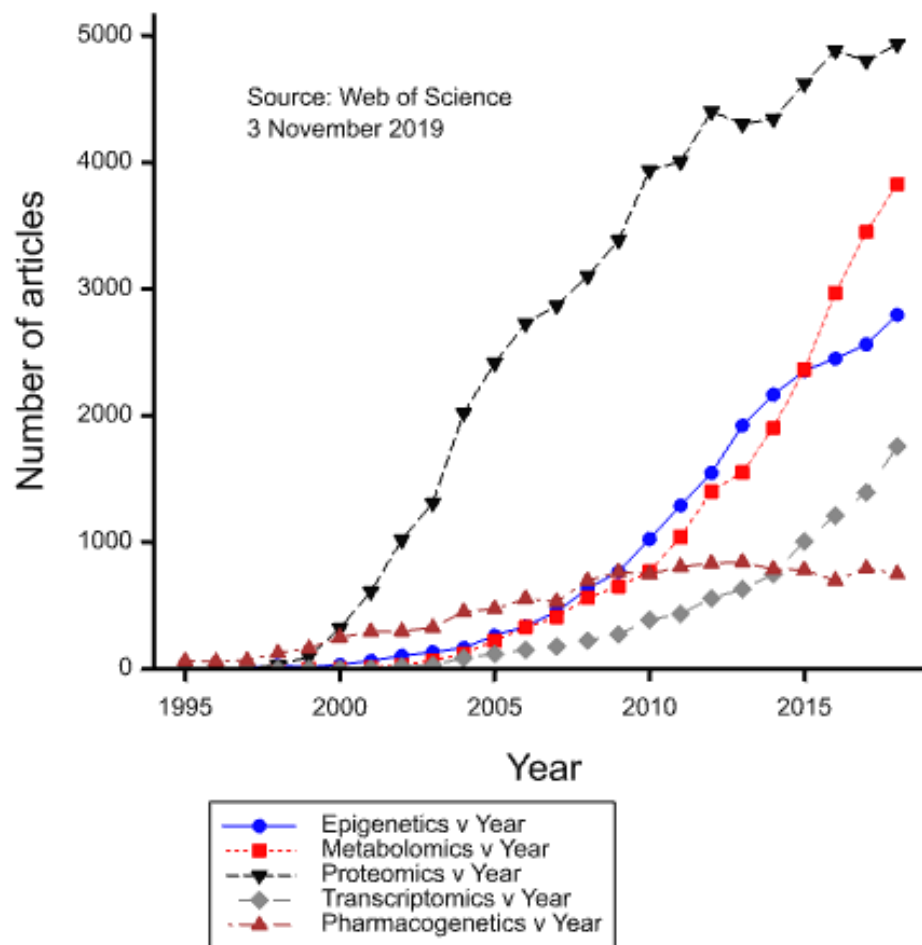
need a diverse toolkit of  
drugs that attack cancer in new ways  
and get ahead of its evolution.  
Dramatic advances in our under-  
standing of cancer biology and genetics  
are helping to deliver an era of precision  
cancer treatment. The number of can-  
cer drugs being licensed by the Euro-  
pean Medicines Agency has doubled in  
less than a decade — and many of these  
are new personalised treatments.

Olivia Rossanese, Institute of  
Cancer Research, December 2018

## Papers published in a given topic



## Papers published in 'omic fields



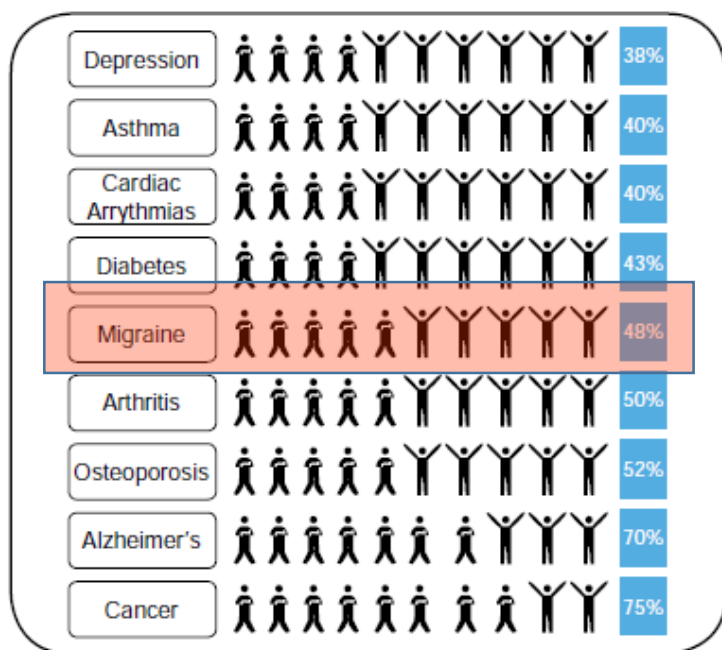
# Warning

We tend to believe the truth is in there.

