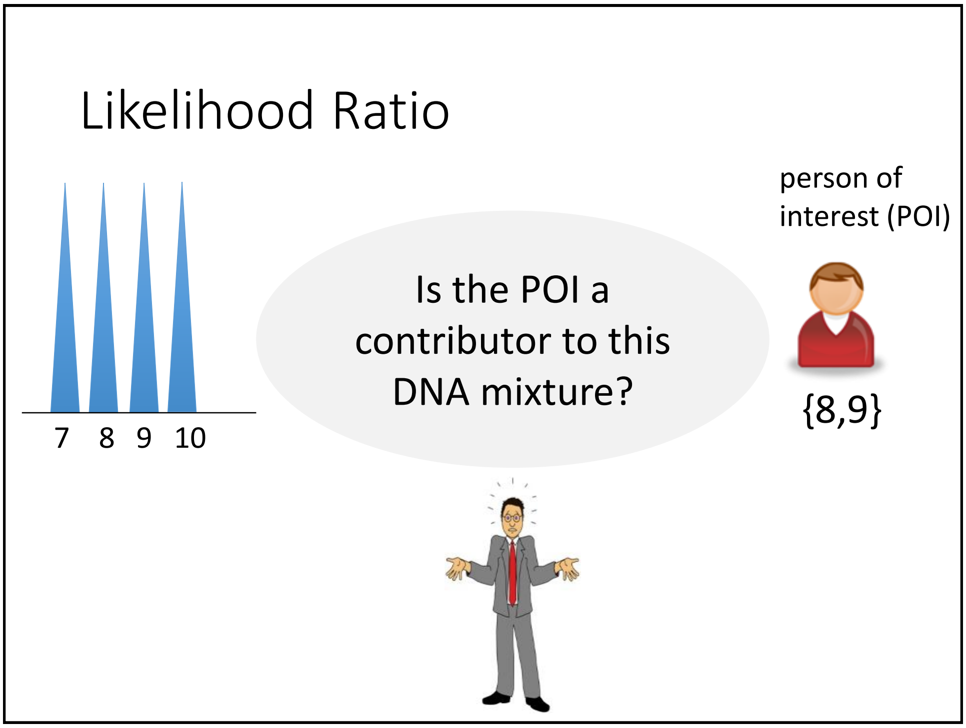
Likelihood Ratios for Mixtures: Binary Approach

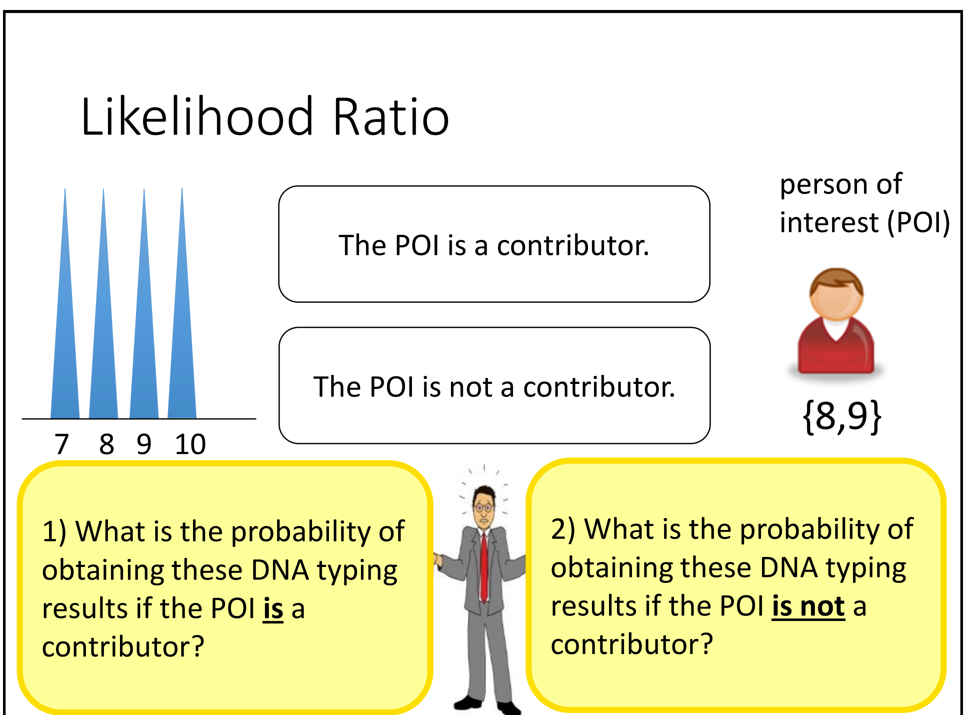
Acknowledgement

I thank Simone Gittelson, Bruce Weir and John Buckleton for their helpful discussions.

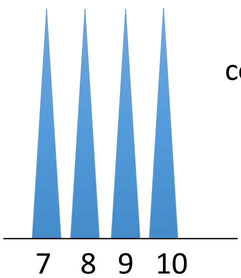
Disclaimer

Points of view in this presentation are mine and do not necessarily represent the official position or policies of the National Institute of Standards and Technology.


Likelihood Ratio
7 8 9 10
Is the POI a contributor to this DNA mixture?
person of interest (POI)
{8,9}


Likelihood Ratio
7 8 9 10
The POI is a contributor.
The POI is not a contributor.
person of interest (POI)
{8,9}
1) What is the probability of obtaining these DNA typing results if the POI **is** a contributor?
2) What is the probability of obtaining these DNA typing results if the POI **is not** a contributor?

Likelihood Ratio



contributors: POI and someone else

$$1 \times 2p_7p_{10}$$

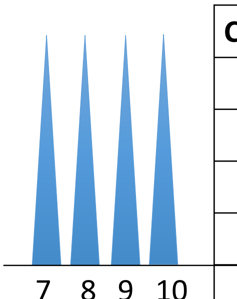
Assumption:
Hardy-Weinberg
Equilibrium

person of
interest (POI)

{8,9}

1) What is the probability of obtaining these DNA typing results if the POI **<u>is</u>** a contributor?

