### 3.2.7. Detailed analysis of immature hindlimbs

Figure 3.18 Inmature hinalimbs


Stan mtago 46


$$
\mathrm{s}
$$





$$
\begin{aligned}
& s-2 \\
& T-12(\text { nissonf } 3)
\end{aligned}
$$


$5-2$
$1-12($ missing 13$)$











s-1
$T$


### 3.3 Uptake of radioactive thymidine

in the presence of $5-F U d R$
The results of the experiments in section 2.2 are shown in Table 3.1 below.

Control: Thymidine $5 \mu \mathrm{Ci} / \mathrm{m}]$
Experiment: Thymidine $5 \mu \mathrm{Ci} / \mathrm{ml}+20 \mathrm{ug} / \mathrm{ml} 5$-FUdk
6 tadpoles per dish
Control Counts Counts Wt limb Counts

| 1 | (50min) | /min | (mg) | /min/mg |
| :---: | :---: | :---: | :---: | :---: |
|  | $\{17767$ | 355,34 | 0,017 | 20902,4 |
|  | \{ 67564 | 1351,28 | 0,090 | 15014,2 |
| 2 | \{55006 | 1100,12 | 0,013 | 84624,6 |
|  | \{55962 | 1119,24 | 0,017 | 65837,6 |
| 3 | \{28272 | 565,44 | 0,066 | 8567,3 |
|  | $\{12701$ | 254,02 | 0,054 | 4704,1 |
| 4 | $\{3225 \%$ | 645,14 | 0,015 | 43009,3 |
|  | (144852 | 2897,04 | 0,026 | 111424,6 |
| 5 | \{13060 | 261,2 | 0,134 | 1949,3 |
|  | \{29973 | 599,46 | 0,009 | 66606,7 |
| 6 | $\{11573$ | 231,46 | 0,031 | 7466,5 |
|  | \{ 78800 | 1576,0 | 0,017 | 92705,9 |


| Expt |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: |
| 1 | $\int 43816$ | 876,32 | 0,012 | 73026,7 |
|  | \{ 9754 | 195,08 | 0,344 | 567,1 |
| 2 | \{6334 | 126,70 | 0.092 | 1377,1 |
|  | \{ 1962 | 39,24 | 0,067 | 585,7 |
| 3 | S 4867 | 97,34 | 0,005 | 19468,0 |
|  | \{ 6339 | 126,78 | 0,099 | 1280,6 |
| 4 | \{19331 | 386,62 | 0,015 | 25774.7 |
|  | \{ 4873 | 97,46 | 0,010 | 9746,0 |
| 5 | \{16693 | 333,86 | 0,044 | 7587,7 |
|  | \{45856 | 917,12 | 0,484 | 1894,9 |
| 6 | $\{4700$ | 94,00 | 0,009 | 10444,4 |
|  | \{5467 | 109,34 | 0,015 | 7289,3 |

Brackets indicate left and right limbs from the same animal.

Table 3.1 Results of the experiments showing the uptake of ${ }^{3}$ II-Thymidine in the presence of $5-T U d R$

The results in Table 3.1 were analysed by an analysis of variance test. First the counts/minutes were analysed of which the results are shown in Table 3.2. Then the counts/minutes/mg were analysed of which the results are shown in Table 3.3 . There are three sources of variance

1. Treatments - experiment versus control.
2. Between animals - differences between the 24 tadpoles used.
3. Within animals - differences between the two hindlimbs of the same tadpole.

| Source | DF | SS | MS | F |  |  |
| :--- | ---: | :--- | :--- | :--- | :--- | :--- |
| 1. Treatments | 1 | 2 | 377 | 622 | 2377 | 622 |
| 2. Between animals | 10 | 3 | 100 | 388 | 310 | 039 |
| 3. Within animals | 12 | 4 | 490 | 245 | 374 | 187 |
| 4. Total | 23 | 9 | 968 | 254 |  |  |

Table 3.2 Analysis of vourones for counts/min

$$
\begin{aligned}
& D F=\text { Degrees of Freelom } \\
& S S=\text { Sum of squares } \\
& M S=\text { Mean of Squares } \\
& F=F \text { Test } \\
& z=\text { Significant } \\
& N S=\text { Not Significant }
\end{aligned}
$$

The mean count per minute for the experimental animals (913) is significantly higher than that of the control animals (283) at the $5 \%$ level i.e, there is a $95 \%$ confidence that this difference is genuine.