Sometimes it isn't and the danger is that we will find it anyway

# Statistics on non-responders

## What the FDA says



Paving the way for personalized medicine, FDA Oct 2013

## Where the FDA got it

Table 1. Response rates of patients to a major drug for a selected group of therapeutic areas<sup>1</sup>

Therapeutic area	Efficacy rate (%)
Alzheimer's	30
Analgesics (Cox-2)	80
Asthma	60
Cardiac Arrhythmias	60
Depression (SSRI)	62
Diabetes	57
HCV	47
Incontinence	40
Migraine (acute)	52
Migraine (prophylaxis)	50
Oncology	25
Osteoporosis	48
Rheumatoid arthritis	50
Schizophrenia	60

Spear, Heath-Chiozzi & Huff, *Trends in Molecular Medicine*, May 2001

# Back to the source of the source

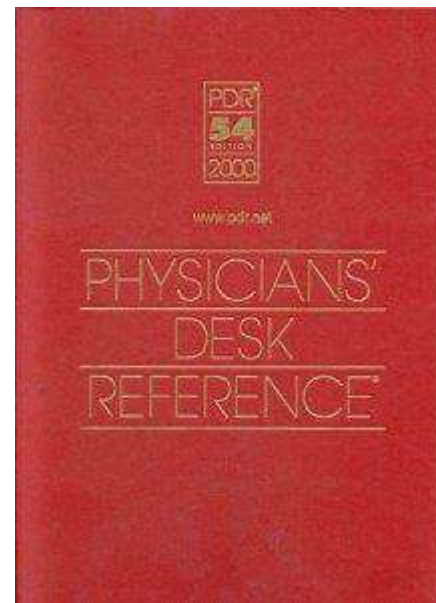
Where the FDA got it

Where those who got it got it

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<sup>1</sup> Physicians' Desk Reference, 54th Edn., 2000



# My thesis

- We have a plague of zombie statistics
  - They are ugly
  - They are evil
  - They refuse to die
- Even if the figures were right in some numerical sense, they wouldn't mean what they are assumed to mean
- We need to do something!

