

Roughness + Curviness

Two geometric attributes to classify IPF and general airways

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Goals

- Characterize airways into 4 categories autonomously
- Give information on an entire core quickly
- Give a consistent mathematical description of the shape of airways for numerical comparison

roughness

B

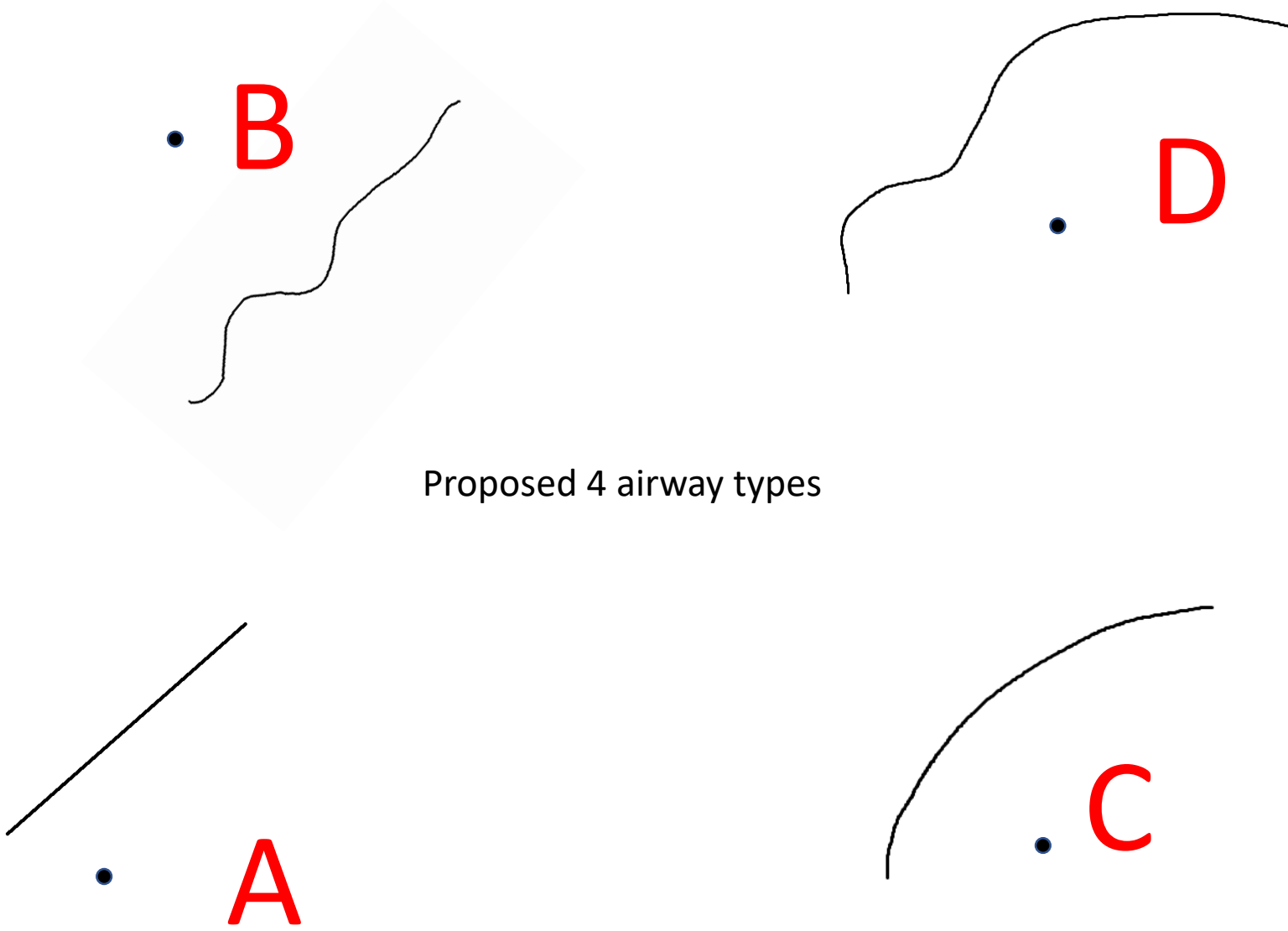
D

Proposed 4 airway types

A

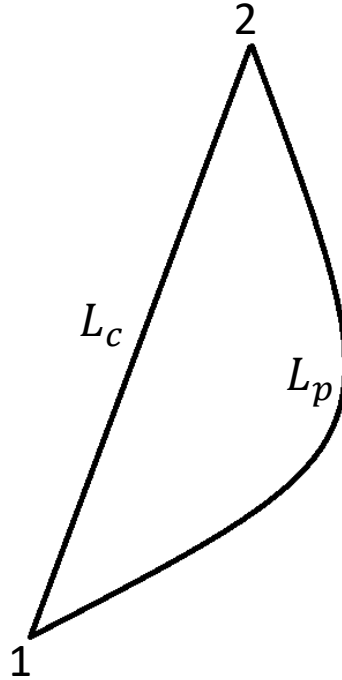
C

curviness



Could we use Tortuosity to characterise airways?