The variability between counts on the same animal i.e, between the counts in the hindlimbs of the same animal, is of the same order as the variability between animals. This shows the errors of the experimental techirique to be of the same order as that of the variability between animals. This is unusual but can be explained by the fact that the hindlimbs of Xenopus laevis are known to develop at different rates and therefore the one limb could be significantly larger than the other hindlimb at the same stage. The standard deviation of the experimental method is : $374187=612$ counts $/$ minute, i.e. the reading is expected to be within $+/-612$ counts $68 \%$ of the time, the reading is expected to be within $+/-1224$ counts $95 \%$ of the time.

| Source | DF | SS |  | MS |  | F |  |  |  |  |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1. Treatments | 1 | 5 | 513 | 660 | 000 | 5 | 513 | 660 | 000 | 4,92 |
| 2. Between animals | 10 | 11 | 205 | 400 | 000 | 1 | 120 | 540 | 000 | 0,85 NS |
| 3. Within animals | 12 | 15 | 731 | 000 | 000 | 1 | 310 | 917 | 000 |  |
| 4. Total | 23 | 26 | 936 | 400 | 000 |  |  |  |  |  |

Table 3.3 Analysis of variance for counts $/ \mathrm{min} / \mathrm{mg}$
$D F=$ Degrees of Freedom
SS = Sum of Squares
$M S=$ Mean of Squares
$F=F$ Test
$u=$ Significont
$N S=$ Not Significant

The difference between the experimental mean and the control mean ( 43568 versus 13254) just fails to achieve significance at the $5 \%$ level when tested by the $F$ test above. ( $F=4.96$ is required for significance $\approx 2$ the $5 \%$ level.)

Again the variability between the hindimbs of the same animal is of the same order as the variability between the different animals.

The standard deviation of the rethod is 36206 counts/minute/mg.

The results show, therefore, that thymidine uptake is depressed in the presence of $5-\mathrm{FUdR}$.

### 3.4 Buoyant density gradient analysis of DNA substituted with 5-BUdR in place of thymidine

This experiment was set up to test the uptake of 5-BUdR into the tadpole DNA in the absence and presence of 5-FUdR (see section 2.3). In the control shown in Figure 3.19 below the photograph shows one main band which, when analysed by the densitometer, shows up on the trace as peak c.


Figure 3.19 uttraviolet absorption photograph
of DMA from tadpoles swum in wat.?


Figure 3.20 Densitomater trace of the photograph in Figure 3.19 , peak $a$ is the main band

In Figure 3.21 below is the ultraviolet photograph of the DNA from tadpoles swum in $0,1 \mathrm{mg} / \mathrm{m} 15-\mathrm{BUd}$ f for five hours. It reveals two bands where there was previously one (in the photograph of the control DNA in Figure 3.19). The densitometer trace in Figure 3.22 below shows these bands as peaks $c$ and $d$.


Figure 3.21 Ultraviolet absorption photograph of the DNA from tadpoles surm in $0,1 \mathrm{mg} / \mathrm{ml} 5-B U d P$ for five hown


Figure 3.22 Densitometer trace of the photograph in Figure 3.21, the main poaks are o mad d

In Figure 3.23 below is the ultraviolet absorption photograph of the DNA from tadpoles swum in $0,1 \mathrm{mg} / \mathrm{ml} 15-B U d R$ and $0,2 \mathrm{ug} / \mathrm{m} 15-$ FUdR for five hours. Two bands are still visible. In the densitometer trace of the photograph the two main peaks are $b$ ard $c$.


Figure 3.23 Ultraviolet absorption photograph of the DNA from tadpoles swim in $0,1 \mathrm{mg} / \mathrm{ml}^{2} 5$-BUdR and $0,2 \mathrm{ug} / \mathrm{ml}$ s-FUdR for 5 hours

otimanco IomAxtiol zototion
$\because$
Fiuure 3.24" Densitometer trace of the photograph in Figune $3.2^{3}$ above, the main peaks are $b$ and $a$

### 3.5 Analys is of the effects of different foods

on the growth of Xenopus laevis tadpoles
A series of experiments tested the effects of different foods on the growth of tadpoles. The Ladpoles were maintained in 2 litre trays and in 200 ml dishes of water, and the food was added in discreet amounts to the water. Financial and experimental constraints required that tadpoles be reared in 200 ml dishes (experiment $C$ ). A parallel series of experiments ( $A$ and $B$ ) was conducted using 2 itre trays. Table 3.4 on page 120 shows that in the small dishes Liquifry was the only suitable food. In the larger trays (Tables 3.5 and 3.6 on pages 123 and 126) optimum growth was obtained using commercial "baby food" and "Complan". In Liquifry, while growth was slower, the tadpoles were carried through metamorphosis. Histograms in Figures 3.25 and 3.26 sumarise the results by comparing the number of tadpoles reaching metamorphosis for each feeding regimen.