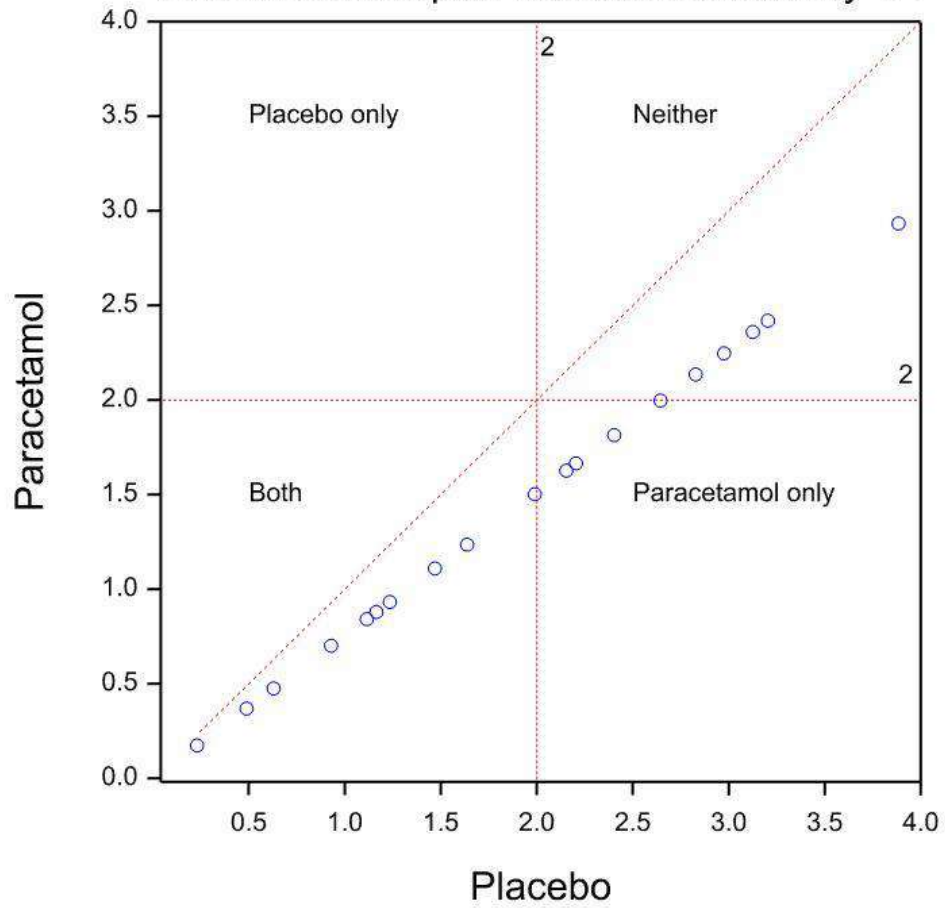


# Back to the headache

## A Recipe to Mimic the Cochrane Results

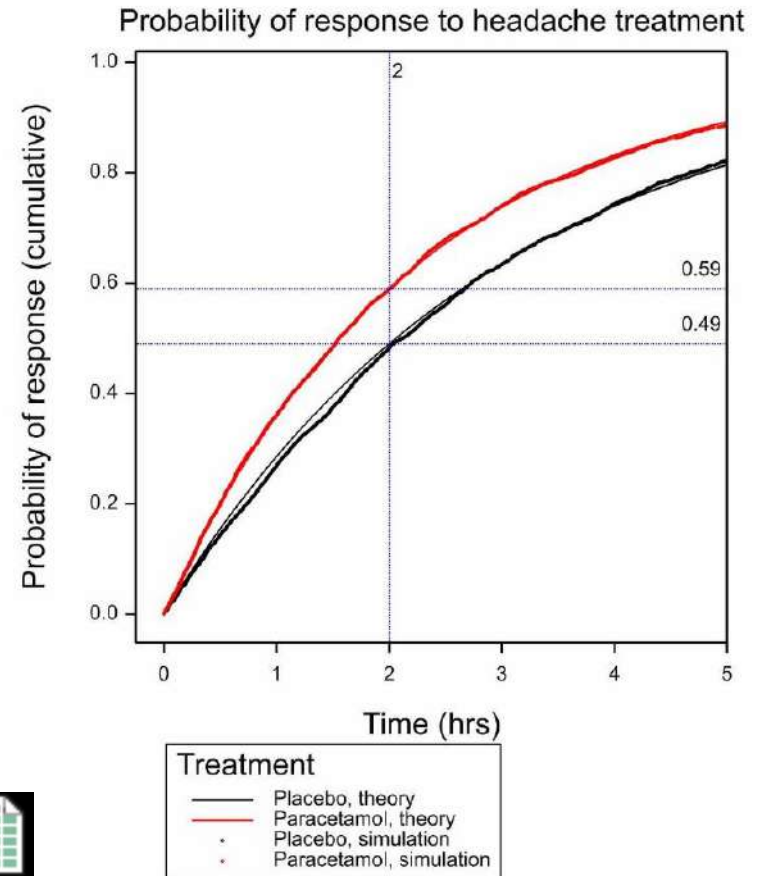
- Generate one random number,  $U_i$ , for each of 6000 headaches,  $i = 1, 2, \dots, 6000$
- Calculate pairs of headache
  - $Y_{i1} = -\log(U_i)2.97$  (placebo headache duration)
  - $Y_{i2} = -\log(U_i)2.24$  (paracetamol headache duration)
- Now randomly erase one member of each pair
  - Because each headache can only receive one treatment
  - The other is *counterfactual*
- Draw the empirical cumulative distribution

Counterfactual: pain duration reduced by 1/4



# Why this recipe?

- The exponential distribution with mean 2.97 is chosen so that the probability of response in under two hours is 0.49
  - This is the placebo distribution
- The exponential distribution with mean 2.24 is chosen so that the probability of response in under two hours of 0.59
  - This is the paracetamol distribution
- This is what you would see if *every* headache were reduced to the same degree (about  $\frac{1}{4}$ )
- It is also mimics exactly the Cochrane result



Microsoft Excel  
Worksheet

# Lessons

## Particular

- The NNT of 10 is perfectly compatible with paracetamol having *exactly the same proportionate effect on every headache*
- Nothing in the data we are given says anything whatsoever about differential response