- $T = L_p/L_c$



Path 1- \rightarrow 2

$$T = \frac{L_p}{L_c} = 1.3$$

Tortuosity could indicate roughness or curviness

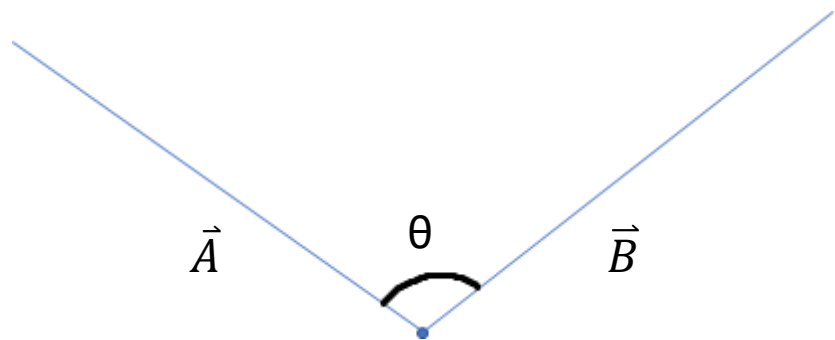
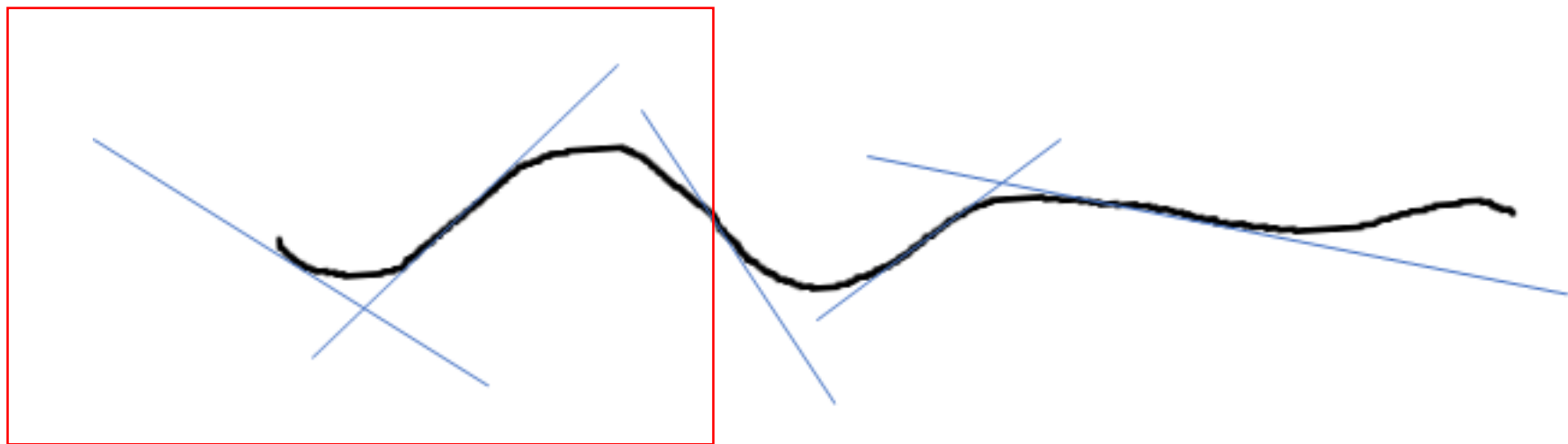


Tortuosity #1 = Tortuosity #2

A new metric for roughness



Comparing direction of tangent lines of neighbors regions, split into sizes of 7 voxels

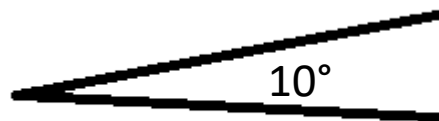


$$\cos \theta = \frac{\vec{A} \odot \vec{B}}{|\vec{A}| * |\vec{B}|}$$

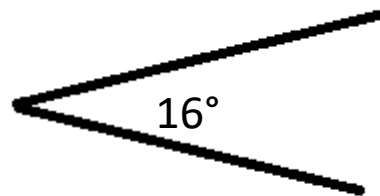
$$\textit{roughness} = 1 - (\cos \theta)^7$$



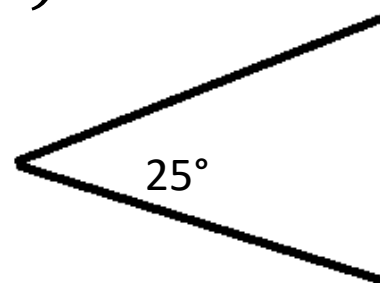
Roughness=0



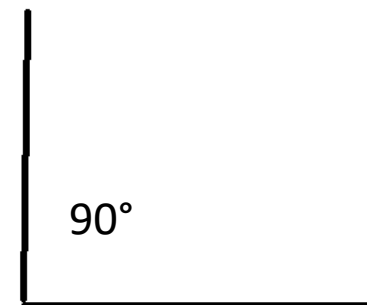
Roughness=0.1



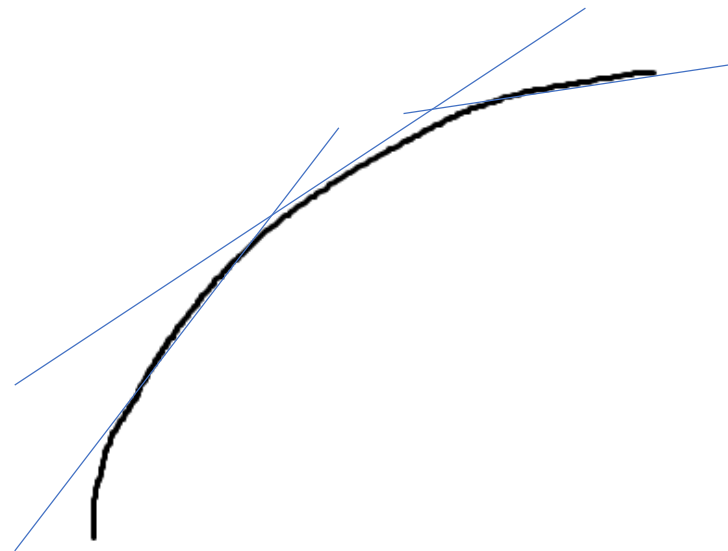
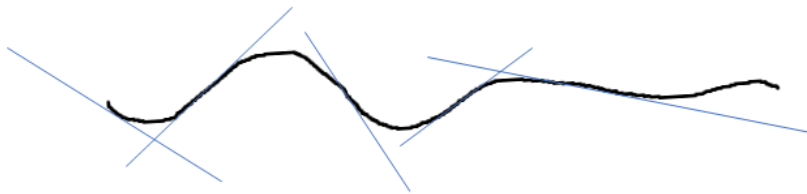
Roughness=0.25