Table 3.4 Feeding experiment in 200 mL dishes

Experiment $C$

KEY
b Commercial baby lood
s. Yeost
f Fish hnor
q Liquify
1 Lettuce

Table recnrding the effect of differ int foods on tadpoles reared in 200 ml dishes of water. Each food is imdicated by c code Tetter e.g. $b=$ conmercial baby food. The figures in the table represent the number of tadpo'es living on a particular food regimen at a particular developmental stage pen lapsed time. The letter $M$ indicates the number of tadpoles metamorphosed per food per week and letter $D$ indicates the number of dead tadpoles per food per week. For example by week 14 all the tadpoles fed on $b, y$ and $f$ had died before metamorphosis. 5 of the tadpoles fed on liquifry survived, of which 1 had reach stage 49 and 4 had reached stage 50.6 of the tadpoles fed on lettuce had survived to stage $50,51,52,57$ and 58. 1 of the tadpoles fed on lettuce died during week 14 . During week 35 only tadpoles fed on liquifry were still growing. Of these 1 had metamorphosed, 1 had reached stage 51 and 2 had reached stage 55 . By week 53,4 out of the initial 6 had metamorphosed. The results are summarised in the histogram in Figure 3.25 .
$\qquad$

Table 3.5 Feeding experiment in 2 litre trays

Experiment $A$

REY
b Commerelat baby food
y Yeast
$f$ Fish food
q Licuirry
1 Letluce
c Complan

Table showing the development of animals being fed a particular food e.g. Indicated by code letter $b=$ commercial baby food, see key below. These tadpoles were reared in 2 litre trays of water. The figures in the table represent the numbers of tadpoles living on a particular regimen at a particular developmental stage per elapsed week. Letter $M$ indicates the number of tadpoles metamorphosed per food per week. For example during week 14 of the tadpoles living on liquifry $=9 ; 2$ tadpoles had reached stage $49 ; 15$ had reached stage 50: 2 had reached stage 51 etc. 1 had metamorphosed and 1 had died. By week 38,1 tadpole was surviving at stage 54 . The results are sumarised in the histogram in Figure 3.26.



Table 3.6 Feeding experiment in 2 Iitre trays
Experiment $B$

## KEY

b Commercial baby food
y Yeast
$f$ Fish rood
q. Liquirry

1 Lettuce
C Complan

Table showing the development of tadpoles being fed a particular food e.g. indicated by code letter $\mathrm{b}=$ commercial baby food, see key below. These tadpoles were reared in 2 litre trays of water. The figures in the table represent the numbers of tadpoles living on a particular food regimen at a particular developmental stage per elapsed week. Letter $M$ indicates the number of tadpoles metamorphosed per food per week. Letter D indicates the number of dead tadpoles for each feeding regimen per week. For examr'e during week 13 (which was measured at week 14) on food $q=1$ iquil,, 2 tadpoles had reached stage 48; 1 had reached stage 49; 3 had metamorphosed etc. By week 44 the last 3 cadpoles grown on liquifry had metamorphosed. The results are summarised in the histogram in Figure 3.26.

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Figure 3.25 Graph of the results from experiment C. Number of tadpoles metomorphosed virsus weeks for each food

Graph showing the results for experiment C (Table 3.4). The histogram shows the number of tadpoles which metamorphosed under a particular food regimen over 5 week intervals as a function of time. For example 4 tadpoles which were fed on liquifry, metamorphosed during weeks 30 to 35 .


Graph sho ing the rasults for experiment C (Table 3.4). The histogram shows the number of tadpoles which metamophosed under a particular food regimen over 3 week intervals as a function of cime, For example 4 tudpoles which were fed on liquifry, metamorphosed during weeks 30 to 35 .

Figure 3.26 Groph of results from experiments $A$ and $B$. Number of tadpoles metamorphosed versus weeks for each food


Graph showing the number of tadpoles which metamorphosed under a particular food regimen in experiment $A$ (TabTe 3.5 ). The histogram shows the number of tadpoles which metamorphosed as a function of time. For example between weeks 26 to 30,10 tadpoles which were fed on liquifry, metamorphosed.