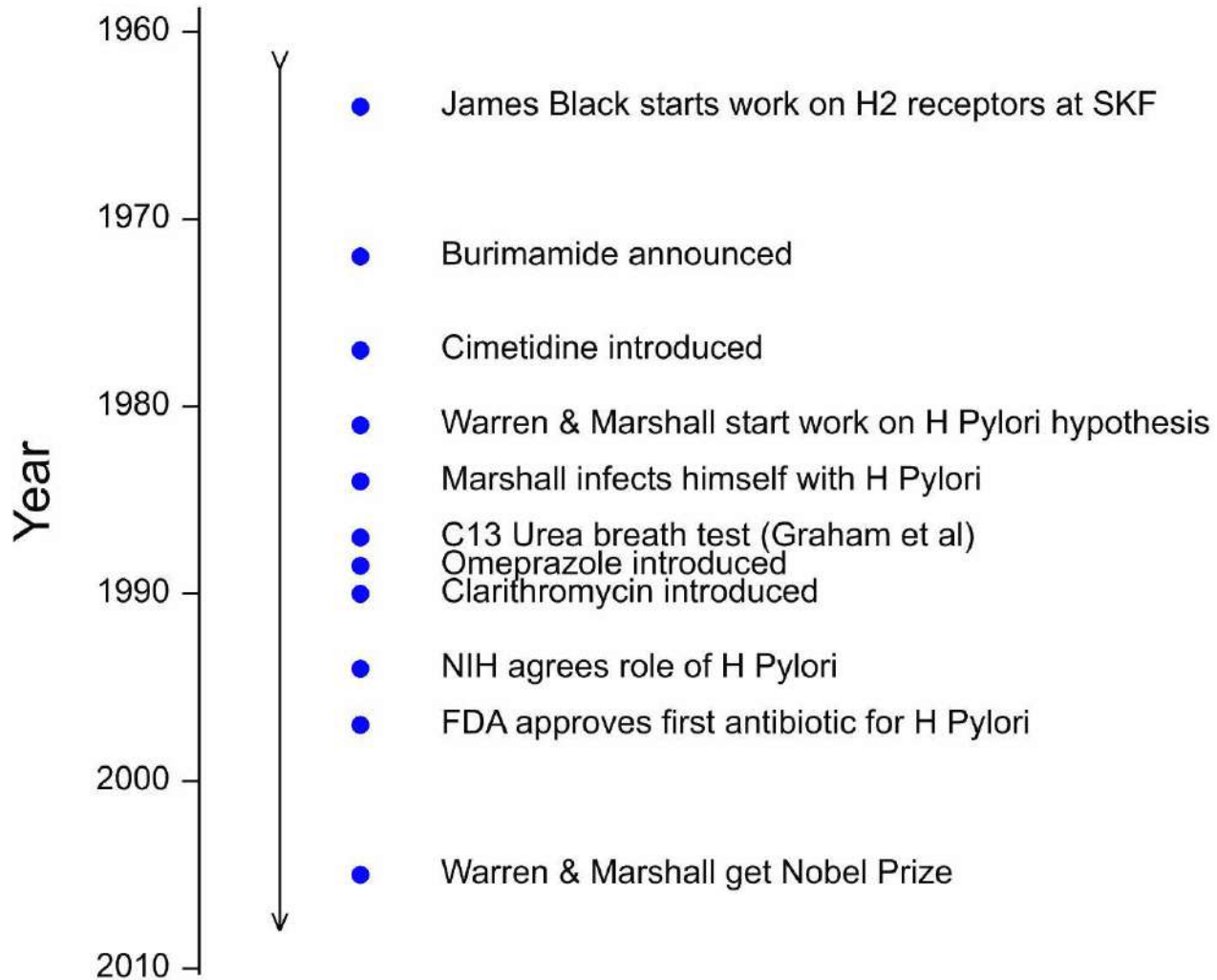
## In general

- An NNT cannot tell you what proportion of patients responded
- To think so is a straightforward conceptual mistake
- Claims regarding the proportion who respond based on NNTs are misleading

## Personalised medicine

A field that has proved highly productive in producing publications and grant funding.