Likelihood Ratio



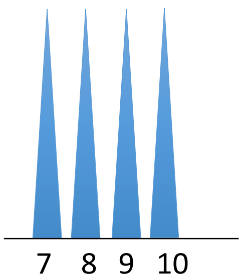
Contributor 1	Contributor 2	
7,8	9,10	$2p_7p_8 \times 2p_9p_{10}$
7,9	8,10	$2p_7p_9 \times 2p_8p_{10}$
7,10	8,9	$2p_7p_{10} \times 2p_8p_9$
8,9	7,10	$2p_8p_9 \times 2p_7p_{10}$
8,10	7,9	$2p_8p_{10} \times 2p_7p_9$
9,10	7,8	$2p_9p_{10} \times 2p_7p_8$

$$\sum$$

$$= 24p_7p_8p_9p_{10}$$

2) What is the probability of obtaining these DNA typing results if the POI **<u>is not</u>** a contributor?

Likelihood Ratio



$$\frac{2p_7p_{10}}{24p_7p_8p_9p_{10}}$$

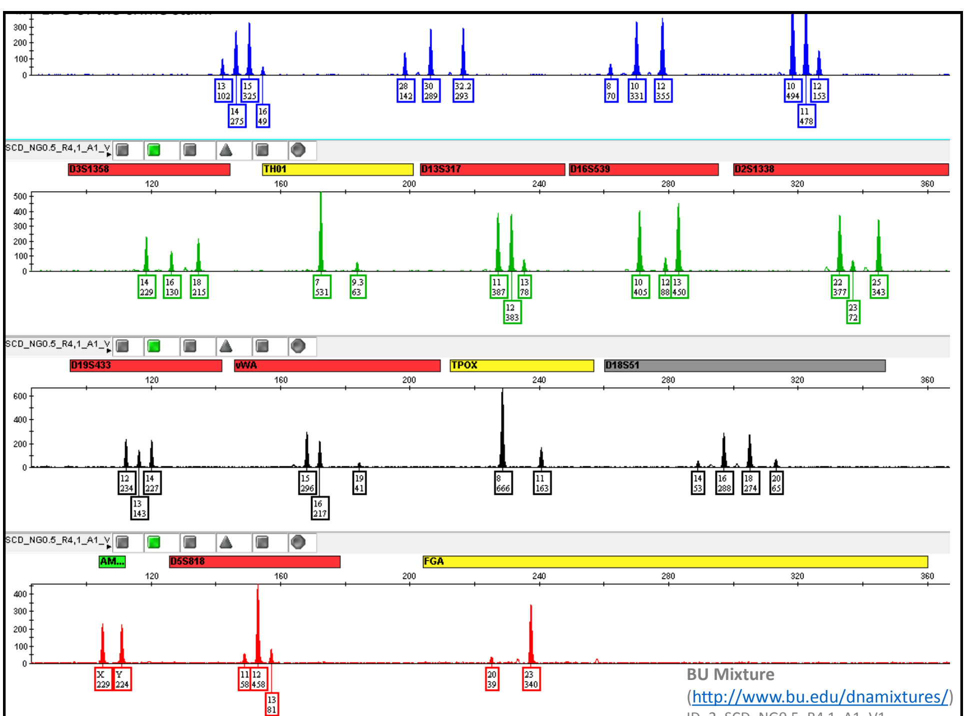
person of interest (POI)

{8,9}

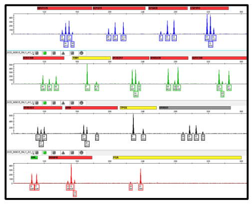
It is 8.3333 times more probable to obtain these DNA typing results if the POI is a contributor than if the POI is not a contributor.

$= 8.3333$

if $p_8 = 0.1$ and $p_9 = 0.1$



Standpoints of the prosecution and the defense



EPG of the crime stain

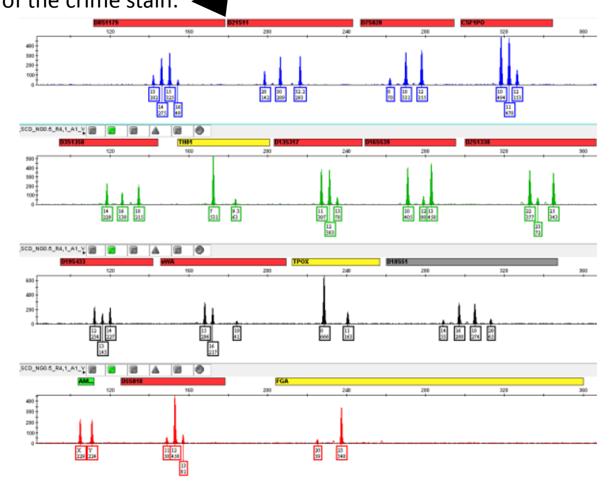
person of interest (POI)

H_p: The DNA came from the POI and an unknown contributor.

H_d: The DNA came from two unknown contributors.

G_{CS} G_{POI}

EPG of the crime stain:



Person of interest (POI)	
D8	13,16
D21	28,28
D7	8,12
CSF1PO	12,12
D3	16,16
TH01	7,9.3
D13	12,13
D16	12,13
D2	23,25
D19	13,13
vWA	15,19
TPOX	11,11
D18	14,20
D5	11,13
FGA	20,28

Boston University Mixture (http://www.bu.edu/dnamixtures/): ID_2_SCD_NG0.5_R4,1_A1_V1

Likelihood Ratio (LR)

The probability of observing the DNA typing results of the crime stain given the POI's genotype and that the DNA came from the POI and one unknown contributor

$$LR = \frac{\Pr(G_{CS} | G_{POI}, H_p)}{\Pr(G_{CS} | G_{POI}, H_d)}$$

numerator

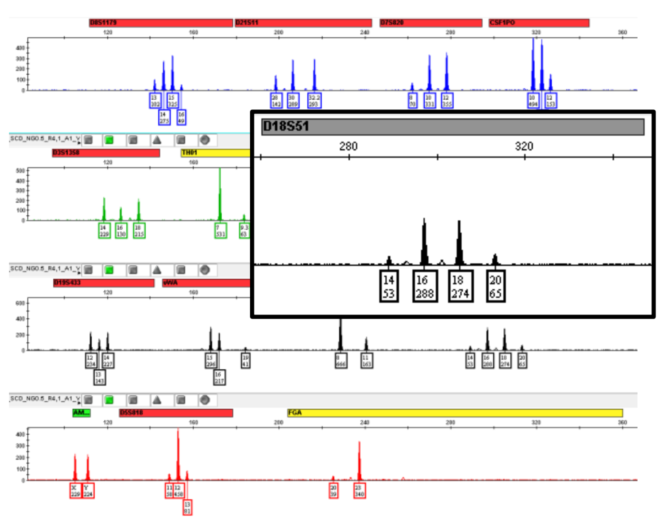
divided by

denominator

the probability of observing the DNA typing results of the criem stain given the POI's genotype and that the DNA came from two unknown contributors.