Graph showing the number of tadpoles which metamorphosed under a particular food regimen in experiment B (Table 3.6). The histogram shows the number of tadpoles which metamorphosed as a function of time. For example between weeks 16 to 20,14 tadpoles, which were fed on yeast, metamorphosed.

### 3.6 Conclusion

In this dissertation a method was devised (the deformity index method) in which each deformity, irrespective of its position a.ong the limb, was given the same weighting. An attempt was made to see whether there was any correlation between the deformity index and the stage of the tadpole, and the concentratio, of the solution.

A uniform weighting was given to a deformity at any position in the limb as discussed. Thus a deformity could receive a particular rating if two elements were missing (one in the proximal and one in the distal part of the limb) or if both elements in the same in the same section of the limb were missing. This deformity index method of analysis offered no new trend to the deformities which were observed. Although visual analysis did reveal bent and missing digits, there was no correlation between the type of deformity, the extent of the deformity, the concentration of the drug and the stage of immersion of the tadpole.

## 4. DISCUSSION

### 4.1 The effects of 5-FUdR on the tadpoles in vivo

As has been mentioned (see page 40) $5-F U d R$ is an inhibitor of ce 11 division. The effect of 5 -FUdR on growing tissues would be observed most markedly in rapidly growing tissues. Such a situation is found during the development of the hindlimb of Xenopus laevis, which was the topic of this investigation. In fact, hindlimb development appears to be a sensitive indicator of cell division, as seen by the variety of abnormalities observed in the basic patterning of the limb when cell division is interfered with. The point of view in this discussion assumes that cell division, together with its consequent events, is an essential parameter in the patterning of the limb.

In the particular experiments carried out in this investigation under 5-FUdR treatment, no cases were observed in which there was no limb development. This suggests that the cells of the limb were dividing, although cell division was presumably continuing at a lower rate. The analysis of FUdR effect must take into account the periodicity of the drug administration. The drug was given in weekly doses and therefore it is assumed that the effect of concentration decayed until the next dose was given. At the high concentration point of drug administration those parts of the limb most actively dividing would be most deleteriously affected. According to Wolpert (1981), one such area of cell division is located at the distal end of the growing limb. He calls this area the "progress zone". (See section 1.5.)

In order to understand how hindlimb abnormalities in Xenopus lacvis could result from $t a$ inhibition of cell division in the "progress zone", two models will be proposed:

1. The first model will try to explain how a constant level of partial inhibition of cell division in the "progress zone" could lead to deformity in shape, which was observed in the early stages of limb development (NF stages $43-53$ ) (see pages 97 to 111).
2. The second model will try to explain the reduction in digit number observed in the later stages of 1 imb development. (NF stages 54 onwards.)

## 1. Model to explain shape deformity

The normal stage 53 hindlimb is observed below in Figure 4.1.


Figure 4.1 Normat stage 53 hindtimb of Xenopus Zapvis

At this stage the first indications of digit fomation are seen externally. These are digits 4 and 5 , although digit 1 may be the first to actually form. The external observation of digits 4 and 5 is based on the projection of a bulge from the paddie as seen in Figure 4.1.

One of the most commonly observed shape deformities at about stage 53 is illustrated below in Figure 4.2.


Fiqure 4.2 Defoxmed stage 53 hindlimb of Xenopun lacvis

It will be noticed that this deformed limb bends upwards. This particular limb went on to form three digits. In the model to be proposed, use is made of Wolpert's (1981) "progress zone" theory. The "progress zone" comprises the vand of rapidly dividing cells near the distal tip of the limb as seen below in Figure 4.3 in Xenopus laevis hindlimb at various stages of development. The "progress zone" theory proposes that all cells spend a period of time in the "progress zone" before being offloaded and differentiating into the forming elements of the 1 mb .




$p z=$ progress zone

Figure 4.3 Iindlimb of Xenopus laevis in various stages of development showing the progress zone
(Summerbetl et al 1973)

If $5-$ FUd is added prior to or during the early stages of "progress zone" development, the number of cells in this zone could be reduced over a period of time and the reduction could be one-sided. If one part of the bud appears to develop ahead of other parts, the conclusion is made that the cells across the antero-posterior axis of the limb are not all at the same stage of development and in fact different regions along the antero-posterior axis (or in the "progress zone") may be dividing at different rates. Perhaps there is a wave of cell division across the antero-posterior axis. This effect could lead to deformities depending on which area is pulsed in high concentration by the applied 5-FUdR. The formation of the deformity in Figure 4.2 is shown progressively in Figure 4.4 below.


