Whisker growth after removal of the dermal papilla and lengths of follicle in the hooded rat

By R. F. OLIVER

From the Department of Zoology and Comparative Physiology, and the Medical Research Council Unit for Research on the Experimental Pathology of the Skin, University of Birmingham

INTRODUCTION

It is generally agreed that the dermal papilla is a vital component of the hair and feather follicle. Lillie & Wang (1941, 1944) and Wang (1943) have shown for feather follicles that if the dermal papilla, which normally maintains its integrity throughout the growth cycles, and its ectodermal investment are removed from the follicle, feather production ceases. However, if a dermal papilla is transplanted into these ‘deprived’ follicles, renewed feather growth is induced. An inductive property is also ascribed to the dermal papilla of the hair follicle (Chase, 1955; Cohen, 1961). Chase has suggested that in the hair follicle the dermal papilla retains its integrity throughout the growth cycles and induces renewed follicle activity at the end of telogen.

However, relatively little experimental work has been performed on the dermal papilla of the hair follicle to determine the exact role of the papilla in follicle maintenance and hair growth. Crounse & Stengle (1959) consider that the dermal papilla is essential for the maintenance of the hair follicle. They demonstrated that human ‘hair roots’ degenerate after removal of the dermal papilla when implanted into Millipore chambers in the peritoneum of mice. Similarly Wolbach (1951), Geary (1952) andBillingham (1958) believe that unrenewed hair growth after the application of various physical agents on to large populations of hairs results primarily from the destruction or inactivation of the dermal papilla.

It has been shown, from histological studies of anagen hair follicles, that the volume of the matrix in the hair bulb varies directly with the height of the dermal papilla and that the number of mitoses present in the matrix bears a constant ratio to the number of cells in the dermal papilla. Similarly, it has been shown that there is a constant proportional relationship between the volume of the

1 Author's address: Medical Research Council, Unit for Research on the Experimental Pathology of the Skin, Medical School, University, Birmingham 15, U.K.
matrix and the size of the dermal papilla (Van Scott & Ekel, 1958; Van Scott, Ekel & Auerbach, 1963). Van Scott and his associates suggest that the dermal papilla is the 'limiting factor' in these correlations.

Cohen (1961) devised techniques for operating on the comparatively large vibrissa follicles in the rat. These enabled him to make an experimental study of the function of the dermal papilla in fibre production by transplanting various root components into ectopic sites. Vibrissae have the same essential structure as pelage hairs (Text-fig. 1) and also produce hairs in a cyclic fashion. He deter-

Text-fig. 1. Diagrammatic sagittal section of a large anagen whisker follicle with details of muscle attachments and blood and nervous supply to follicle omitted. AP, Apex of papilla; BS, basal stalk of papilla; C, capsule; CS, cavernous sinus; CV, club vibrissa; DP, dermal papilla; GM, glassy membrane; IE, inferior enlargement; IRS, inner root sheath; M, matrix; ME, medulla; ML, mesenchymal layer; ORS, outer root sheath; RS, ring sinus; RW, ringwulst.
mined that transplanted ‘end bulbs’ and ‘whole papillae’ (the dermal papilla and its ectodermal matrix) were capable of producing generations of whiskers ectopically and thought it likely that follicles deprived of their papillae ceased to produce further whiskers.

It was thought that it might be profitable to utilize Cohen’s elegant operative technique to make a detailed study of the effects on the vibrissa follicle of removal of its various root components, including the dermal papilla. In order to assess the effects of these operations it was also necessary to study the normal growth of whiskers.

**MATERIALS AND METHODS**

An inbred strain of hooded rats was used. Preliminary observations showed that the major vibrissal follicles on the upper lip are widely spaced and constantly arranged in well-defined antero-posterior and ventro-dorsal rows, so that any follicle can be identified by cross-reference (Text-fig. 2).

Text-fig. 2. Arrangement of the major vibrissal follicles on the upper lip of the hooded rat and method of annotation. Large dots indicate the follicles studied in this work; the smaller dots indicate lesser vibrissal follicles which also occur anterior and ventral to those marked.

1. **Observation of follicles**

Observations of the whisker follicles were undertaken routinely on all animals. The rats were anaesthetized with ether and the whiskers or follicle positions on the whole lip were examined under a binocular microscope to determine whether the follicles contained one or two whisker shafts. This information was then recorded on a ‘whisker map’ (e.g. Text-fig. 3), a diagrammatic representation of the follicle arrangement on the lip; single dots were used to represent follicles with a single whisker merging from them, circles were drawn around the dots if
the follicles contained a club and a growing whisker. If no whisker was present a cross was drawn.

![Text-fig. 3. Record of distribution of clubs and growing whiskers on both upper lips of the same rat at the first observation taken in the study of normal whisker growth. (Cf. Text-fig. 2.)](image)

2. Determination of rates of growth and cycle duration

Whiskers were measured in millimetres using a split-down ruler. In this way the club lengths and the rates of whisker production for any follicle position were obtained. After operations, measurements were also taken of whiskers present in the corresponding unoperated follicles on the opposite lip. This enabled a comparison to be made of club lengths produced naturally and after operation.

