MODELLING SURFACE AREA TO VOLUME RATIO IN CELLS

Research Question

To investigate the effect of increasing the SA:V ratio on the percentage of penetration of HCL, when cubes of bromothymol blue agar are placed in the HCL. (Concentration of the HCL → 0.1 M)

Background Info

A cell needs a large surface area in order to carry out metabolic functions (as chemical reactions require a surface). As a cell grows, it needs to carry out more and more reactions. Therefore, since a cell has to maintain a certain surface area to volume ratio, its size is limited.
(http://en.wikibooks.org/wiki/IB_Biology/Cells)

The surface area to volume ratio in living organisms is very important. Nutrients and oxygen need to diffuse through the cell membrane and into the cells. Most cells are no longer than 1mm in diameter because small cells enable nutrients and oxygen to diffuse into the cell quickly and allow waste to diffuse out of the cell quickly. If the cells were any bigger than this then it would take too long for the nutrients and oxygen to diffuse into the cell so the cell would probably not survive.

Single celled organisms can survive as they have a large enough surface area to allow all the oxygen and nutrients they need to diffuse through. Larger multi celled organisms need specialist organs to respire such as lungs or gills.
(http://www.neiljohan.com/projects/biology/sa-vol.htm)

A cell is a metabolic compartment where a multitude of chemical reactions occur. The number of reactions increase as the volume of metabolic volume within a cell increases. (The larger the volume the larger the number of reactions) All raw materials necessary for metabolism can enter the cell only through its cell membrane. The greater the surface area the larger the amount of raw materials that can enter at only one time. Each unit of volume requires a specific amount of surface area to supply its metabolism with raw materials. The amount of surface area available to each unit of volume varies with the size of a cell. As a cell grows its SA/V decreases. At some point in its growth its SA/V becomes so small that its surface area is too small to supply its raw materials to its volume. At this point the cell cannot get larger.
(http://www.ucs.mun.ca/~iemerson/lectures1001/coursenotes/SAtoV.html)

Hypothesis

We predicted that as the Surface Area / Volume Ratio increased, the penetration volume of HCL into the agar cubes would increase . This is because a small block has a large amount of surface area compared to its volume so the hydrochloric acid will have a large surface area to diffuse through. A larger block has a smaller amount of surface area in relation to its size so it should take longer for the hydrochloric acid to diffuse into the centre of the cube. The actual rate of the hydrochloric acid diffusing through the agar should be the same for all the blocks but when the surface area / volume ratio goes up, it will take less time for the hydrochloric acid to reach the centre of the cube.

Variables

Controlled Variables:
Temperature – thermostatically controlled room
Time – the length of time you leave the cubes in the HCL (6 minutes)
Volume of HCL + Concentration of HCL – there has to be enough HCL in the beaker so that the agar cube is completely covered each time (50cm3) and the concentration of the HCL is 0.1 M
Source of agar – each agar cube that you cut should be from the same block of bromothymol blue agar

Independent Variable: Surface area to volume ratio of the cubes
Dependent Variable: penetration volume

Materials/Apparatus

- 1 beaker (250cm^3)
- Bromothymol Blue Agar Cubes of sides 1cm, 2cm and 3cm
- 0.1M Hydrochloric Acid (HCL)
- Stop Watch
- Knife
- Chopping Board
- Ruler (+/- 0.5mm x 2)
- Paper Towel

Method

1. A block of bromothymol blue agar should be cut into the following sizes using the chopping board, knife and ruler:

- 1cm x 1cm x 1cm
- 2cm x 2cm x 2cm
- 3cm x 3cm x 3cm

2. Fill the beaker with hydrochloric acid and put the 1cm ^{3} agar cube into the beaker, making sure to completely immerse the cube in the acid.
3. Start the stop watch as soon as you put the agar cube into the HCL.
4. Write down any qualitative observations you see.
5. After 6 minutes, take the agar cube out onto a paper towel and cut the cube in half.
6. Using a ruler, measure the uncoloured and coloured areas of one side of the cube.
7. Calculate the volume and record all your results.
8. Repeat these steps for the agar cubes sizes 8cm ^{3} and 27cm^3

Results

Table 1 The penetration percentage (%) of hydrochloric acid (HCL -0.1M) when cubes of bromothymol blue agar (side lengths 3cm, 2cm, 1cm) with increasing surface area to volume ratio's (2:1, 3:1, 6:1) are placed into the acid for a period of 6 minutes.

Surface Area: Volume Ratio	**Volume of Bromothymol Blue Agar UN-COLOURED (penetrated) (cm^3 +/- 1mm)**			
	Trial 1	**Trial 2**	**Trial 3**	**Trial 4**
2:1 (3cm)	22.087	23.625	19.00	23.625
3:1 (2cm)	7.488	7.875	7.000	7.657
6:1 (1cm)	1.000	1.000	1.000	1.000

Table 2 The penetration volume (cm3) of hydrochloric acid (HCL -0.1M) when cubes of bromothymol blue agar (side lengths 3cm, 2cm, 1cm) are placed into the acid for a period of 6 minutes.