Figure 4. 4 Model describing a possible shape deformity in the hinditimb

By varying the model slightly many other shape deformities could also be explained.
2. Model to explain reduction in the number of
digits as a consequence of 5 -FUdR treatment
It will be recalled that cells divide in the "progress zone"
(Saunders 1977). After a certain period of time, a portion of the cells leave the zone and stop dividing, in order to form the most proximal limb element, the femur. The rest of the cells in the "progress zone" continue dividing and eventually another portion of the cells leave the zone to form the next most distal element, the tibio-fibula. In a similar manner after certain time periods, the tibiale fibulare, metatarsals and phalanges are formed. Now, if a reduction in cell division occurs throughout the process of 1 imb formation then a reduction in the total number of cells in the 1 mb bud should occur. The effect would reach crisis level when the number of cells in the "progress zone" failed to be sufficient to form a particular element. In the model presented be? ow, this crisis stage is reached during the formation of the digits. In this model it is assumed that $5-$ FUdR inhibits 25 \% of the dividing cells in the "progress zone". (Continued on page 137a.)

An approximation based on the actual size of the limb eiements is made and it is assumed that in the model :

1. The femur has 40 cells.
2. The tibio-fibula has 60 cells.
3. The tibiale fibulare has 80 cells.
4. The digits (metatarsals and phalanges) have 350 cells ( 70 cells per digit).
A schematic diagram of the model is shown on proge 138.

The figure $25 \%$ is arrived at in the following way :
It is known from experiments on cells in tissue culture treated with 5-FUdR, that the inhibition of mitosis by the drug can be $100 \%$ (Simon 1963). In the experiments in this study, the animals were maintained in 5-FUdR and the drug was renewed once a week, yet the animals continued living. It was clear that 5 -FUdR did not inhibit cell division completely, since the animals continued to grow slowly. As a first order approach, it was decided to assume a level of $25 \%$ inhibition of mitosis for the model. However, the principle of the model would hold whatever percentage is used, as long as the rate of formation of new cells by mitosis is chosen such that a point is reached when there are insufficient cells to produce a digit of normal size.


Figure 4.5 Model to cxplain the formation of a reduced number of digits

The crisis now occurs as there are only 210 cells which is enough to form three full digits or perhaps five half-digits. The formation of three full digits or digits with phalanges missing was the normal finding in this research project.

The next question to be dealt with follows from the above model and findings, namely how the cellular material available for digit formation can be partitioned into three elements, as in the above case. To understand the problem, we must introduce the concept of biological inhibition. One type of inhibition has been postulated to occur in biological systems wherever repetitive structures are formed. These repetitive structures may result from a focus of differentiation and an inhibitory influence which spreads out from the focus. The inhibitory influence is assumed to prevent a second structure from forming in the immediate surroundings of the initial focus of differentiation. As the inhibitory influence is thought to decay with distance, a second repeat structure will be able to form at a certain distance from the initial focus, where the initial inhibitory focus fades out. In this way repetitive structures can be formed as is found for example in the distribution of hairs (Balinsky 1981).

Such an analysis could apply to the formation of digits 1,2 , 3, 4 and 5 , given that a sufficient mass of cells was present and that all cells are capable of differentiation into digits, and also that certain cells in one region differentiate ahead of others to form digit 1. The result of such a condition could explain the formation of five normal digits as shown in the sketches in Figure 4.6 below.

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Figure 4.6 Formation of five digits acsionk to seruesthat "diffenantiation inhtitition" hypothesis

It is obvious that if there are a li..ited number of cells available for digit formation, then the sequential differenti tion of digits alternating with inlibition s:ggests that elements will be formed in sequential o. der, until there are no more cells to form the last digit. This implies that if there are enough cells to form three digits, then three full digits and not six half-digits will form.

It will be recalled (see section 1.4.2.) that the ZPA (zone of polarising activity) exerts a strong influence on the limb pattern in the $A-P$ direction (antero-posterior). The gradient uf influence of this zone has a high point of influence on the limb pattern at the posterior end of the limb and a low point at the anterior end. Balinsky (1981) has found that the digits 1 and 2 appear first followed by 3, 4 and 5 . This could mean that the lower gradient of influence anteriorly advances the development of digits 1 and 2 so that they form before 3,4 and 5 .