Note that the conditioning information I has been omitted in the above equation to focus your attention on G_{CS} and G_{POI}.

EPG of the crime stain:



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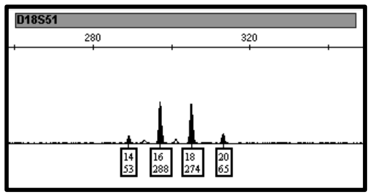
Boston University Mixture (http://www.bu.edu/dnamixtures/): ID_2_SCD_NG0.5_R4,1_A1_V1

Likelihood Ratio (LR)

D18S51

$p_{14} = 0.134$
$p_{16} = 0.147$
$p_{18} = 0.078$
$p_{20} = 0.018$



$G_{POI} = \{14,20\}$

Numerator:

What is the probability of obtaining these DNA typing results for the crime stain if the POI **is** a contributor and the POI has genotype {14,20}?

Major	Minor
16,18	14,20

$Pr(16,18) \times Pr(14,20)$

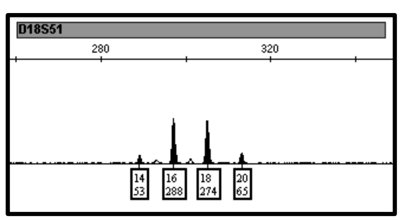
$= 2p_{16}p_{18} \times 1$

$= 2p_{16}p_{18}$

Likelihood Ratio (LR)

D18S51

$p_{14} = 0.134$
$p_{16} = 0.147$
$p_{18} = 0.078$
$p_{20} = 0.018$



$G_{POI} = \{14,20\}$

Denominator:

What is the probability of obtaining these DNA typing results for the crime stain if the POI **is not** a contributor?

Major	Minor
16,18	14,20

$Pr(16,18) \times Pr(14,20)$

$= 2p_{16}p_{18} \times 2p_{14}p_{20}$

$= 4p_{14}p_{16}p_{18}p_{20}$

Likelihood Ratio (LR)

D18S51

$p_{14} = 0.134$
$p_{16} = 0.147$
$p_{18} = 0.078$
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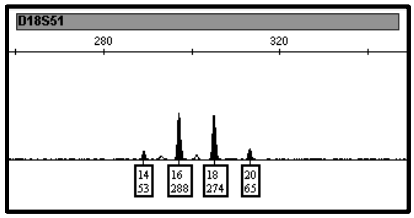


$G_{POI} = \{14{,}20\}$

$$LR = \frac{2p_{16}p_{18}}{4p_{14}p_{16}p_{18}p_{20}}$$

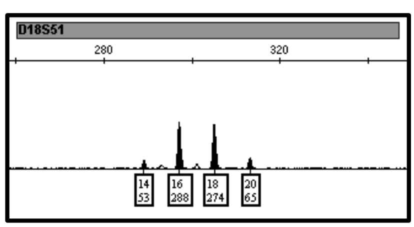
$$= \frac{1}{2p_{14}p_{20}}$$

$$= 207.30$$

Likelihood Ratio (LR)

D18S51

$p_{14} = 0.134$
$p_{16} = 0.147$
$p_{18} = 0.078$
$p_{20} = 0.018$



$G_{POI} = \{14{,}20\}$

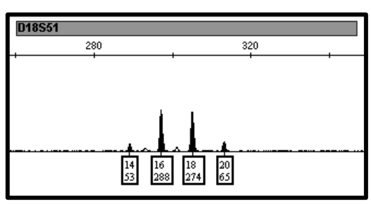
The DNA typing results are 207 times more probable if the DNA came from the person of interest and an unknown contributor than if the DNA came from two unknown contributors.

Unrestricted LR - Peak Heights are ignored

Likelihood Ratio (LR)

D18S51

$p_{14} = 0.134$
$p_{16} = 0.147$
$p_{18} = 0.078$
$p_{20} = 0.018$



$G_{POI} = \{14,20\}$

Numerator:

What is the probability of obtaining these DNA typing results for the crime stain if the POI **is** a contributor and the POI has genotype {14,20}?

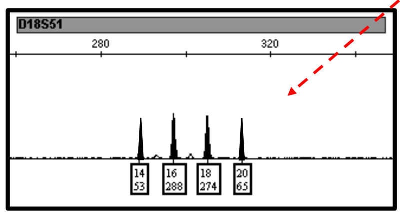
$$Pr(16,18) \times Pr(14,20)$$
$$= 2p_{16}p_{18} \times 1$$
$$= 2p_{16}p_{18}$$

Likelihood Ratio (LR)

Think of it like this!

D18S51

$p_{14} = 0.134$
$p_{16} = 0.147$
$p_{18} = 0.078$
$p_{20} = 0.018$

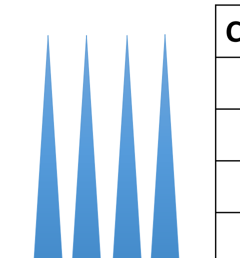


$G_{POI} = \{14{,}20\}$

Denominator:

What is the probability of obtaining these DNA typing results for the crime stain if the POI **<u>is not</u>** a contributor?