## A time line of ulcer treatment



# Ulcer treatment in the last quarter of the 20th century

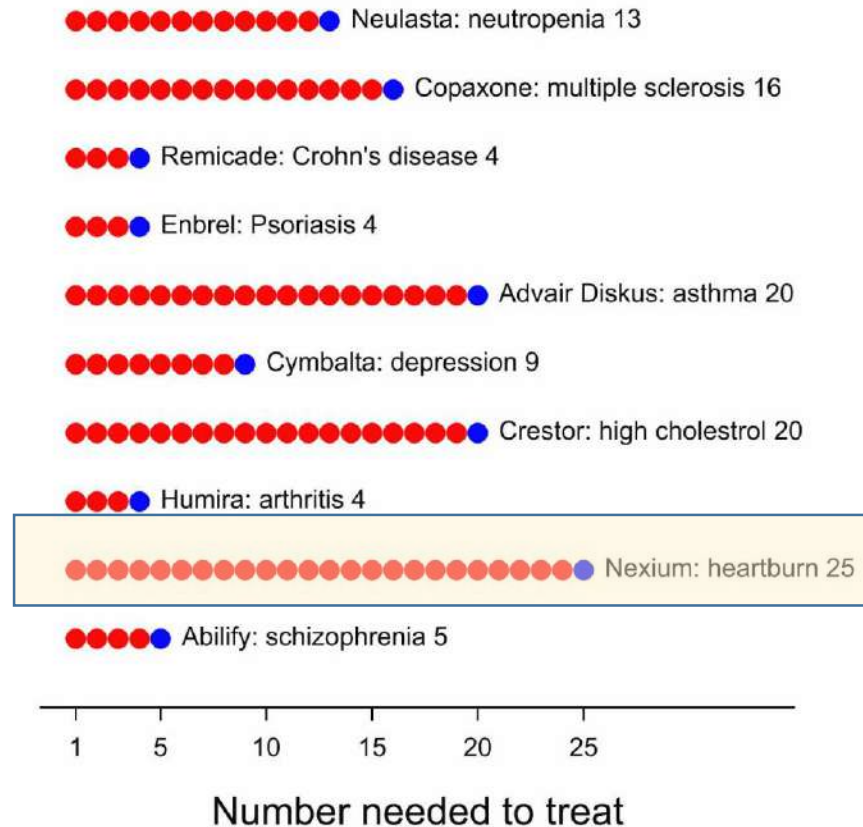
- A great success story
- Four to five major innovations/discovery
  - H2 antagonists
  - Proton pump inhibitors
  - The role of H Pylori
  - C13 Urea breath test
  - Antibiotics developed to treat H Pylori
- Together these transformed the treatment of ulcer treatment
- General surgery largely wiped out
- For the many not just the few
  - Admittedly the combination of the C13 test and antibiotic treatment involves a degree of personalisation
- But now look at how the personalised medicine bandwagon misrepresents it

## Wasteful medicine?

“Every day, millions of people are taking medications that will not help them. The top ten highest-grossing drugs in the United States help between 1 in 25 and 1 in 4 of the people who take them. “

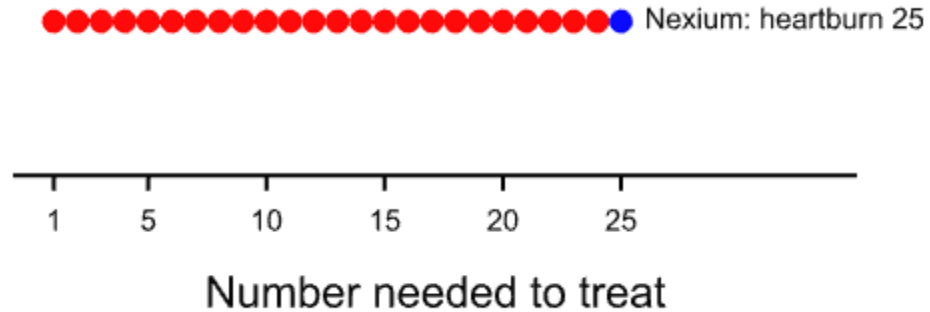
Schork, N, *Nature* 2015

## NNTs according to Schork 2015





# Nexium revisited



- This is for Nexium (*Esomeprazole*) compared to other proton pump inhibitors
- This is a highly successful class of treatment
- ‘Response’ is 92% in one case and 88% in the other *at 8 weeks* (Labenz et al, 2005)
- Response rises over time and would probably increase *beyond 8 weeks*
- The claim that only 1 in 25 benefit is nonsense

## Two extreme cases Illustrated with the EXPO study

		Esomeprazole		
		Not healed	Healed	Total
Pantoprazole	Not healed	7.9	4.8	12.7
	Healed	0.0	87.3	87.3
Total		7.9	92.1	100.0

*Case where no patient would respond on Pantoprazole who did not on Esomeprazole (Nexium)*

		Esomeprazole		
		Not healed	Healed	Total
Pantoprazole	Not healed	0.0	12.7	12.7
	Healed	7.9	79.4	87.3
Total		7.9	92.1	100.0