To sum up, it is seen that, as each digit forms, it inhibits the adjacent cells from forming another digit. This effect is used in the model being proposed to explain how a limited number of ce 17 s in the progress zone could be partitioned to form a reduce number of digits.

In support of the above proposal, in which insufficient cells are available for digit formation, is the observation of Cairns (1977). This worker observed a mutant in the chick, which exhibits the phenomenon of polydactyly. The mutant was called Talpid ${ }^{2}$ and the mutant chick had a limb bud of much larger diameter than the normal 1 imb bud. What is most interesting is that the 1 imb bud went on to form more than the usual number of digits. This would be expected according to the arguinent proposed above as the sequential process of differentiation and inhibition would continue across the 1 imb bud until there was no more available tissue.

The inhibitory model of repeating structures can also be used to explain the formation of a series of bent digits. If the limb bud is initially bent as in the early stages (see pages 97 to 111), differentiation and inhibition would follow the shape of the initial bent bud, as illustrated in Figure 4.7 on page 142, and a series of bent digits would form.


Figure 4.7 Fomation of bent digits

### 4.2 Effects of concentration and stage on the severity of the resulting deformities

in the present research, it was nucessary to find a favourable concentration of 5-FUAR for the in vivo experiments. Various concentrations ranging from $0,2 \mu \mathrm{~g} / \mathrm{m} 7$ to $20 \mu \mathrm{~g} / \mathrm{ml}$ were tried. All the concentrations used produced similar deformities, as was seen in section 3.2. There does not seen to be a definite relationship between the concentration (at the concentrations used) and the Tevel of eformity, possible due to the periodic nature of the drug treatment. More serious deformities were not produced by the higher concentrations. (N.B * Much higher concentrations than these were not used due to the prohibitive cost of the drug.) This suggests that at the concentrations used, there were always enough cells to form proximal elements of the limbs as mentioned in section 3.2 and that cell depletion only occured during the formation of the digits.

The stage at which the animals were first treated with the 5 FUdR did not appear to affect the severity of the deformity. The animal could be placed into the solution at any stage between 43 and 50 and the same effects were noticed, see section 3.2. This once again suggests that there were enough cells for the proximal elements and the crisis of cell production only occurs during the formation of the distal elements. When treated for the first time beyond stage 50, deformities did not develop, suggesting that the "progress zone" cells required for the formation of "Il the elements of the 1 imb had already been produced as discussed on pages 13 to 18.

### 4.3 The use of 5 -BUdR to produce deformities

We turn now to some experiments which were carried out to evaluate the effect of a related drug, viz 5-BUdR, which is known to inhibit cell differentiation but not cell division in cells in culture.
(5-BUdR was initially used alone or in combination with 5 -FUdR due to its effect in preventing cell differentiation.) Stockdale (1964) preverited the differentiation of muscle celts in culture by using $5-B U d R$. In the present research, it was found that $5-B U d R$ did not appear to cause any deformity as the deformities only appeared when 5-FUdR was present, either in combination with 5 -BUdR or on its own. Deformities never appeared when the animals were treated with 5-BUdR only. One explanation for this could be that in the swimming tadpole not enough 5-BUdR was absorbed to have any effect or the giving of periodic doses once weekly allowed the DNA to replicate nomally without taking up 5-BUdR between doses and differentiation was not sufficiently affected to be noticed.
$\rightarrow$ (1) It will be recalled that Agnish and Kochnar (1976) grew isolated limbs in tissue culture with 5 -BUdR and found that chondrogenesis was completely suppressed. In the present study whole animals were maintained continuously in water to which the drug was added once a week. During this time the animals would be continuously synthesizing their own supply of 'endogenous' thymidine. It is well known from experiments on the culture of cells in 5-BUdR (Levitt and Doffman 1972) that the simultaneous addition of thymidine in equimolar amounts to the medium can override the effects of $5-B U d R$. It is assumed that 5 -BUdR did not affect the experimental animals in this study as endogenous thymidine competed with 5-BUdR; blocking its normally deleterious interference with differentiation as reported in the article by Anderson and Wilt (1972). A number of other tissues also have differentiation blocked reversibly when treated with $5-B U d R$. In all these cases, however, isolated cells or tissues were cultured in 5 -BUdR continuously in the absence of thymidine.