Likelihood Ratio



Contributor 1	Contributor 2	
14,16	18,20	$2p_{14}p_{16} \times 2p_{18}p_{20}$
14,18	16,20	$2p_{14}p_{18} \times 2p_{16}p_{20}$
14,20	16,18	$2p_{14}p_{20} \times 2p_{16}p_{18}$
18,20	14,16	$2p_{18}p_{20} \times 2p_{14}p_{20}$
16,20	14,18	$2p_{16}p_{20} \times 2p_{14}p_{18}$
16,18	14,20	$2p_{16}p_{18} \times 2p_{14}p_{20}$

$\sum$

$$= 24p_{14}p_{16}p_{18}p_{20}$$

2) What is the probability of obtaining these DNA typing results if the POI **<u>is not</u>** a contributor?

$$\frac{2p_{16}p_{18}}{24p_{14}p_{16}p_{18}p_{20}} = \frac{1}{12p_{14}p_{20}} = \frac{1}{0.0289}$$

$$= 34.55$$

Restricted LR

$$LR = \frac{2p_{16}p_{18}}{4p_{14}p_{16}p_{18}p_{20}}$$

$$= \frac{1}{2p_{14}p_{20}}$$

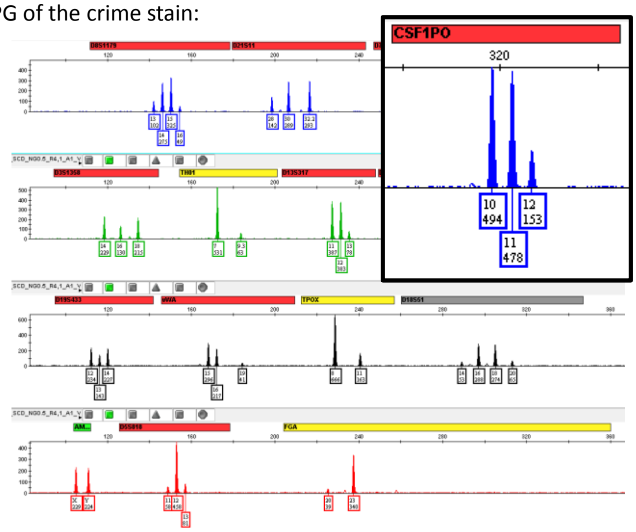
$$= 207.30$$

Unrestricted LR

$$\frac{1}{12p_{14}p_{20}}$$

$$= 34.55$$

EPG of the crime stain:



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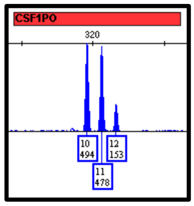
Boston University Mixture (http://www.bu.edu/dnamixtures/): ID_2_SCD_NG0.5_R4,1_A1_V1

Likelihood Ratio (LR)

CSF1PO
$p_{10} = 0.220$
$p_{11} = 0.309$
$p_{12} = 0.360$



$G_{POI} = \{12,12\}$

allele at 12 is ***above*** *the stochastic threshold*

Numerator:

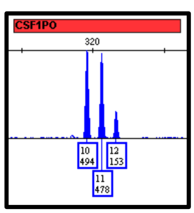
What is the probability of obtaining these DNA typing results for the crime stain if the POI **is** a contributor and the POI has genotype {12,12}?

Major	Minor
10,11	12,12
10,11	10,12
10,11	11,12

$$Pr(10,11) \times Pr(12,12)$$
$$= 2p_{10}p_{11} \times 1$$
$$= 2p_{10}p_{11}$$

Likelihood Ratio (LR)

CSF1PO
$p_{10} = 0.220$
$p_{11} = 0.309$
$p_{12} = 0.360$



$G_{POI} = \{12,12\}$

allele at 12 is ***above*** *the stochastic threshold*

Denominator:

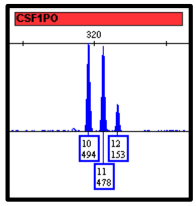
What is the probability of obtaining these DNA typing results for the crime stain if the POI **is not** a contributor?

Major	Minor
10,11	12,12
10,11	10,12
10,11	11,12

Likelihood Ratio (LR)

CSF1PO

$p_{10} = 0.220$
$p_{11} = 0.309$
$p_{12} = 0.360$



$G_{POI} = \{12{,}12\}$

*allele at 12 is **above** the stochastic threshold*

Denominator:

$$Pr(10{,}11) \times Pr(12{,}12) + Pr(10{,}11) \times Pr(10{,}12) + Pr(10{,}11) \times Pr(11{,}12)$$

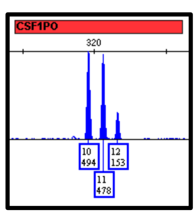
Major	Minor
10,11	12,12
10,11	10,12
10,11	11,12

$$= 2p_{10}p_{11} \times p_{12}^2 + 2p_{10}p_{11} \times 2p_{10}p_{12}$$
$$+2p_{10}p_{11} \times 2p_{11}p_{12}$$
$$= 2p_{10}p_{11}p_{12}(p_{12} + 2p_{10} + 2p_{11})$$

Likelihood Ratio (LR)

CSF1PO

$p_{10} = 0.220$
$p_{11} = 0.309$
$p_{12} = 0.360$



$G_{POI} = \{12{,}12\}$

*allele at 12 is **above** the stochastic threshold*

$$LR = \frac{2p_{10}p_{11}}{2p_{10}p_{11}p_{12}(p_{12} + 2p_{10} + 2p_{11})}$$

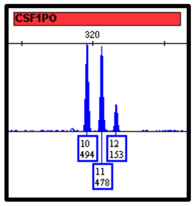
$$= \frac{1}{p_{12}(p_{12} + 2p_{10} + 2p_{11})}$$

$$= 1.96$$

Likelihood Ratio (LR)

CSF1PO

$p_{10} = 0.220$
$p_{11} = 0.309$
$p_{12} = 0.360$

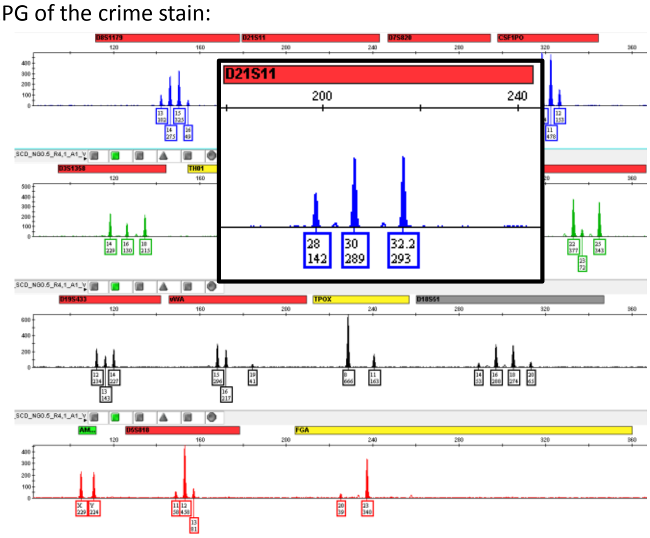


$G_{POI} = \{12,12\}$

allele at 12 is ***above*** *the stochastic threshold*

The DNA typing results are about 2 times more probable if the DNA came from the person of interest and an unknown contributor than if the DNA came from two unknown contributors.