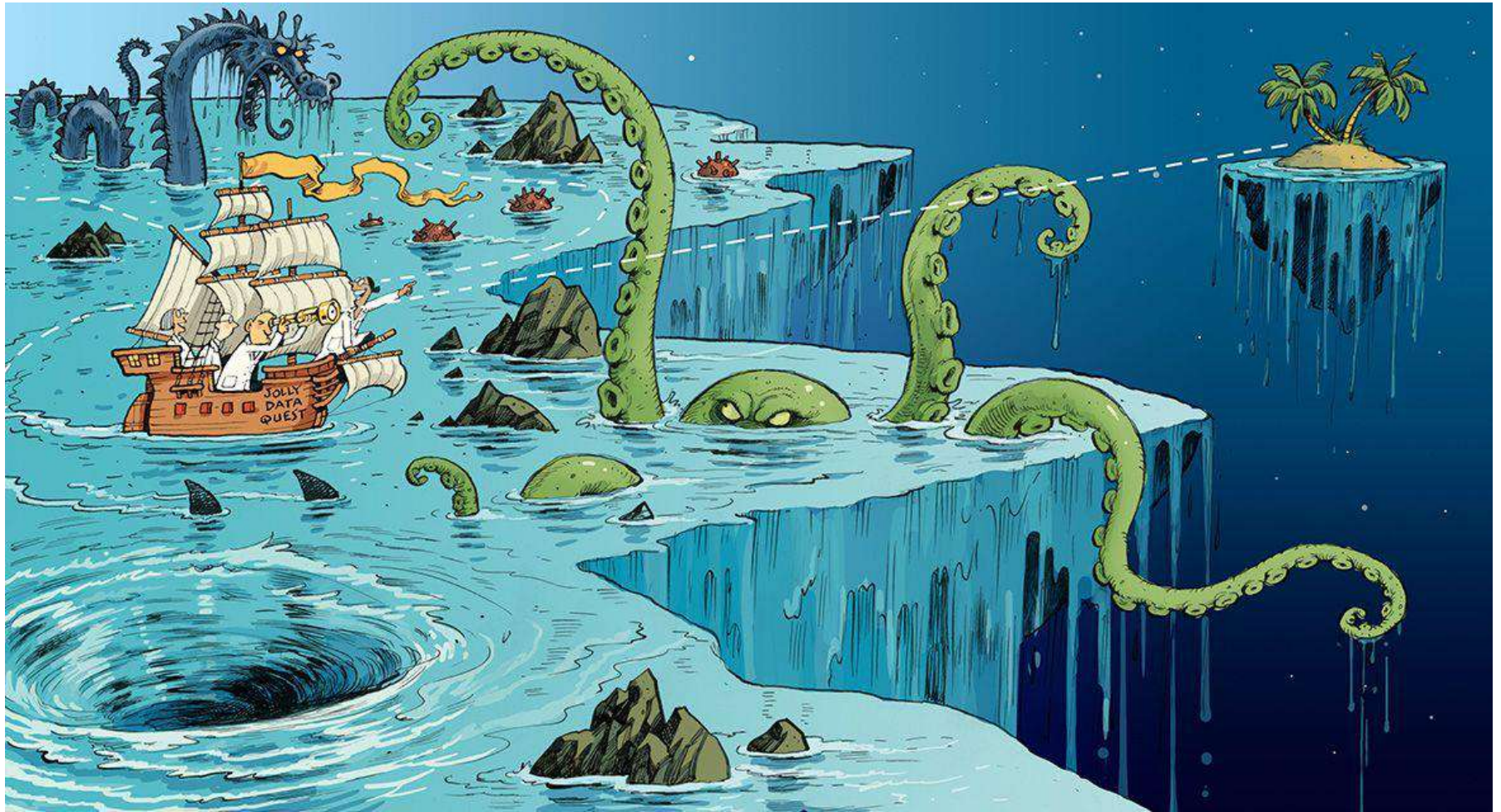
*Case where all patients who did not respond on Esomeprazole (Nexium) would respond on Pantoprazole*

We have moved from finding highly effective treatments for most patients to trying to find expensive ones for almost nobody at all

# How responder analysis misleads us: Six depressingly common sins

- Poor choice of counterfactual
  - Baseline does not necessarily predict what would happen in the absence of treatment
- Bad measures
  - Percent change from baseline is known to be a highly variable and badly behaved measure
- Arbitrary dichotomy
  - There is nothing magic about the standards we use and dichotomising loses information
- Linguistic confusion
  - *Responder* does not mean 'was caused to improve' it means 'was observed to improve'
- Causal naivety
  - Subsequence is not consequence
- Failure to replicate
  - If you want to exclude within-patient variability as an explanation you have to know how big it is. That involves measuring patients more than once

