# Problem ~~1~~ 1: Cell Migration

Calculations:

$Path\ length\ (um) = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$ for each time interval. Sum over total time for total path length.

$Speed\ (\frac{um}{\min}) = path\ length/time$ for each time interval. Average over all time intervals.

$MSD = abs(x_f - x_0)^2 + abs(y_f - y_0)^2$ where f denotes the final time point and 0 denotes the initial time point.

→ mean squared displacement

$Displacement\ (um) = \sqrt{(x_f - x_0)^2 + (y_f - y_0)^2}$ where f denotes the final time point and 0 denotes the initial time point.

$MSD = 2S^2P\left(t - P\left(1 - e^{t/P}\right)\right)$

$CI = Displacement/Path\ length$

See Excel spreadsheet for answers.

Persistence time. Use

Will need to use

A) Solver, or

B) Excel Goal Seek (Iterative Method)

Speed: known (calculated earlier)

MSD: known (can be calculated)

Fix these, solve for P.

**Cell 1**

| x | y | Path Length (um) | Speed (um/min) |
|---|---|---|---|
| 91.23 | 12.42 | | |
| 86.07 | 3.24 | 10.53081193 | 0.702054129 |
| 102.84 | -4.92 | 18.64989276 | 1.243326184 |
| 109.29 | 1.2 | 8.891394716 | 0.592759648 |
| 119.61 | 18.54 | 20.17865209 | 1.345243472 |
| 117.03 | -1.86 | 20.56249985 | 1.370833323 |
| 115.74 | 0.18 | 2.41364869 | 0.160909913 |
| 113.16 | 1.2 | 2.774310725 | 0.184954048 |
| 110.58 | 4.26 | 4.002499219 | 0.266833281 |
| 108 | 6.3 | 3.289072818 | 0.219271521 |

| | |
|---|---|
| Average Speed (um/min) | 0.676242836 |
| MSD | 318.6873 |
| Displacement (um) | 17.85181503 |
| Total Path Length (um) | 91.2927828 |
| CI | 0.195544648 |
| Time (min) | 15 |
| **Persistence (min)** | **10.24** |
| MSD calc | 459.5426956 |

**Cell 2**

| x | y | Path Length (um) | Speed (um/min) |
|---|---|---|---|
| 9.96 | 25.46 | | |
| -2.94 | 68.3 | 44.74008941 | 2.982672627 |
| -4.23 | 59.12 | 9.270194173 | 0.618012945 |
| 4.8 | 48.92 | 13.62280808 | 0.908187205 |
| 3.51 | 29.54 | 19.42288599 | 1.294859066 |
| 20.28 | 32.69 | 17.06327636 | 1.137551757 |
| 46.08 | 38.72 | 26.49529958 | 1.766353306 |
| 53.82 | 34.64 | 8.749514272 | 0.583300951 |
| 84.78 | 32.6 | 31.02713651 | 2.068475767 |
| 88.65 | 14.24 | 18.76343519 | 1.250895679 |

| | |
|---|---|
| Average Speed (um/min) | 1.401145478 |
| MSD | 6318.0045 |
| Displacement (um) | 79.4858761 |
| Total Path Length (um) | 189.1546396 |
| CI | 0.420216371 |
| Time (min) | 15 |
| **Persistence (min)** | **49.47720273** |
| MSD calc | 6318.0045 |

**Cell 3**

| x | y | Path Length (um) | Speed (um/min) |
|---|---|---|---|
| 109.29 | 23.18 | | |
| 122.19 | 23.18 | 12.9 | 0.86 |
| 111.87 | 31.34 | 13.15629127 | 0.877086085 |
| 108 | 30.32 | 4.002161916 | 0.266810794 |
| 89.94 | 24.2 | 19.06877028 | 1.271251352 |
| 3.81 | 31.34 | 86.42543896 | 5.761695931 |
| 93.81 | 43.58 | 90.82850654 | 6.055233769 |
| 102.84 | 44.6 | 9.087425378 | 0.605828359 |
| 95.1 | 47.66 | 8.322932176 | 0.554862145 |
| 96.39 | 50.72 | 3.320798097 | 0.22138654 |

| | |
|---|---|
| Average Speed (um/min) | 1.830461664 |
| MSD | 924.8616 |
| Displacement (um) | 30.41153728 |
| Total Path Length (um) | 247.1123246 |
| CI | 0.123067667 |
| Time (min) | 15 |
| **Persistence (min)** | **7.5** |
| MSD calc | 3162.182249 |