It coulu be argued that $5-B U d R$ did rot enter the circulation and therefore prosent reaults did not respond to typical 5 -BUdR inhibition of differentiation. This is, however, unlikely as tadpoles maintained in water containing ${ }^{3} H$-thymidine, take it up, and $H$-thymidine has been demonstrated in the dividing cells of various organs of the tadpnle (Goldin 1977). It is extremely likely that 5 -BUdR would be taken up in the same way as ${ }^{3}$ H-thymidine by tadpoles, in line with the way cells in culture take up 5-BUdR. This highly likely assumption could be tested by maintaining tadpoles in $3_{H-5-B U d R}$, although the cost of thir approach would be prohibitive. A less costly approach would entail injecting small amount of 5 -BUdR into the tadpole on a daily basis, although this approach would probably result in a high rate of mortality.*

### 4.4 The effect of 5 -FUdR on the uptake of thymidine

These experiments were set up (see section 2.2) to test the effect of 5 -FUdR on thymidine uptake, on the 11 mb in vivo. It will be seen from the results that 5 -FUdR inhibited the uptake of ${ }^{3} H$-thymidine into the hindlimb buds. There are two possible explanations for this, either so many cells had stopped dividing that less thymidine Was required for overall cell division, or (for some reason) 5-FUdR is also able to block the uptake of both enodenous and applied ${ }^{3} \mathrm{H}$ thymidine (see Figure 1.46). However, the most sensible esplanation at this stage would seem to be that the experiment does show that 5FUdR inhibits the DNA synthesis and thus it blocks and interferes with the metabolism. However, the degree of variance in the method caused this line of experimentation to be abandoned. This degree of variance could be caused by the fact that tadpoles grown in crowded conditions show varying mitotic rates. This variance can be reduced if they are grown singly in ${ }^{3} H$-thymidine as Hurwitz (1979) showed that growing tadpoles show different mitetic rates.

### 4.5 Buoyant density analysis of DNA

by analytical ultracentrifugation
At an early stage of this project, some experiments were carried out, but were discontinued for various reasons. These experiments are briefly summarised.

Experiments were set up to see whether the $5-B U d R$ was beins incorporated into the tadpole DNA during metanorphosis and to see whe ther the 5-FUdR had any effect on metamorphosis. In the DNA from tadpoles not treated with 5-BUdR (see Figure 3.21) only one main band of DNA was found as should be expected. On the densitometer trace (see Figure 3.23 ) this is seen as peak c. When 5 -BUdR was added, the ultraviolet absontion photograph of the ONA showed two bands, the normal DNA band and the heavy DNA band due to the $5-B U d R$. On the densitometer trace this showed up as peak d. When 5-FUdR was added to the solution these same two bands are also seen, peak $b$ and c. However, peak c representing the heavy DNA appears to be wider than peak $d$ the heavy DNA band in the experiment using only 5 -BUdR. This suggests that more 5 -BUdR was taken up in the presence of 5 FUdR due to the lower concentration of thymidine. Because of the relative insensitivity of the method, these experiments were dicontinued.
$\rightarrow$-(3) The order of resolution in terms of the analys is of heavy DNA. by the analytical ultracentrifuge could be increased by using an a) ternate strategy. In this alternate approach the DNA could be labelled with an isotope such as ${ }^{3} \mathrm{H}$ and/or ${ }^{14} \mathrm{C}$ ( ${ }^{14} \mathrm{C}$-thymidine ${ }^{3} \mathrm{H}-5$ BUAR) and the heavy and light peaks followed in the preparative ultracentrifuge in a CsCl gradient as in the approach followed by Fabian and Wilt (1973). This would increase the degree of sensitivity of the method allowing one to examine small changes.

### 4.6. Experiments on growth and feeding of tadpoles

As the chemical 5-FUdR was costiy and in short supply, it was necessary to grow the tadpoles in small dishes of 200 ml capacity. The feeding experiments were designed to compare the growth in the normal 2 litre capacity trays with the growth in the 200 ml dishes and to find food that gave optimum growth in the smaller dishes. In the large trays feeding with Complan (commercial product) or feeding with liver and vegetables (commercial baby food) gave the best results as speedy growth was observed.

Liquifry, although not giving such fast growth allowed more of the tadpoles to grow to maturity (Liquifry is a commercial feed for small fish). In the small diches the best growth was given by Liquifry ar in the small quantity of water it did not go bad and cause deaths, which the other two foods did. In the larger trays this was not a problem. As the water could only be changed once weekly owing to the expense of the chemical, it was decided to use the safer and slower Liquifry, which proved to be totally adequate.