Roughness=0.5



Roughness=1



Roughness #1 >> roughness #2

Determining a second metric for curviness

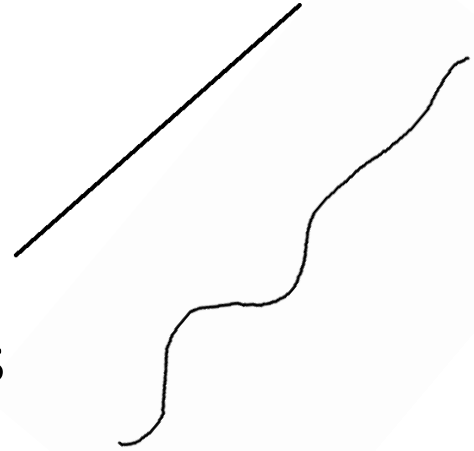
$$\text{Roughness} = 1 - \text{mean}((\cos\theta)^5)$$

- Experimentation provides justification for original equation
- Curviness = tortuosity – 1 – (C * roughness)
- Could we determine the equation with less initial assumptions?

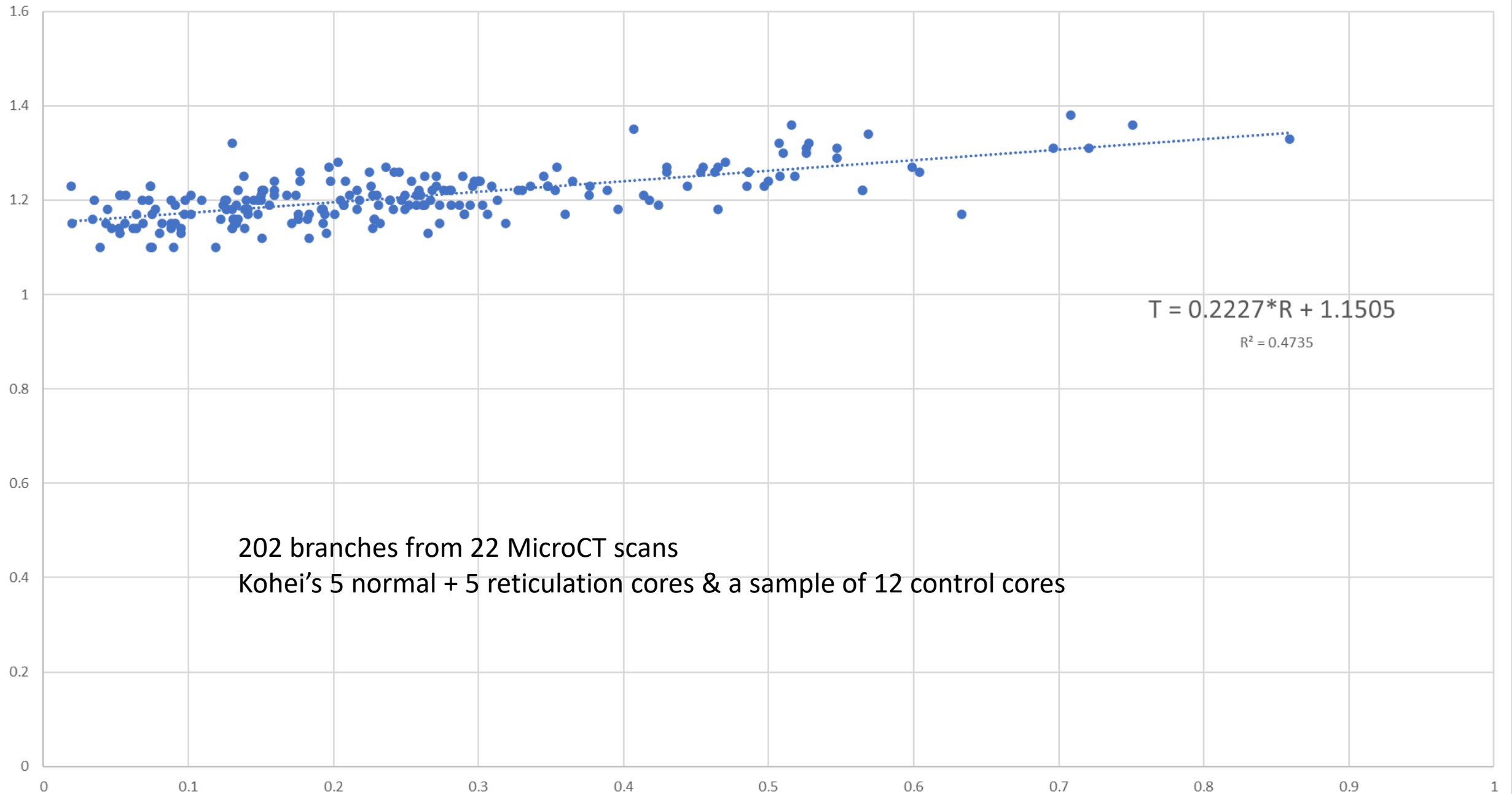
- Curviness = tortuosity – 1 – (C * roughness)
- $C = T - f(R)$; C -> Curviness T -> Tortuosity R -> roughness
- I guessed $f(R) = 1 - C * R$ but can we find it experimentally
- Unfortunately $f(R)$ is dependant on both T and C

Straight airways curviness should be 0

- $C = T - f(R)$; $C \rightarrow$ Curviness $T \rightarrow$ Tortuosity $R \rightarrow$ roughness
- For straight airways $C=0$ so $T=f(R)$
- Once we determine $f(R)$ we can write $C=T-f(R)$ for all airways using the equation determined using straight airway data
- Thankfully the data produced a linear fit with an easy explanation