EPG of the crime stain:



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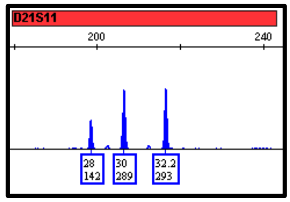
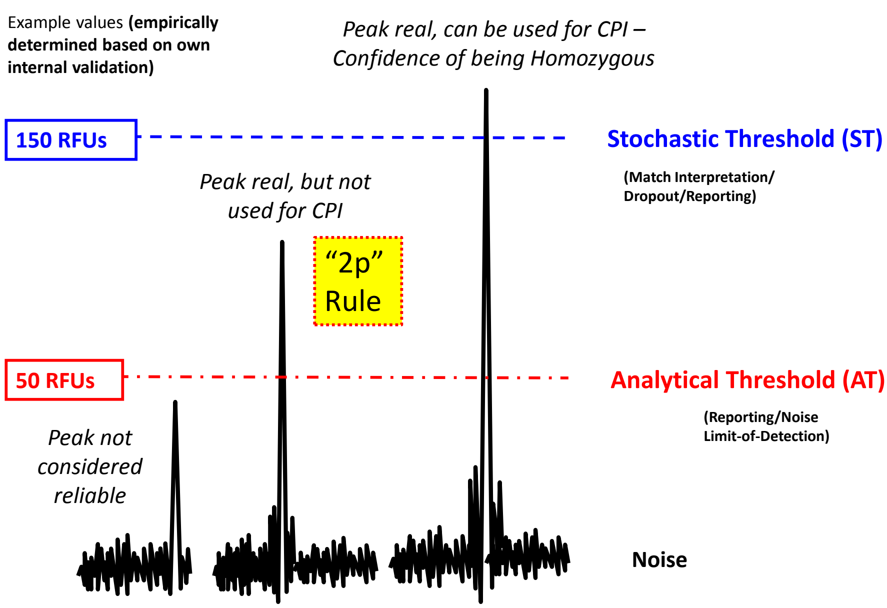


Allele 28 is ***below*** *the stochastic threshold*

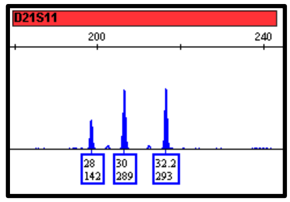
Different Thresholds Used with CE Data



Likelihood Ratio (LR)

D21S11

$p_{28} = 0.159$
$p_{30} = 0.283$
$p_{32.2} = 0.090$



*Allele 28 is **below** the stochastic threshold*

$G_{POI} = \{28,28\}$

Numerator:

What is the probability of obtaining these DNA typing results for the crime stain if the POI **is** a contributor and the POI has genotype {28,28}?

Major	Minor
30,32.2	28,F

$$Pr(30,32.2) \times Pr(28,F)$$
$$= 2p_{30}p_{32.2} \times 1$$
$$= 2p_{30}p_{32.2}$$

"2p" or $p^2 + 2p(1-p)$

Likelihood Ratio (LR)

D21S11

$p_{28} = 0.159$
$p_{30} = 0.283$
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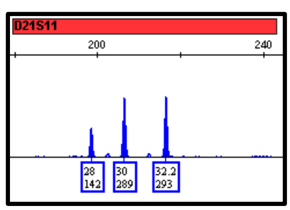


*Allele 28 is **below** the stochastic threshold*

$G_{POI} = \{28,28\}$

Denominator:

What is the probability of obtaining these DNA typing results for the crime stain if the POI **is not** a contributor?

Major	Minor
30,32.2	28,F

$$Pr(30,32.2) \times Pr(28,F)$$
$$= 2p_{30}p_{32.2} \times [2p_{28}(1 - p_{28}) + p_{28}^2]$$
$$= 2p_{30}p_{32.2}(2p_{28} - p_{28}^2)$$

"2p" or $p^2 + 2p(1-p)$

Derivation of the 2p Rule

- Two ways to think of it… (easy)

$$2pq \longrightarrow 2p\color{red}{q} \longrightarrow 2p$$

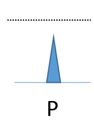
"2p" or $p^2 + 2p(1-p)$

Derivation of the 2p Rule

- Two ways to think of it… (mathematical)

5 allele system - P Q R S T

"P" is below ST



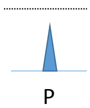
ANY genotype with a "P" allele cannot be excluded

PP PQ PR PS PT

"2p" or $p^2 + 2p(1-p)$

5 allele system - P Q R S T

"P" is below ST



ANY genotype with a "P" allele cannot be excluded

PP PQ PR PS PT

$$\text{Prob} = p^2 + 2pq + 2pr + 2ps + 2pt$$

$$\text{Prob} = p^2 + 2p(q + r + s + t)$$

$$\text{Prob} = p^2 + 2p(1-p)$$

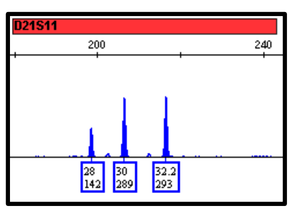
$$\text{Prob} = p^2 + 2p - 2p^2$$

$$\text{Prob} = 2p - p^2$$

Likelihood Ratio (LR)

D21S11

$p_{28} = 0.159$
$p_{30} = 0.283$
$p_{32.2} = 0.090$



Allele 28 is ***below*** *the stochastic threshold*

$G_{POI} = \{28,28\}$

$$LR = \frac{2p_{30}p_{32.2}}{2p_{30}p_{32.2}(2p_{28} - p_{28}^2)}$$

$$= \frac{1}{(2p_{28} - p_{28}^2)}$$

$$= 3.42$$

What does a $LR \approx 3$ mean?

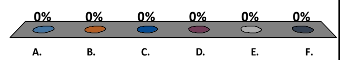
A. The person of interest committed the crime.

B. A total of 3 peaks were observed at this locus.

C. It is about 3 times more probable that the DNA came from the person of interest and an unknown contributor than that the DNA came from two unknown contributors.