	Volume of Bromothymol Blue Agar COLOURED (un-

Surface Area: Volume Ratio	penetrated) (cm^3 +/- 1mm)			
	Trial 1	**Trial 2**	**Trial 3**	**Trial 4**
2:1 (3cm)	4.91	3.38	8.00	3.38
3:1 (2cm)	0.51	0.13	1.00	0.34
6:1 (1cm)	0.00	0.00	0.00	0.00

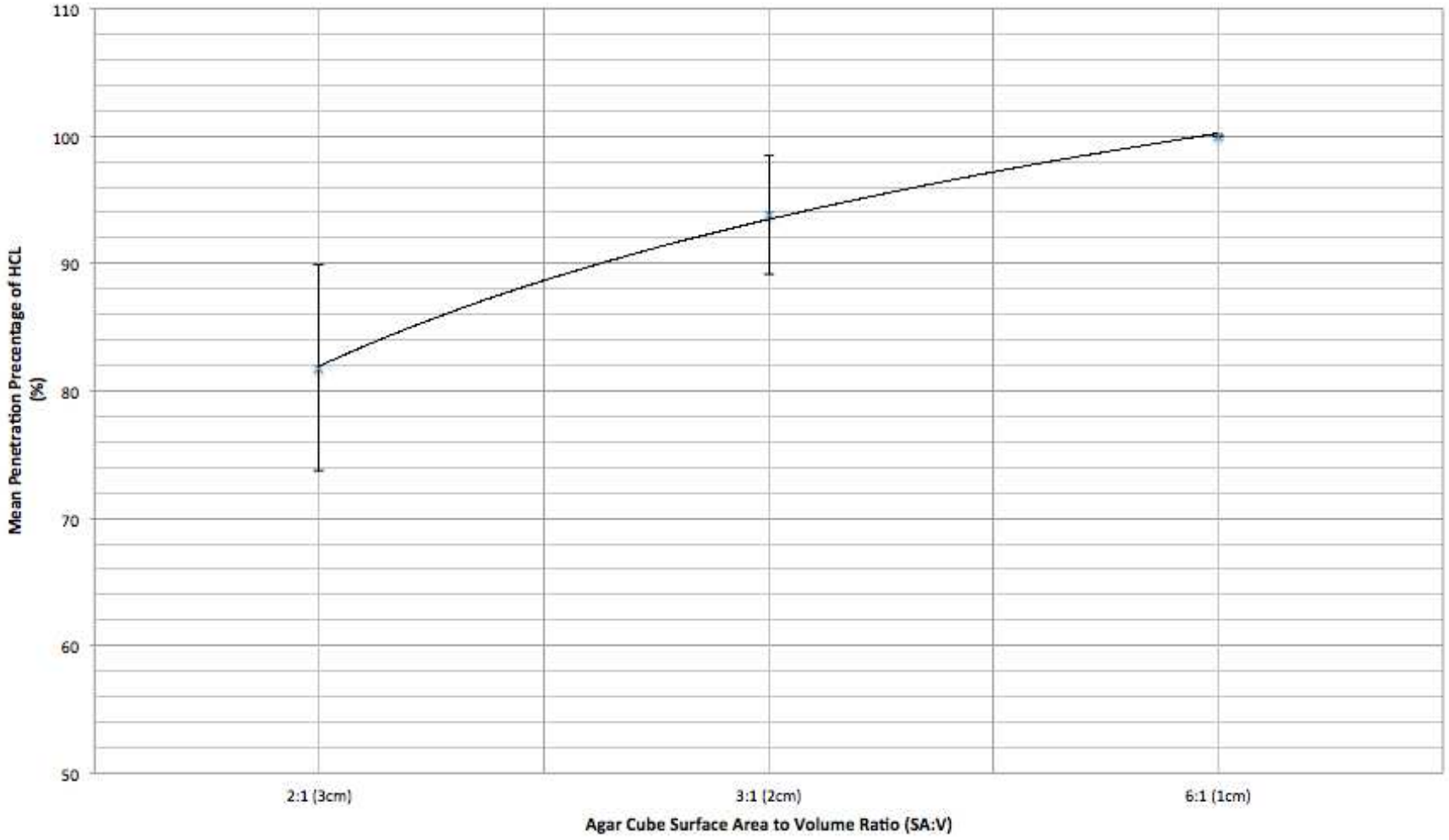
Table 3 The mean penetration percentage (%) and standard deviation of hydrochloric acid (HCL-0.1M) when cubes of bromothymol blue agar (side lengths 3cm, 2cm, 1cm) with increasing surface area to volume ratio's (2:1, 3:1, 6:1) are placed into the acid for a period of 6 minutes.