# Slide with the Obligatory Purloined Cartoon



Senn, *Nature*, 29 November 2018

# 15% increase in forced expiratory volume in one second (FEV<sub>1</sub>)

## Some regulatory magic

Some key efficacy PD responses were similar between xxx and yyy following 180 µg single dose inhalation. The percentage of responders (15% increase in FEV<sub>1</sub> from baseline) was 63% and 52% for xxx and yyy, respectively

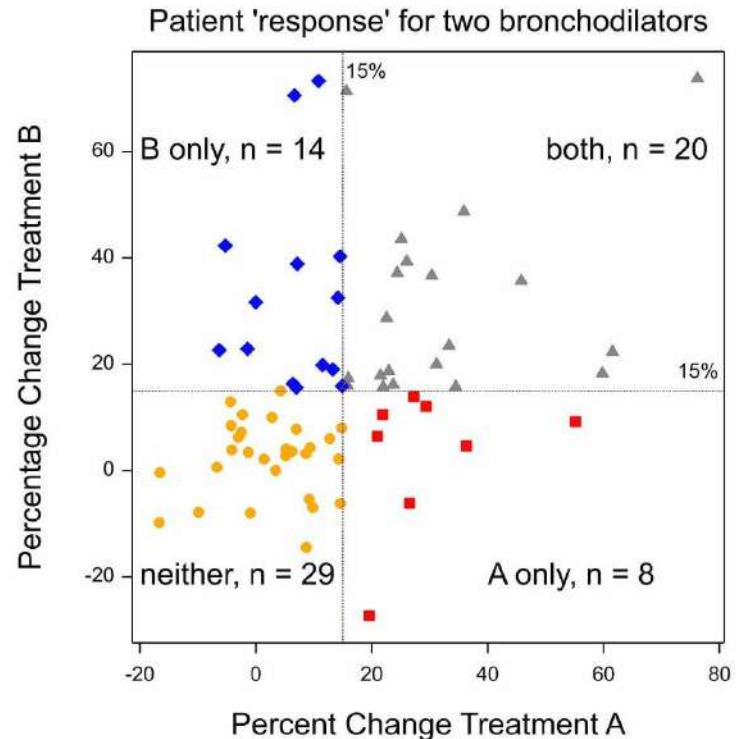
From a cross-over trial submitted to the FDA as part of a review

This is cited just to show that the standard of 15% bronchodilation is used

I shall now use an example of my own

# So can we identify individual response with cross-overs?

- Cross-over trial in asthma
  - 71 patients
  - Forced expiratory volume in one second (FEV<sub>1</sub>) at 12 hours
- FDA definition of response is  $\geq 15\%$  increase compared to baseline
- There seem to be a number of patients who respond to B and not to A and vice versa
- Clearly if we can find predictive characteristics of them we can improve treatment
- Can't we?