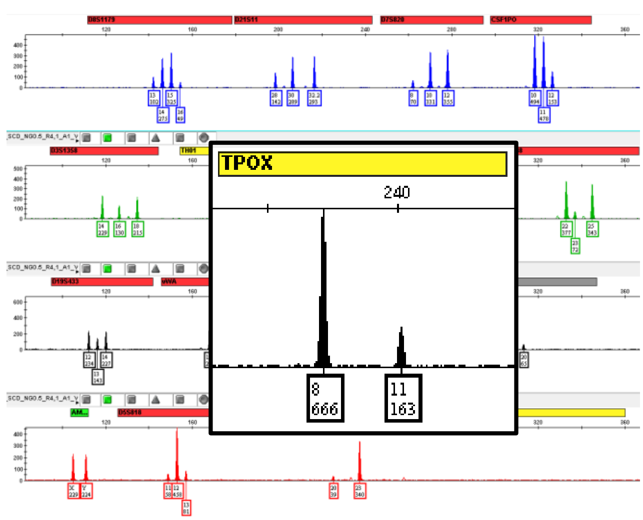
D. There are 3 contributors to this DNA mixture.

E. The DNA typing results are about 3 times more probable if the DNA came from the person of interest and an unknown contributor than if the DNA came from two unknown contributors.



Response Counter

EPG of the crime stain:

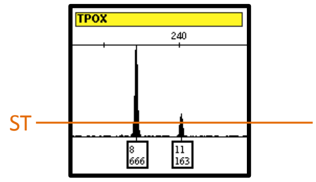


Person of interest (POI)	
D8	13,16
D21	28,28
D7	8,12
CSF1PO	12,12
D3	16,16
TH01	7,9.3
D13	12,13
D16	12,13
D2	23,25
D19	13,13
vWA	15,19
TPOX	11,11
D18	14,20
D5	11,13
FGA	20,28

Boston University Mixture (http://www.bu.edu/dnamixtures/): ID_2_SCD_NG0.5_R4,1_A1_V1

Likelihood Ratio (LR)

TPOX
$p_8 = 0.525$
$p_{11} = 0.252$



*The peak at 11 is **above** the stochastic threshold.*

$G_{POI} = \{11,11\}$

Numerator:

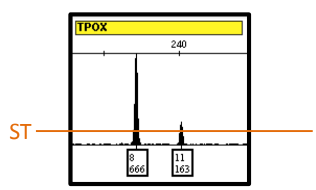
What is the probability of obtaining these DNA typing results for the crime stain if the POI **is** a contributor and the POI has genotype {11,11}?

Major	Minor
8,8	11,11
8,8	8,11

$$Pr(8,8) \times Pr(11,11)$$
$$= \cdots$$

Likelihood Ratio (LR)

TPOX
$p_8 = 0.525$
$p_{11} = 0.252$



*The peak at 11 is **above** the stochastic threshold.*

$G_{POI} = \{11,11\}$

Denominator:

What is the probability of obtaining these DNA typing results for the crime stain if the POI **is not** a contributor?

Major	Minor
8,8	11,11
8,8	8,11

$$Pr(8,8) \times Pr(11,11) + Pr(8,8) \times Pr(8,11)$$
$$= \cdots$$

What is the likelihood ratio?

A. $\frac{p_8^2}{p_8^2(p_{11}^2+2p_8p_{11})} = \frac{1}{p_{11}(p_{11}+2p_8)}$

B. $\frac{1}{p_{11}+2p_8}$

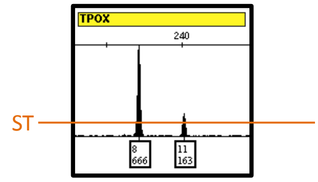
C. 1

D. $\frac{1}{2p_8p_{11}}$

E. $\frac{1}{p_{11}^2}$

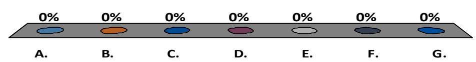
F. infinity

G. ???



*The peak at 11 is **above** the stochastic threshold.*

Response Counter

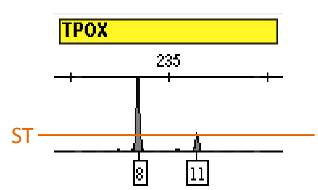


Likelihood Ratio (LR)

TPOX

$p_8 = 0.525$

$p_{11} = 0.252$



$G_{POI} = \{11,11\}$

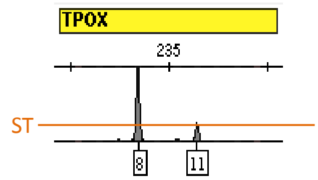
$= 3.05$

Likelihood Ratio (LR)

TPOX

$p_8 = 0.525$

$p_{11} = 0.252$



$G_{POI} = \{11,11\}$

The DNA typing results are about 3 times more probable if the DNA came from the person of interest and an unknown contributor than if the DNA came from two unknown contributors.

Likelihood Ratio (LR) for all loci

H_p: The DNA came from the POI and an unknown contributor.

H_d: The DNA came from two unknown contributors.

If H_p is true, is the POI the major contributor or the minor contributor?

If H_p is true, the POI could be either the major contributor or the minor contributor. Let us consider these possibilities to be equally probable. So if H_p is true, there is a probability of $\frac{1}{2}$ that the POI is the major contributor and a probability of $\frac{1}{2}$ that the POI is the minor contributor.

We can only observe these DNA typing results if the POI is the minor contributor.

D18S51:

Major	Minor
16,18	14,20

$G_{POI} = \{14,20\}$

CSF1PO:

Major	Minor
10,11	12,12
10,11	10,12
10,11	11,12

$G_{POI} = \{12,12\}$

D21S11:

Major	Minor
30,32.2	28,F

$G_{POI} = \{28,28\}$

TPOX:

Major	Minor
8,8	11,11
8,8	8,11

$G_{POI} = \{11,11\}$

Likelihood Ratio (LR) for all loci

H_p: The DNA came from the POI and an unknown contributor.

H_d: The DNA came from two unknown contributors.

Numerator:

Because these DNA typing results are only possible when the POI is the minor contributor, and the POI is the minor contributor with a probability of $\frac{1}{2}$, we multiply the numerator of the likelihood ratio for the entire profile by $\frac{1}{2}$.