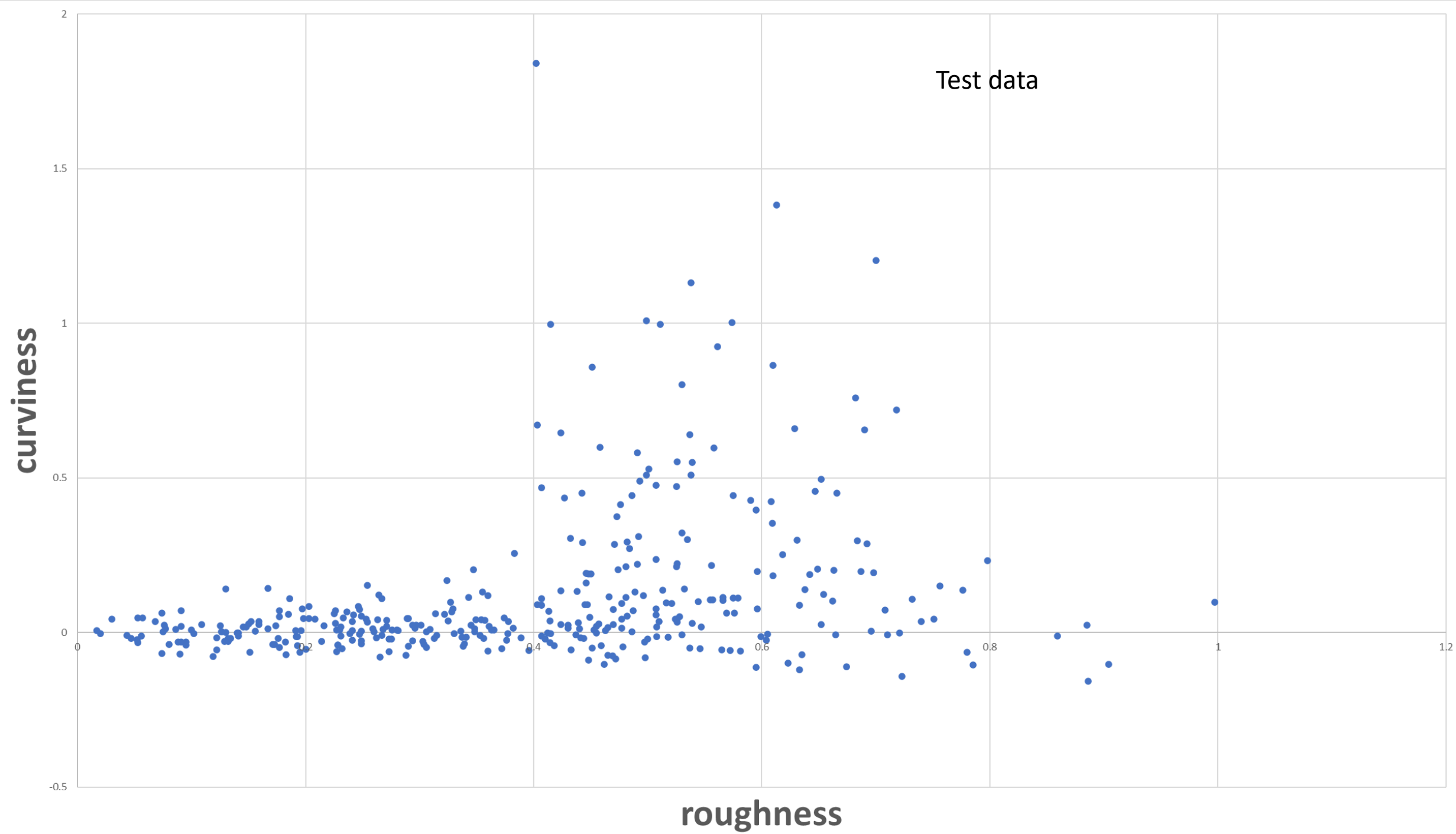
Tortousity vs. Roughness



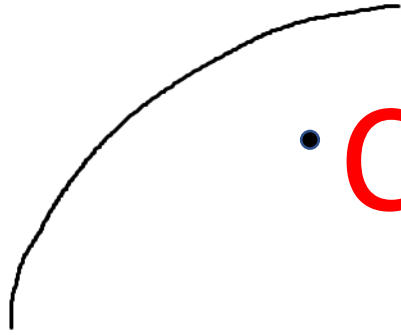
results

- $T = 0.223 * R + 1.15$
- $C = T - 1.15 - 0.223 * R$ vs. previously $C = T - 1 - 0.2 * R$ from experimentation
- Coefficient of roughness is reasonable and explained by roughness adding to path length
- 1.15 implies constant overcalculation of tortuosity
- Straight and smooth airways should have tortuosity of 1 because they are straight lines but are being measured at higher tortuosity
- Attributed to the pixelation of skeletonization