Surface Area: Volume Ratio	Mean of the percentage of cube uncolored (%)	Standard Deviation *(3 significant figures)*
2:1 (3cm)	81.8	8.06
3:1 (2cm)	93.8	4.64
6:1 (1cm)	100.0	0.00

Qualitative data: table 7 – qualitative data from experiment

Surface Area to Volume Ratio	**Qualitative Observations**			
	Trial 1	**Trial 2**	**Trial 3**	**Trial 4**
2:1 ($3cm^3$ cube)	• Minimal change observed in first minute. • Appears to be minimally penetrated by hydrochloric acid.	• Solution had acidic odour • Remained constant throughout experiment	• The cube was pale on the outside with a slight yellow/white tinge • The inside of the cube was a darker blue colour • Whitest on edges- almost transparent	• Not much change occurred at first • During the third minute the penetration became more obvious however did not penetrate more that ¼ of cube.
3:1 ($2cm^3$ cube)	• Cube penetrated less than that of the $3cm^3$	• Minimal change after 1.5minutes	• Started turning clear on edges • Blurry appearance in solution • Blue area slowly shrinking and fading slightly	• Penetration was most obvious after the 2nd minute, by which the edges of the cube became transparent. About 1/3 of the cube was penetrated.
6:1 ($1cm^3$ cube)	• Full penetration occurred. • Change in colour noticeable within first minute.	• Lost colour very quickly (percentage of cube) – completely in less than 1 minute. • Stayed same for remainder of time.	• Started turning clear on edges • Blurry appearance in solution • Blue area slowly shrinking and fading slightly	• The entire cube became transparent, meaning the entire cube was penetrated. • This penetration was completed within the first 1.5 minutes.

Graph The mean penetration pe
agar (3cm, 2cm, 1cm) with incr


110
100
90
80
70
60
50
Mean Penetration Precentage of HCL (%)
2:1 (3cm)
3:1 (2cm)
6:1 (1cm)
Agar Cube Surface Area to Volume Ratio (SA:V)

In all the cubes of agar the penetration of the hydrochloric acid from each side were the same but all the cubes had different percentages of the cube being penetrated by the HCL (un-coloured) because of their different sizes and surface areas. As the cubes got bigger it took longer for the hydrochloric acid to diffuse completely through the cube. It took longer to reach the centre of the cube even though the rate of diffusion was the same for all the cubes.

The results of our experiment supported our hypothesis because as the surface are to volume ratio increased from the largest cube of agar to the smallest cube of agar, the penetration percentage also increase, with the smallest cube having a penetration percentage of 100% compared to the largest cube having a penetration percentage of 81.8%.

As the volume of the cubes goes up the surface area to volume ratio goes down. The larger cubes have a smaller proportion of surface area than the smaller cubes. The smallest cube has a surface area to volume ratio of 6:1 and the largest cube only has a surface are to volume ratio of 2:1.This means that the hydrochloric acid is able to diffuse to the centre of the smallest cube much faster than the largest cube. The HCL penetration percentage of the smallest cube was 100% while the percentage penetration of the largest cube was only 81.8 %. A living cell would not survive if oxygen only penetrated 81.8% of the cell so this shows us that living cells need to be very small and have a large surface area to volume ration in order to survive and make sure all the essentials can diffuse quickly and easily all the way through the cell.

When the surface area to volume ratio goes down it takes longer for the hydrochloric acid to diffuse into the cube but if the ratio goes up then the hydrochloric acid diffuses more quickly into the cube. Some shapes have a larger surface area to volume ratio so the shape of the object can also have an effect on the penetration percentage of diffusion.

It is important that cells have a large surface area to volume ratio that they can get enough nutrients into the cell. They can increase their surface area by flattening and becoming longer or by having a rough surface with lots of folds of cell membrane.

Single celled organisms such as amoebas have a large surface area to volume ratio because they are small. They are able to get all the oxygen and nutrients they need by diffusion through the cell membrane. By increasing the surface area the penetration percentage of diffusion will increase.

Evaluation

One of the weaknesses of our experiment was that we only had 4 trials, which means our results could be unreliable. In the future, we sh ould do at least 5 trials to increase reliability.

Also, we did not turn the cubes over throughout the duration of the 6 minutes and because our experiment was about diffusion and surface area, if one side of the cube is touching the bottom of the beaker the whole time that surface is not exposed to diffusion as equally as the other sides. In the future , we would systematically turn the cube throughout the 6 minutes to ensure each side had even exposure to diffusion.

When we were measuring and cutting th e cubes, it was hard to be exact because the agar was quite flexible and so when you cut through it, it was hard to cut it straight and to get an exact cube. Also, when we were measuring the cube, not all the edges were straight on the cube and also we were using a regular 30cm ruler with and uncertainty of 1 mm, so it was hard to be exact with our measurements. In the future, we could use set molds to increase the uniformity of the cubes and increase the exactness and straightness of all the sides.

The original big block of agar we received was also not consistently blue all the way through to start with which indicated that the bromothymol blue wasn't consistently distributed or maybe a reaction had occurred between the agar and the air. However, when we cut our 3 different sizes of agar cubes, we still had a lot of agar left over so in the future, we would try to choose an area of the agar which was more consistently blue (therefore indicating that the bromothymol blue is more evenly distributed thro ugh the agar) and use that area to create our different sized cubes.