Locus	Likelihood Ratio
D8S1179	3.66
D21S11	3.42
D7S820	3.74
CSF1PO	1.96
D3S1358	2.39
TH01	1.75
D13S317	4.58
D16S539	1.89
D2S1338	5.03
D19S433	1.29
vWA	1
TPOX	3.05
D18S51	207.30
D5S818	3.77
FGA	1

Likelihood Ratio (LR)

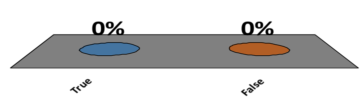
All Loci: $\boldsymbol{LR = 2.5 \times 10^{7}}$

True or false?

A likelihood ratio of $\mathbf{2.5 \times 10^{7}}$ means that it is $\mathbf{2.5 \times 10^{7}}$ times more probable that the DNA came from the person of interest and an unknown contributor than that the DNA came from two unknown contributors.

A. True
B. False

Response Counter



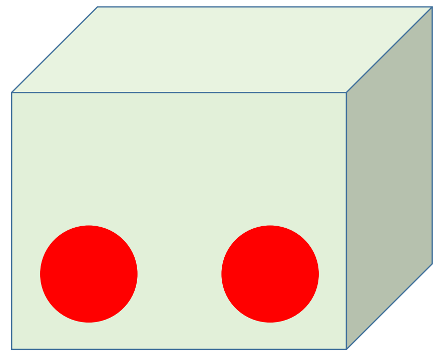
Likelihood Ratio (LR)

$$LR = 2.5 \times 10^{7} = 25\ million$$

The DNA typing results are about 25 million times more probable if the DNA came from the person of interest and an unknown contributor than if the DNA came from two unknown contributors.

Factor of 2

Suppose…

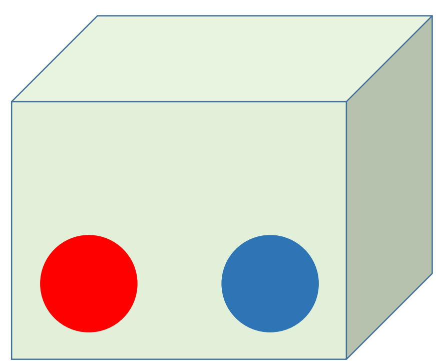


What is the probability you will randomly pick a red marble?

Pr(picking left) x Pr(left is red) + Pr(picking right) x Pr(right is red)

0.5 x 1 + 0.5 x 1
= 1

Suppose…



What is the probability you will randomly pick a red marble?

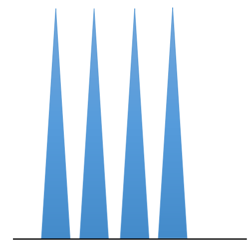
Pr(picking left) x Pr(left is red) + Pr(picking right) x Pr(right is red)

0.5 x 1 + 0.5 x 0
= 0.5

Now Suppose…

person of interest (POI)

{A, B}



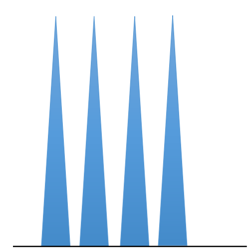
A B C D

Hp: POI and someone else

Hd: DNA came from 2 unknowns

person of interest (POI)

{A, B}



A B C D

	Contributor 1	Contributor 2	probability of peaks in crime stain EPG if H_p is true	probability of peaks in crime stain EPG if H_d is true
1	AB	CD	$1 \times 2p_C p_D$	$2p_A p_B \times 2p_C p_D$
2	AC	BD	0	$2p_A p_C \times 2p_B p_D$
3	AD	BC	0	$2p_A p_D \times 2p_B p_C$
4	BC	AD	0	$2p_B p_C \times 2p_A p_D$
5	BD	AC	0	$2p_B p_D \times 2p_A p_C$
6	CD	AB	$2p_C p_D \times 1$	$2p_C p_D \times 2p_A p_B$

Only 2 genotype combinations are possible for Hp

	Contributor 1	Contributor 2	probability of peaks in crime stain EPG if H_p is true	probability of peaks in crime stain EPG if H_d is true
1	AB	CD	$1 \times 2p_C p_D$	$2p_A p_B \times 2p_C p_D$
2	AC	BD	0	$2p_A p_C \times 2p_B p_D$
3	AD	BC	0	$2p_A p_D \times 2p_B p_C$
4	BC	AD	0	$2p_B p_C \times 2p_A p_D$
5	BD	AC	0	$2p_B p_D \times 2p_A p_C$
6	CD	AB	$2p_C p_D \times 1$	$2p_C p_D \times 2p_A p_B$

Hp

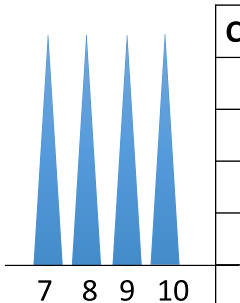
Row 1 - $0.5 \times 1 \times 2p_c p_d$

Row 6 - $0.5 \times 2p_c p_d \times 1$

$$= 0.5 \times 1 \times 2p_c p_d + 0.5 \times 2p_c p_d \times 1$$

$$= 2p_c p_d$$

For the H_d (recall this?)



Contributor 1	Contributor 2	
7,8	9,10	$2p_7p_8 \times 2p_9p_{10}$
7,9	8,10	$2p_7p_9 \times 2p_8p_{10}$
7,10	8,9	$2p_7p_{10} \times 2p_8p_9$
8,9	7,10	$2p_8p_9 \times 2p_7p_{10}$
8,10	7,9	$2p_8p_{10} \times 2p_7p_9$
9,10	7,8	$2p_9p_{10} \times 2p_7p_8$

$\sum$

$$= 24p_7p_8p_9p_{10}$$

2) What is the probability of obtaining these DNA typing results if the POI **<u>is not</u>** a contributor?