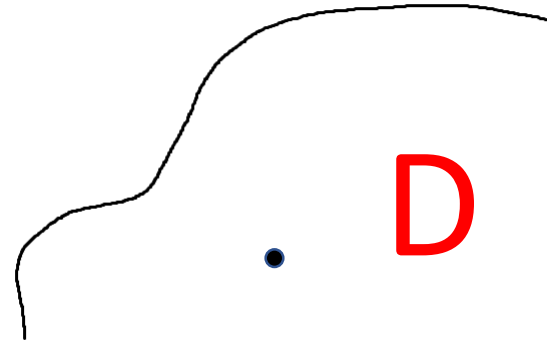




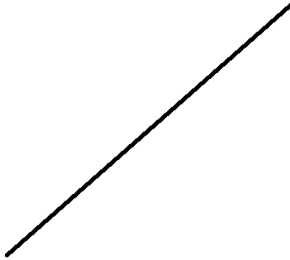
curviness



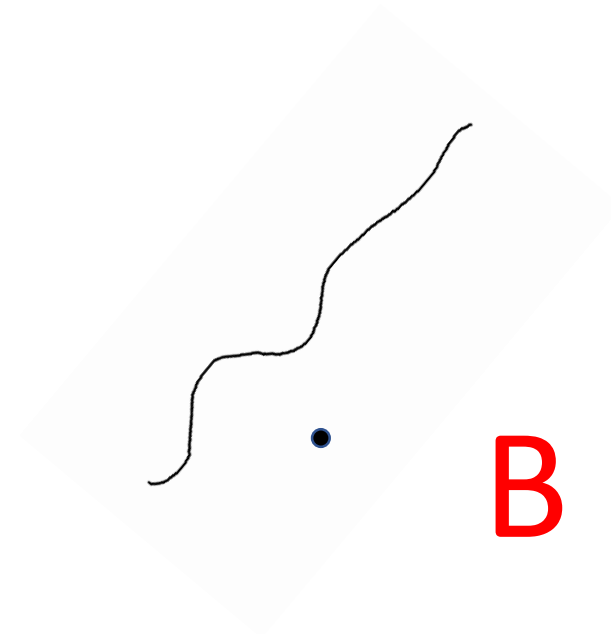
C



D



A



B

roughness



A

Roughness = 0.083
Curviness = 0.091

B

Roughness = 0.607
Curviness = -0.005

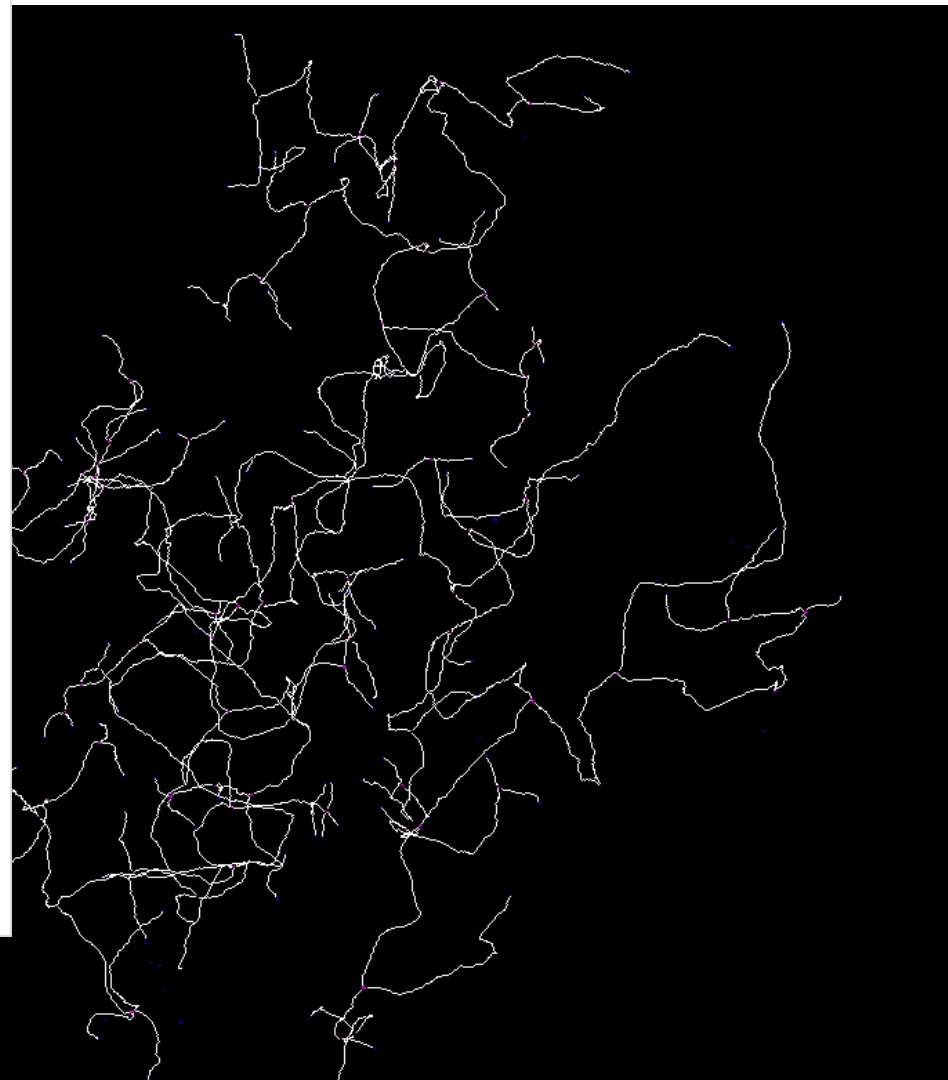
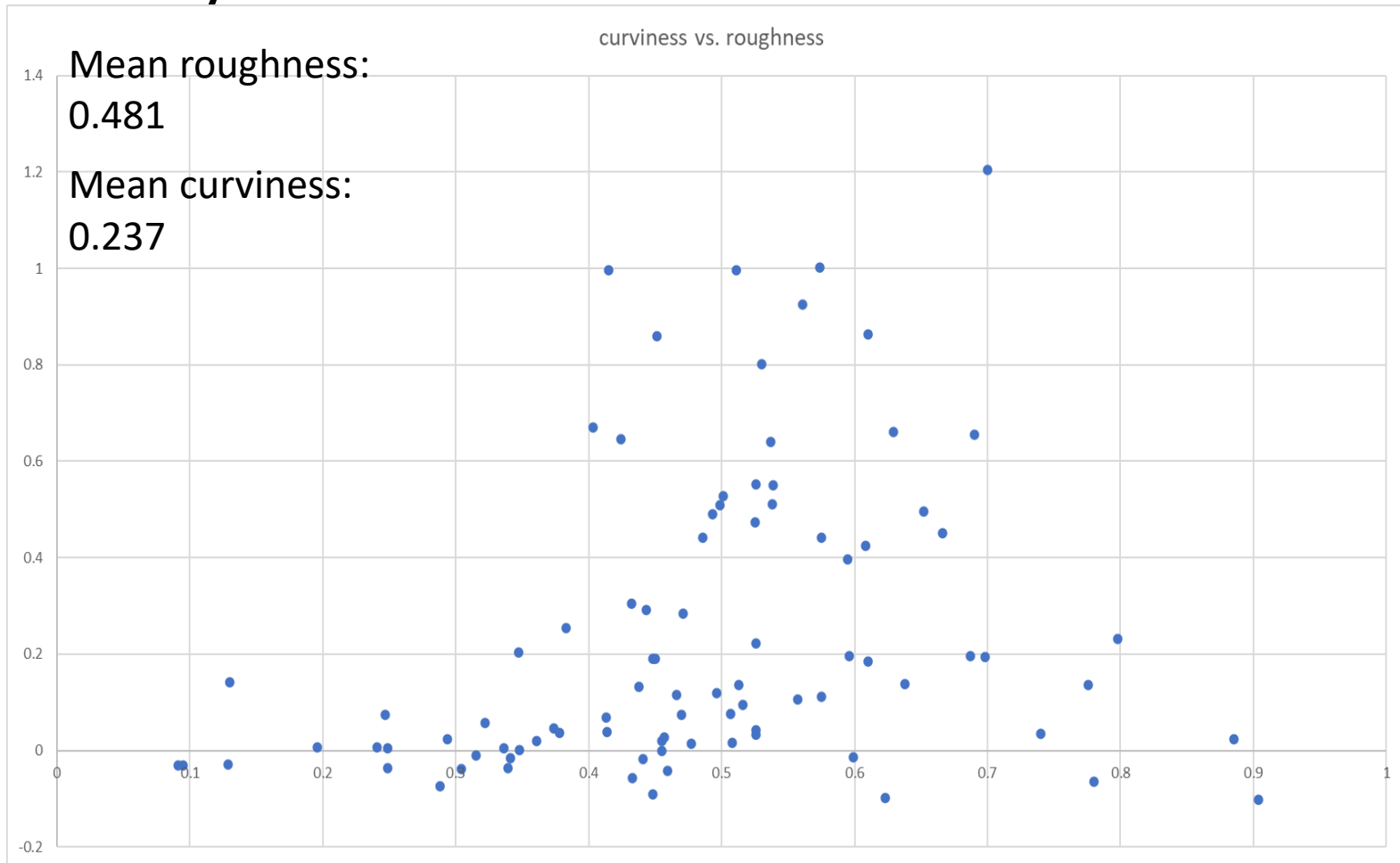
C