**Cell 4**

| x | y | Path Length (um) | Speed (um/min) |
|---|---|---|---|
| 12.25 | 41.64 | | |
| 22.57 | 39.6 | 10.51969581 | 0.701313054 |
| 23.86 | 55.92 | 16.37090407 | 1.091393605 |
| 27.73 | 70.2 | 14.79511068 | 0.986340712 |
| 34.18 | 56.94 | 14.74551118 | 0.983034079 |
| 41.92 | 54.9 | 8.004323832 | 0.533621589 |
| 56.11 | 31.44 | 27.41765307 | 1.827843538 |
| 66.43 | 23.28 | 13.15629127 | 0.877086085 |
| 78.04 | 33.48 | 15.45419361 | 1.030279574 |
| 62.56 | 45.72 | 19.73443691 | 1.315629127 |

| | |
|---|---|
| Average Speed (um/min) | 1.038504596 |
| MSD | 2547.7425 |
| Displacement (um) | 50.47516716 |
| Total Path Length (um) | 140.1981204 |
| CI | 0.360027417 |
| Time (min) | 15 |
| **Persistence (min)** | **35.0240479** |
| MSD calc | 2547.7425 |

**Cell 5**

| x | y | Path Length (um) | Speed (um/min) |
|---|---|---|---|
| 109.34 | 113.04 | | |
| 119.66 | 114.06 | 10.37028447 | 0.691352298 |
| 124.82 | 116.16 | 5.57096042 | 0.371397361 |
| 113.21 | 106.92 | 14.83811646 | 0.989207764 |
| 104.18 | 111 | 9.908950499 | 0.6605967 |
| 105.47 | 99.78 | 11.29391429 | 0.752927619 |
| 97.73 | 106.92 | 10.53029914 | 0.702019943 |
| 91.28 | 107.94 | 6.530153138 | 0.435343543 |
| 99.02 | 103.86 | 8.749514272 | 0.583300951 |
| 105.47 | 114.06 | 12.06824345 | 0.804549563 |

| | |
|---|---|
| Average Speed (um/min) | 0.66563286 |
| MSD | 16.0173 |
| Displacement (um) | 4.002161916 |
| Total Path Length (um) | 89.86043614 |
| CI | 0.044537531 |
| Time (min) | 15 |
| **Persistence (min)** | **7.5** |
| MSD calc | 418.1529147 |

**Cell 6**

| x | y | Path Length (um) | Speed (um/min) |
|---|---|---|---|
| 72.68 | 67.22 | | |
| 71.39 | 75.38 | 8.261337664 | 0.550755844 |
| 7.52 | 86.6 | 64.84801693 | 4.323201129 |
| 77.84 | 96.8 | 71.05591038 | 4.737060692 |
| 84.29 | 72.32 | 25.3154676 | 1.68769784 |
| 90.74 | 54.98 | 18.50075944 | 1.233383963 |
| 107.51 | 41.72 | 21.37897331 | 1.425264888 |
| 110.09 | 39.68 | 3.289072818 | 0.219271521 |
| 103.64 | 47.84 | 10.40135087 | 0.693423392 |
| 106.22 | 46.82 | 2.774310725 | 0.184954048 |

| | |
|---|---|
| Average Speed (um/min) | 1.672779257 |
| MSD | 1541.0916 |
| Displacement (um) | 39.25673955 |
| Total Path Length (um) | 225.8251998 |
| CI | 0.173836842 |
| Time (min) | 15 |
| **Persistence (min)** | **7.51** |
| MSD calc | 2640.848437 |

**Cell 7**

| x | y | Path Length (um) | Speed (um/min) |
|---|---|---|---|
| -4.76 | -23.7 | | |
| 2.98 | -4.32 | 20.86844508 | 1.391229672 |
| 13.3 | -11.46 | 12.54918324 | 0.836612216 |
| 33.94 | -18.6 | 21.84008242 | 1.456005494 |
| 17.17 | -7.38 | 20.17724709 | 1.345149806 |
| 0.4 | -6.36 | 16.80099104 | 1.120066069 |
| -4.76 | 2.82 | 10.53081193 | 0.702054129 |
| -11.21 | 13.02 | 12.06824345 | 0.804549563 |
| -22.82 | -9.42 | 25.26550415 | 1.684366943 |
| -3.47 | -1.26 | 21.00019286 | 1.400012857 |

| | |
|---|---|
| Average Speed (um/min) | 1.193338528 |
| MSD | 505.2177 |
| Displacement (um) | 22.47704829 |
| Total Path Length (um) | 161.1007013 |
| CI | 0.139521728 |
| Time (min) | 15 |
| **Persistence (min)** | **7.52** |
| MSD calc | 1343.987682 |

**Cell 8**

| x | y | Path Length (um) | Speed (um/min) |
|---|---|---|---|
| 11.49 | 74.94 | | |
| 34.71 | 81.06 | 24.01297149 | 1.600864766 |
| 32.13 | 95.34 | 14.51119568 | 0.967413045 |
| 25.68 | 94.32 | 6.530153138 | 0.435343543 |
| 25.68 | 102.48 | 8.16 | 0.544 |
| 8.91 | 95.34 | 18.22669745 | 1.215113163 |
| -11.73 | 104.52 | 22.5894223 | 1.505961487 |
| -11.73 | 104.52 | 0 | 0 |
| -10.44 | 102.48 | 2.41364869 | 0.160909913 |
| -11.73 | 105.54 | 3.320798097 | 0.22138654 |

| | |
|---|---|
| Average Speed (um/min) | 0.738999162 |
| MSD | 1475.5284 |
| Displacement (um) | 38.41260731 |
| Total Path Length (um) | 99.76488685 |
| CI | 0.385031332 |
| Time (min) | 15 |
| **Persistence (min)** | **40.75889141** |
| MSD calc | 1475.00027 |

**EXAM 2** **NAME:** ______________________ **ID #:** ______________________

ChE 590B: Tissue Engineering

**2. Cell adhesion strength (20 points)** 5pts. each A - D

Taken from *Tissue Engineering* exercise 6.5.