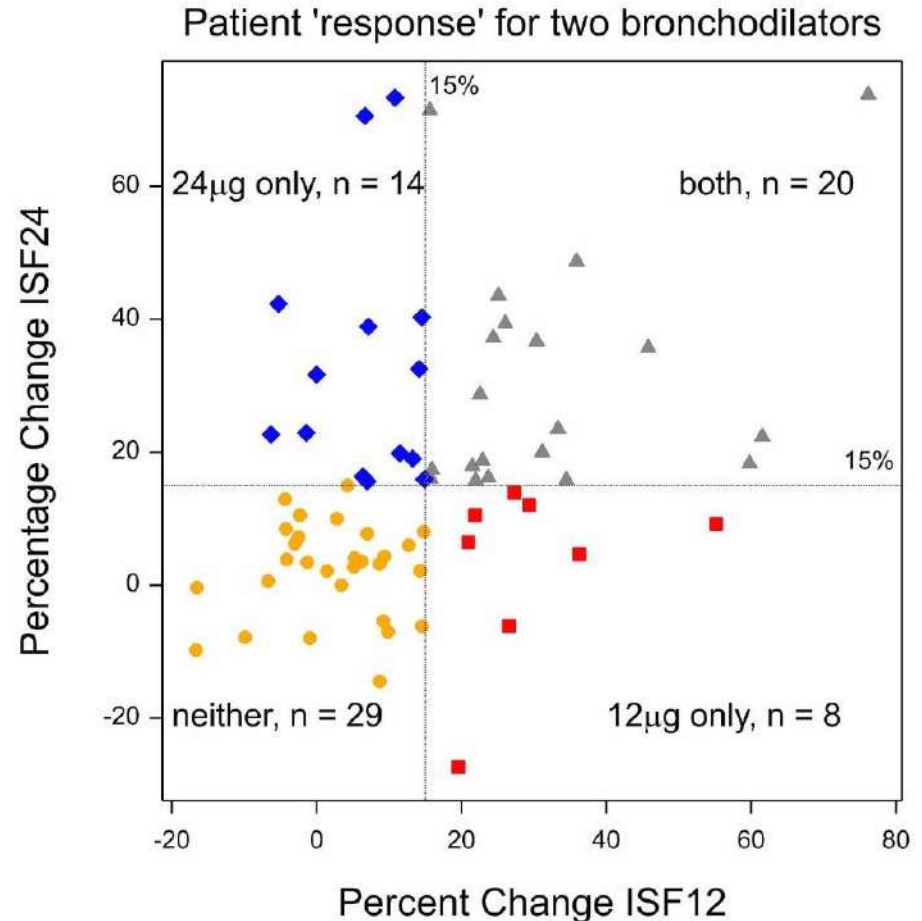




# Differential response?

## Not so fast

- A is ISF 12 $\mu$ g, formoterol
- B is ISF 24 $\mu$ g formoterol
- It is biologically extremely implausible that patients could respond to 12 $\mu$ g and not to 24 $\mu$ g
- Yet apparently 8 out of 71 patients did
- What can the explanation be?
- ***Large within patient variability***
- Conclusion: naive simple views of causality and response aren't good enough and more complex design and analysis is needed





# The real lessons

- *Other things being equal* a high NNT is indicative of a poorer treatment but it is not a valid shortcut to studying variation
- We need to understand and master the variation in the system
- We need to not naively over-interpret differentiation in observed response
  - Some of it may be genuine treatment-by-patient interaction
  - Much of it may be within-patient variation
- In many (but not all) cases the task facing us will be to deliver better average medicine
- In this connection there is one big problem we continually overlook
- The main source of variation in the system is not patients
- It's doctors

*The central problem in management and leadership is failure to understand the information in variation.* Lloyd S Nelson  
(quoted by WE Deming)

- As Deming, the guru of quality control taught us, it is the duty of every manager to understand the variation in the system
- This is what is inspiring what Brent James is doing at Inter-Mountain health
- At the moment we are making a bad job of this
- NNTs and responder analysis are no substitute for serious study of components of variation
- There is no point publishing and developing yet more complicated fancy stuff involving mixed models if we fall at the first hurdle
- Once you have sold the post by permitting naïve causal definitions the battle is already lost
- We must do better in fighting the omic hype
  - and I would include me but I am retired

### Giving this medicine to children:

It is important to know how much your child weighs to make sure you give them the correct amount of medicine. As a guide a child of 9 years of age will weigh about 30 kg (four and a half stone). If in doubt weigh your child, then follow the instructions in the table.

Do not give to children who weigh less than 30 kg.

Do not give to children under 2 years.

Age	How many to take	How often to take
<u>Adults and children of 12 years and over</u>	<u>One tablet</u>	Once a day
Children of 2 to 11 years who weigh <u>more than 30 kg</u>		
Children of 2 to 11 years who weigh <b>less than 30 kg</b>		

The supply of truth always greatly exceeds its demand

John F Moffitt

# Suggested further reading

Araujo, A., S. Julious and S. Senn (2016). "Understanding Variation in Sets of N-of-1 Trials." PLOS ONE **11**(12): e0167167.

Holland, P. W. (1986). "Statistics and Causal Inference." Journal of the American Statistical Association **81**(396): 945-960.

Robins, J. and S. Greenland (1989). "The probability of causation under a stochastic model for individual risk." Biometrics **45**(4): 1125-1138.

Rubin, D. B. (1974). "Estimating causal effects of treatments in randomized and nonrandomized studies." Journal of educational Psychology **66**(5): 688.

Senn, S. J. (2001). "Individual Therapy: New Dawn or False Dawn." Drug Information Journal **35**(4): 1479-1494.

Senn, S. J. (2004). "Individual response to treatment: is it a valid assumption?" BMJ **329**(7472): 966-968.

Senn, S. J. (2016). "Mastering variation: variance components and personalised medicine." Statistics in Medicine **35**(7): 966-977.

Senn SJ. (2018) Statistical pitfalls of personalized medicine. *Nature*. 2018;563(7733):619-621.

Snapinn, S. and Q. Jiang (2011). "On the clinical meaningfulness of a treatment's effect on a time-to-event variable." Stat Med **30**(19): 2341-2348.