Roughness = 0.29
Curviness = 0.275

D

Roughness = 0.634
Curviness = 0.219

Data for reticulation and ginger root(rough) airway 7352-7817



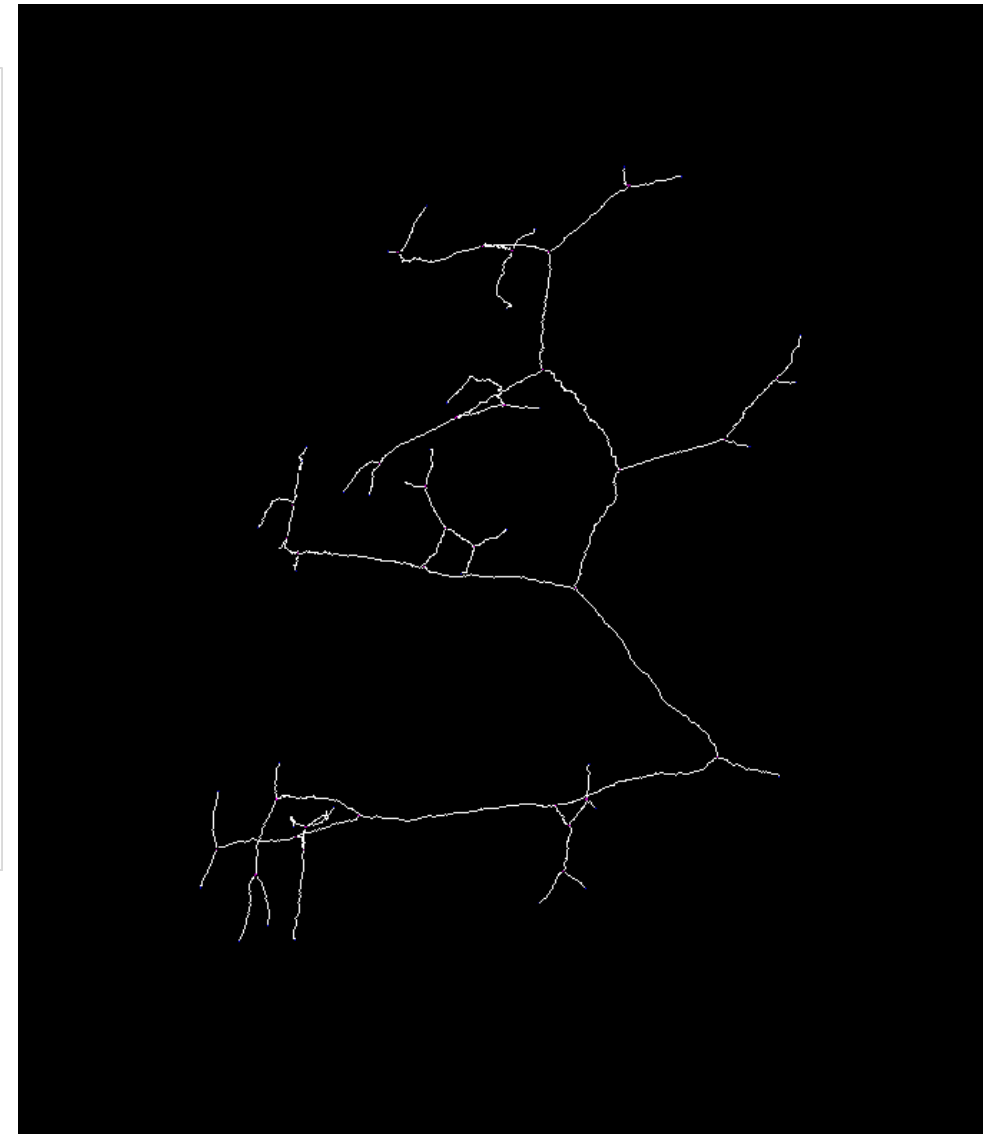
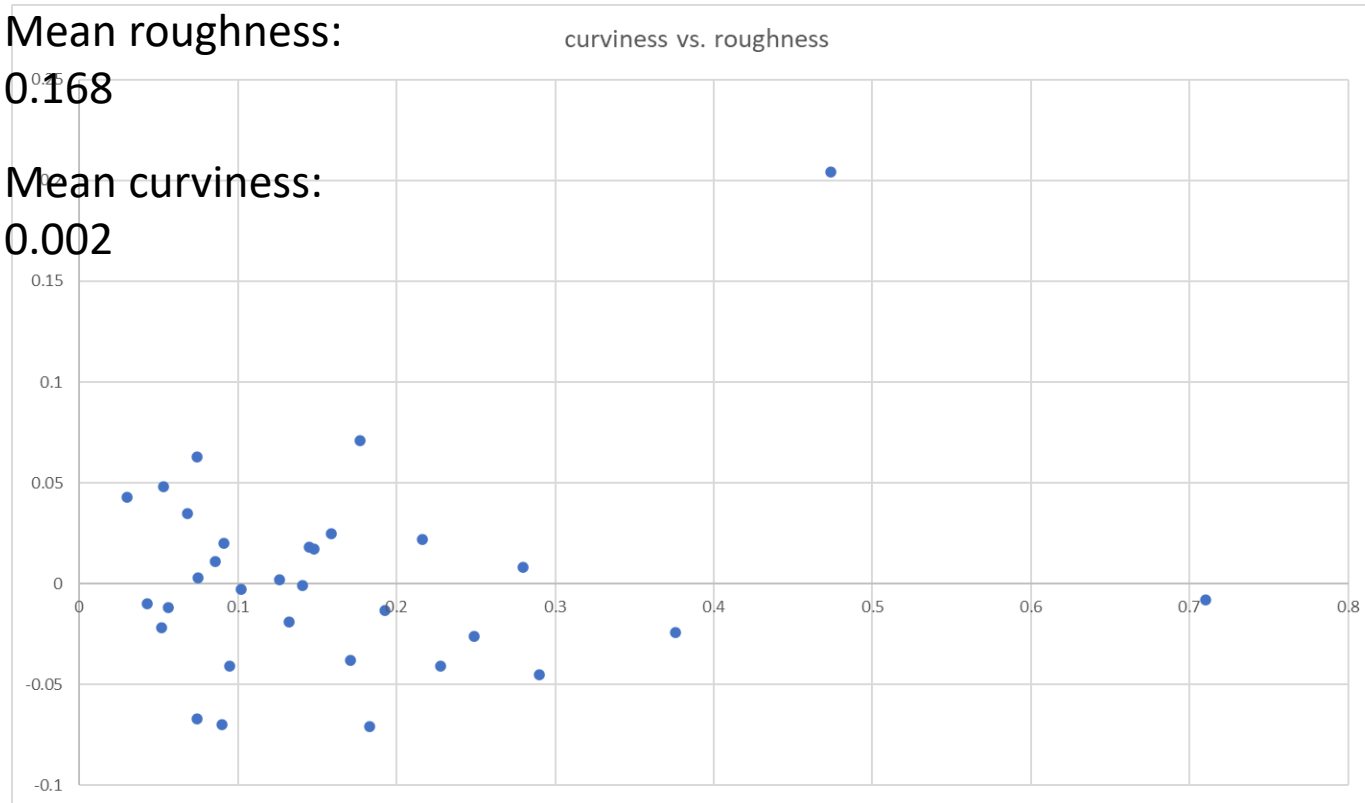
Data for normal marked airway 7357-7794