### 4.7 Conclusion

The hindlimb development of Xenopus laevis was afficted by 5-FUdR With respect to shape and patterning. This was expected due to the anti-mitotic effect of $5-$ FUdR. The resulting pattern of the deformed 1 imb was explained in terms of the sequential "differentiation inhibition" model with refcrence to the "progress zone". 5-BUdR was found to have no effect on the experiments in this study, possibly due to the periodic nature of adminis ration of the drug. That 5FUdR was the definite cause of the deformities in the Xenopus laevis hindimb is borne out by the fact that during the examination of 576 control tadpoles (reared in water during the feeding experiments in section 2.4) not one hindlimb deformity was observed, whereas five out of six tadpoles in the experimental dishes ( 5 -FUdR + water) showed some kind of deformity.

5-FUdR was found to depress external thymidine uptake, confirming the previous finding that 5-FUdR depresses DNA replication, thus having a direct effect on mitosis. It will be seen from the results that the uptake of thymidine by the left and right hindlimbs varied significantly. It has been observed that in some cases, at least, the hindlimbs of Xenopus laevis start to develop asynchronously. (Personal communication B. Fabian.) For this reason the left and right hindlimbs could differ in weight at the same stage in the animal's growth. A buoyant density analysis confirmed the uptake of 5 -BUdR into the DNA of Xenopus laevis tadpoles.

A series of feeding experiments singled out Liquifry as the most suitable nutrient for the experiments carried out in small 200 ml capacity dishes.

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## ADDENDUM TO DISSERTATION

Since the time of writing and the preparation of the dissertation for publication, a number of references pertaining to this fast moving field have appeared. Some of the more relevant referenues are listed below:

Holder N., 1981. Pattern formation and growth in the regenerating limbs of urodelean amphibia. J. Embryol. Exp.Morph. 65 (supp T.) 19-36

Maden M., 1981a. Experiments on Anuran limb buds and their significance for principles of vertebrate development. J. Embryol.Exp.Morph. 63, 243-265

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Of these references, the following relate directly to the work described in this dissertation.
Maden (1981a) showed that the frequency of supernumerary hindlimb formation by Xenopus laevis is low. This work is similar to the experiments of Cameron and Fallon (1977) discussed on page 23 of this dissertation.
Maden (1981a) also showed that when a large slice of tissue from the embryonic hindlimb (between the proximal and distal axis) is removed, the expected intercalation of missing tissue does not occur. This is contrary to what happens in the forelimbs of the newts Notopthalmus viridiscens and Amblystoma maculata as discussed on page 31 of this dissertation.
Smith and Wolpert (1981) use x-irradiation to reduce the limb bud width after a graft of the polarising region in the chick wing. This causes a loss in the expected number of duplicate digits. This type of experiment is discussed on pages 22-23 of this dissertation. A work in the literature that has a distant but interesting bearing on the findings in this dissertation is the work by Tickle (1981) in which she mixed ZPA (polarising) cells with inactive cells from the region along the anterior region of the wing bud of the chick. This mixture was grafted to the anterior region of another wing bud. This grafting of a second ZPA to the limb causes duplicate digits to form (Saunders and Gasseling 1968 on page 22 of this dissertation). Tickle progressively diluted cells from the ZPA (polarising region) with inactive cells, and a definite relationship emerged between the number of ZPA (polarising) cells and the number of duplicate digits formed.

More polarising cells were required to form duplicate digit 4 , fewer to form duplicate digit 3 and when there were too few cells no duplicate digits formed.
Therefore it appears that the number of polarising cells present can influence morphogenetic development.
These findings by Tickle (1981) concur with the proposal in this dissertation that a particular number of cells is needed for the formation of each element, and that an insufficient number of cells causes absence of digits.
While other recent papers have a bearing on the theoretical aspects of 1 imb development, none concern the experimental findings in this dissertation.

$$
\text { 6. } \quad . \quad \text { APPENDIX A }
$$

A series of normal stages in the development of the Xenopus laevis tadpole (Nieuwkoop and Faber 1967)

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$$



## Author Christie C A

Name of thesis The effect of 5-bromodeoxyuridine and 5-fluorodeoxyuridine on differentiation and metamorphosis in Xenopus Laevis Tadpoles 1982

## PUBLISHER:

University of the Witwatersrand, Johannesburg © 2013

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