Likelihood Ratio

$$\frac{2p_c p_d}{24p_a p_b p_c p_d} = \frac{1}{12p_a p_b}$$

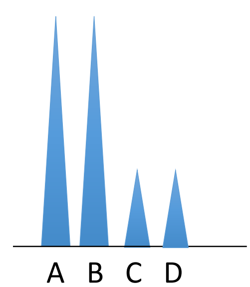
This is like the box with 2 red marbles: 0.5 + 0.5 = 1 in the numerator

Anytime you have a “mirror image” for the numerator, there is no factor of 0.5 (or factor of 2 in the denominator)

Now Suppose…

person of interest (POI)

{A, B}



Hp: POI and someone else

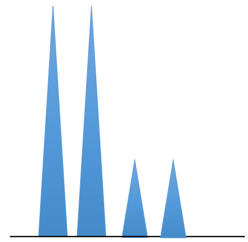
Hd: DNA came from 2 unknowns

person of interest (POI)

{A, B}

Hp: POI and someone else

Hd: DNA came from 2 unknowns



	Contributor 1 (MAJOR)	Contributor 2 (MINOR)	probability of peaks in crime stain EPG if H_p is true	probability of peaks in crime stain EPG if H_d is true
1	AB	CD	$1 \times 2p_Cp_D$	$2p_Ap_B \times 2p_Cp_D$
2	AC	BD	0	0
3	AD	BC	0	0
4	BC	AD	0	0
5	BD	AC	0	0
6	CD	AB	0	0

	Contributor 1 (MAJOR)	Contributor 2 (MINOR)	probability of peaks in crime stain EPG if H_p is true	probability of peaks in crime stain EPG if H_d is true
1	AB	CD	$1 \times 2p_Cp_D$	$2p_Ap_B \times 2p_Cp_D$
2	AC	BD	0	0
3	AD	BC	0	0
4	BC	AD	0	0
5	BD	AC	0	0
6	CD	AB	0	0

$$Hp = 0.5 \times 1 \times 2p_c p_d = 0.5 \times 2p_c p_d$$

$$Hd = 2p_a p_b \times 2p_c p_d$$

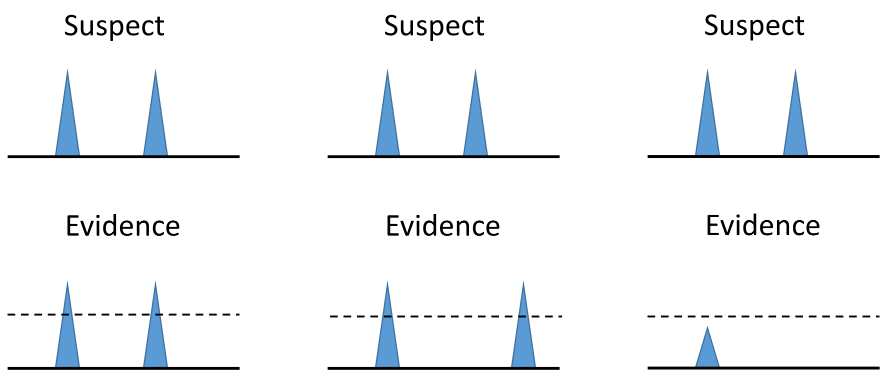
Likelihood Ratio

$$\frac{0.5 \times 2p_c p_d}{4p_a p_b p_c p_d} = \frac{0.5}{2p_a p_b} = \frac{1}{4p_a p_b}$$

This is like the box with 1 red, 1 blue marble: 0.5 (left)+ 0.5 (right)

Therefore, a factor of 0.5 appears in the numerator
(or factor of 2 in the denominator)

So - why do we even need probabilistic genotyping?

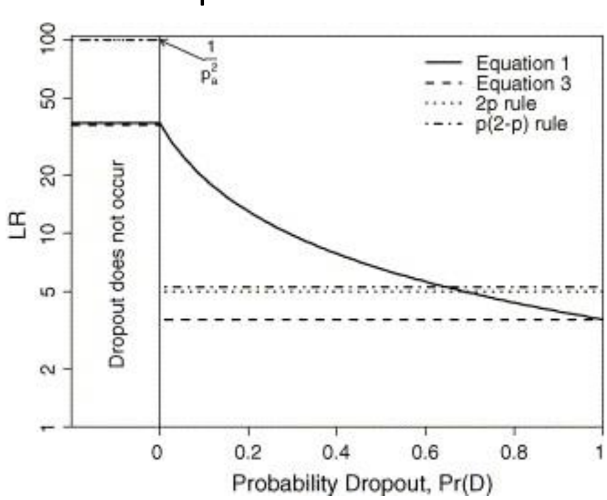


$$LR = \frac{1}{2pq} \qquad LR = \frac{0}{2pq} \qquad LR = \frac{?}{2pq}$$

The Binary LR approach

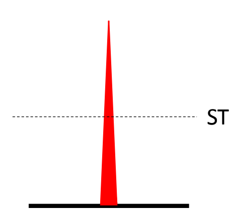
"2p"

The "2p" Rule



Stain = AA

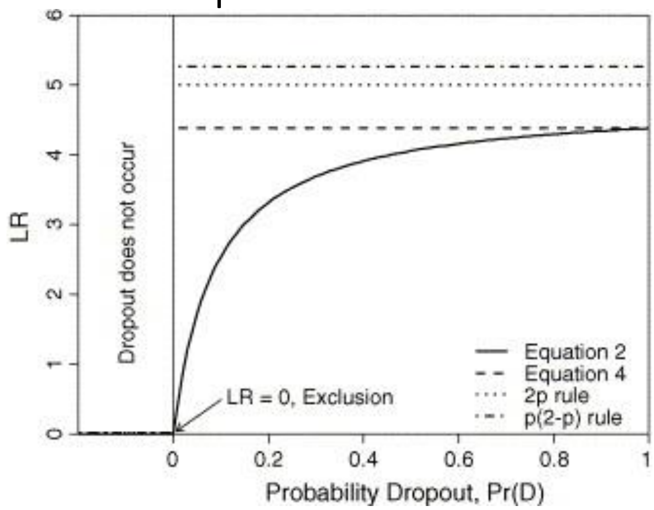
Suspect = AA



LR = 100

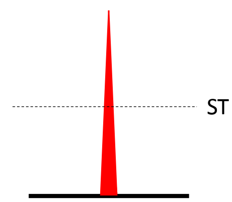
f(a) = 0.10 $1/p^2 = 100$ $1/2p = 5$

The "2p" Rule



Stain = AA

Suspect = AB



Exclusion

f(a) = 0.10   1/2p = 5

Whatever way uncertainty is approached, probability is the *only* sound way to think about it.

-Dennis Lindley