Mean roughness:

0.168

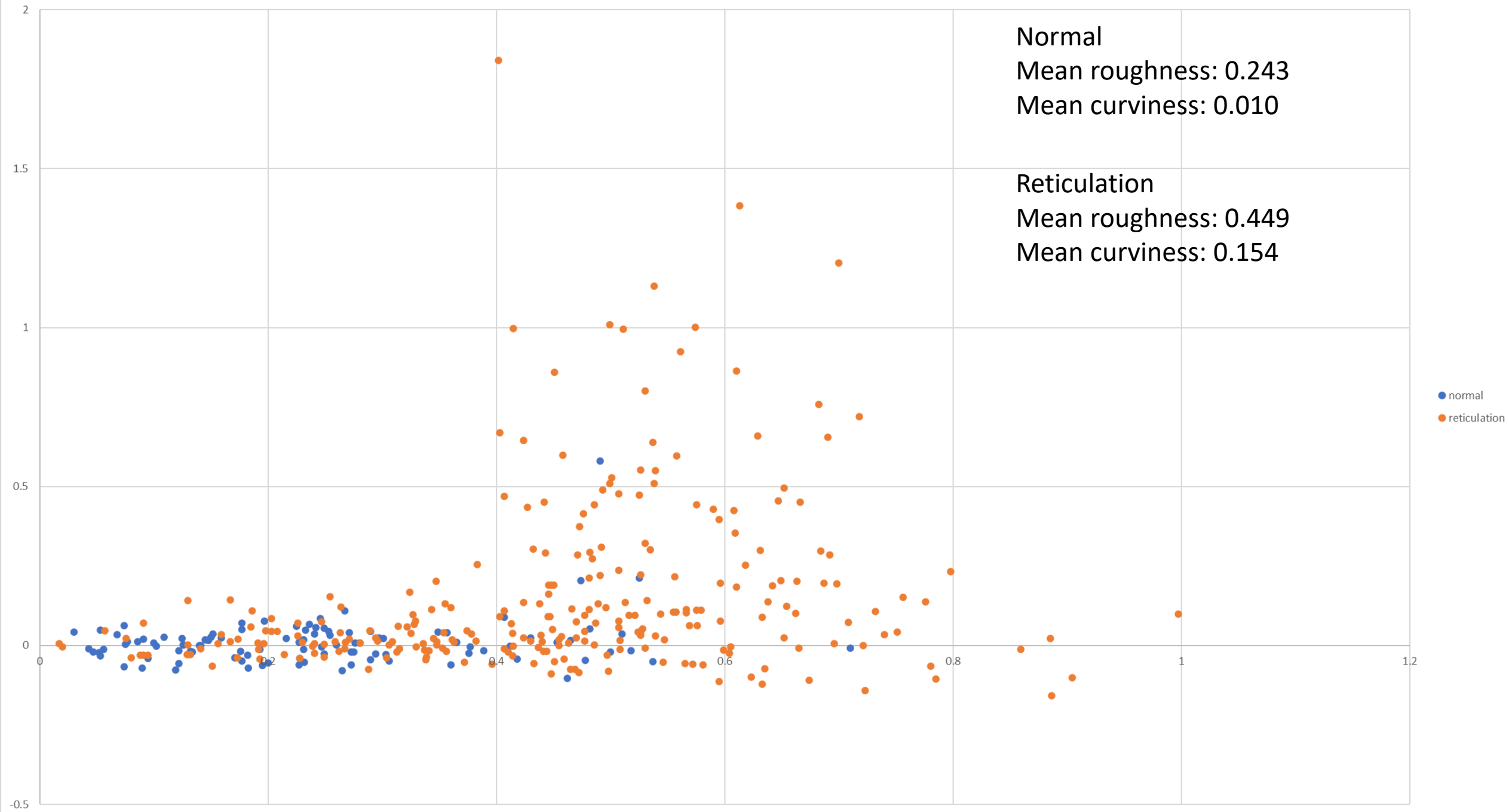
Mean curviness:

0.002

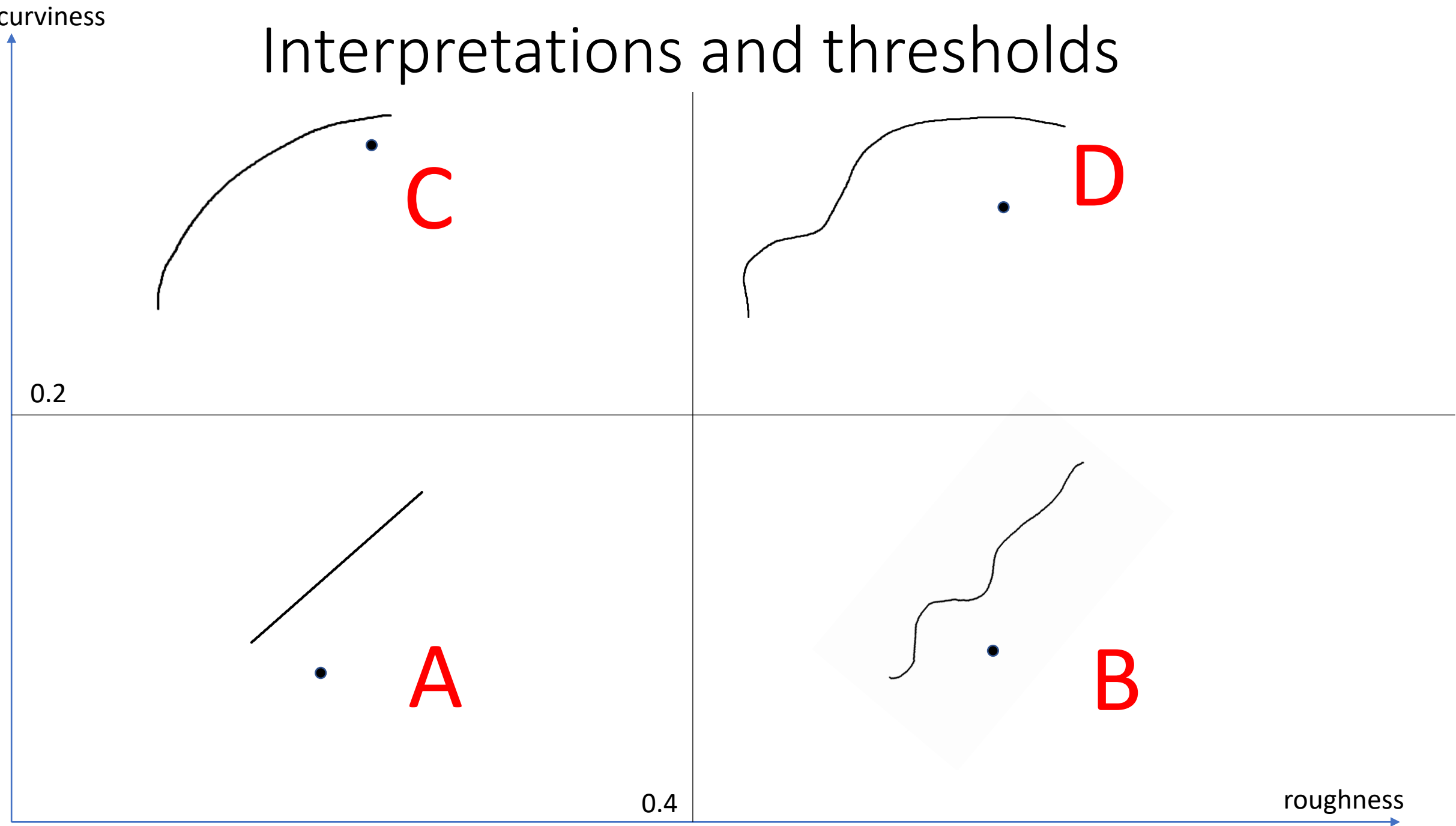


All five reticulation & normal cores

curviness vs. roughness



Interpretations and thresholds



A

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Curviness = 0.091

B

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Curviness = -0.005

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D

Roughness = 0.634
Curviness = 0.219

references

- M. D. Jones and J. Long, "Tortuosity as a metric for evaluating branch motion paths under dynamic loading," 2012 IEEE 4th International Symposium on Plant Growth Modeling, Simulation, Visualization and Applications, Shanghai, 2012, pp. 172-179.