An adherent cell is exposed to shear forces from a buffered water flowing in a parallel plate flow chamber. The gap thickness is 250μm, and the channel width is 14mm. The flow rate is adjusted so that the wall shear stress varies from 0.25 to 4 dyne/cm$^2$. Attach additional pages as necessary.

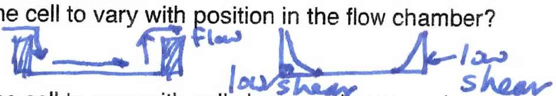
A) Calculate the volumetric flow rate that is reuired to achieve each value of shear stress in the following table.

| Shear stress at the wall (dyne/cm$^2$) | 0.25 | 0.5 | 1 | 2 | 4 |
|---|---|---|---|---|---|
| Volumetric flow rate (cm$^3$/s) | $8.19\times10^{-3}$ | $1.64\times10^{-2}$ | $3.28\times10^{-2}$ | $6.55\times10^{-2}$ | $1.31\times10^{-1}$ |
| Force on adherent cell (dyne/cell) | | | | | |

B) Calculate the force experienced by an "average" endothelial cell attached to the surface of the lower plate. Make and justify whatever assumptions are necessary to perform this calculation.

C) How much would you expect the force experienced by the cell to vary with position in the flow chamber?

→ Very likely position dependent




D) How much would you expect the force experienced by the cell to vary with cell shape and pattern of attachment? Shape: ⊙ ↑shear ⌓ ↓shear (flat cells experience less shear)

Dense cells, shear only at top (less shear)

A)

$\mu = 8.9\times10^{-3}$ dyn·s/cm$^2$

$a = 0.0125$ cm

$b = 1.4$ cm

Eqn. 6-8 in Tiss Eng. book

$$\tau = \frac{3}{2}\frac{\mu Q}{2a^2 b}$$

$\tau$: fluid shear stress @ wall

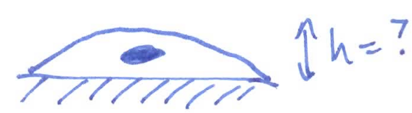
$Q$: vol. flow rate

B) Will accept multiple answers.

This can be estimated in a number of ways.

Can assume cell diameter (spherical) = 10 μm


Cell on a surface is different




Can assume height is ~5 μm, where cell would experience shear force.

Use. $\tau = -\mu \left.\frac{dv_y}{dx}\right|_{x=a}$

**EXAM 2** **NAME:** SOLUTIONS **ID #:** ______________

ChE 590B: Tissue Engineering

**3. Engineered Tissue (50 points)**

In class on March 10th, we heard a wiki presentation on cell sheets used for tissue engineering. If you can remember, way back on February 7th, we heard a wiki on dialysis. Dialysis has been typically used for replacing kidney function, i.e. to clean waste from blood and concentrate urea; however, one could envision a similar technique being used to supplement both liver and pancreas function, where blood is "sampled" and enzymes are then released back into the bloodstream to break down carbohydrates. Replacements for liver and pancreas, if made financially effective, obviously, could have a huge impact on global human health.

Think, for a moment, about how cell sheet engineering techniques could be implemented in *ex vivo* liver or pancreas replacements (i.e. not implanted, but will run outside the body). Pick one target (i.e. liver or pancreas), research the literature, and use resources from lecture and the wikis to answer each of the following:

(A) What disease(s) might you impact with such a device?
(B) What physiological functions must your device perform to be a substitute for a liver or pancreas?
(C) What will your device look like (draw a sketch)?
(D) What biomaterials, if any, will have to be incorporated into the device and why?
(E) What **SINGLE** cell type would use as a cell sheet, and why?
(F) Since you only want to incorporate one cell type in the engineered device, what features are you missing that are normally provided by other cell types? Can you replace this function with structural or chemical aspects of the device?
(G) Where will you get the cell type of interest, how will you grow up the cells, and how will you incorporate them into the device?
(H) Do you think this will work? If yes, why doesn't it already exist? If not, what advances need to be made to get it to work?

Attach additional pages if necessary. Cite your references used. **Limit your response to no more than 2 total pages.**

A-H 5 pts. each

page length + turn it in : } 5 pts.

grammar / spelling: 5 pts.