The cycle time of a follicle was determined either by obtaining the time between the successive presentation of the same length of growing shaft, or, less accurately, by determining the period of time between the successive presentation of the same pattern of whisker emergence in the vertical row in which the follicle occurred. The basis for the latter method is described in the Results section on normal whisker growth.

(i) General procedure

Anaesthesia was induced by intraperitoneal injection of Nembutal (Abbott), 0.055 c.c./100 g body weight.

Whisker roots were exposed for operation by the technique described by Cohen (1961). The lip was bathed in spirit and an incision made below the most ventral horizontal row of whiskers. The incision was extended dorsally by cutting parallel to the skin surface. The whisker pad was reflected and retained with a pair of artery forceps. In some rats the initial incision was made dorsal and parallel to the top row of whiskers, then extended ventrally, to expose the dorsal pigment-bearing whisker roots.

The ‘proximal’ ends of whisker roots were then dissected free from connective tissue. (Throughout, ‘proximal’ will refer to the bulbar end of the follicle, as
exposed on reflecting the lip-flap at operation; ‘distal’ will refer to the upper region of the follicle, which is immediately confluent with the epidermis.)

The follicles were thus exposed either for the removal of dermal papillae or for the removal of root ends. Only one of these procedures was ever performed on any one rat.

After operation the whisker pad was stitched back in position. The wound healed within a week, and at no time did the animals have difficulty in drinking or feeding.

(ii) Removal of dermal papillae

The whisker root was held firmly with a fine pair of forceps, well away from its bulbar end, and a small incision made in the centre of the bulb at its most proximal aspect with a fine-pointed sliver from a double-edged razor blade mounted on a needle holder. The incision was usually extended with the razor, and the bulb gently squeezed with another pair of fine forceps to extrude the dermal papilla. The papilla was then removed and dropped into fixative and the follicle from which it had been removed was recorded. Dermal papillae were removed from eighteen follicles in a total of seven rats.

Operated follicles were kept under periodic observation for at least 4 months.

(iii) Removal of root ends

Varying lengths of whisker root were cut off from the proximal end of the follicles. The amount removed was deliberately varied, from just less than the ‘end bulb’ (which term Cohen (1961) used to describe the bulbar proximal part of the follicle) up to a level within the ring sinus. Removed root ends were either deposited into saline, prior to transplantation, or into fixative.

Root ends were removed from thirty-seven follicles in a total of eight rats. Sixteen of the root ends were implanted as autografts under ear skin as a test of viability of the detached root segment, using the technique described by Cohen (1961). Thirteen were fixed, processed and sectioned serially. They were then examined to assess the stage of the cycle at operation, to determine whether the complete dermal papilla, especially the apex, had been removed, and to determine whether the Vth cranial nerve supply to the follicle had also been removed. The length of each root end was calculated by using a calibrated eye-piece micrometer or, in one case, from the number of transverse sections. The width of the matrix at its widest point was measured so that the length of root removed could also be assessed as a ratio of its length against width of matrix. In this way the disparity in follicle dimensions, according to the disposition on the lip, is in some measure compensated for.

The growing shafts were plucked immediately after root end removal, at approximately the end bulb level, from the five follicles in one rat, but not in the other rats.

Operated follicles were kept under periodic observation for at least 3 months,
except for one rat which died during a routine observation, 38 days after opera-
tion.

The ears into which root ends had been implanted were also examined for
evidence of whisker growth.

(iv) Histological methods

Removed dermal papillae were fixed in formol-saline, stained with Mayer’s
haemalum and mounted whole.

Root ends were fixed in formol-saline, Zenker’s or Bouin’s fixatives. They
were cut serially at 8 μm, either in the vertical or transverse plane with respect to
the long axis of the follicle, and stained with Ehrlich’s haematoxylin and eosin,
Cason’s trichrome stain, or a combination of Weigert’s haematoxylin, and alcian
blue, and counterstained with Curtis’s Ponceau S. The alcian blue was particu-
larly instructive since it is specific for acid mucopolysaccharides and stains
dermal papillae blue-green in anagen follicles.

RESULTS

1. Normal whisker growth

The arrangement of the major vibrissal follicles on the upper lip of hooded
rats is shown in Text-fig. 2. This arrangement is constant; it can be observed in
rats of either sex selected at any age.

The growth pattern was studied in detail in two male litter-mate rats aged
6 weeks. Observations were made at intervals of 4–9 days for over 2 months.
When observations were first started both lips of the same rat exhibited almost
identical whisker maps (Text-fig. 3), while the maps for both rats were very
similar, differing only in the number of club shafts lost in row d. The relations-
ships of the patterns of whisker gain and loss of both lips of both rats, and the
relationships of each rat to each other, were maintained over the whole period
of observation—some 9 weeks.

Over the first 3–4 weeks all the follicles on the lips exhibited a regular gradual
loss of clubs present at the first recordings, with the gradual appearance of new
whiskers throughout the vertical rows up to the 52nd day.

Club loss and the gain of new whiskers proceeded in an antero-posterior
direction over all four lips, either activity being completed, or very nearly com-
pleted, in any particular vertical row before occurring in the next more posterior
row.

New whiskers emerged in the most ventral follicle first, in each of the vertical
rows a–f, then, progressively, in the more dorsal follicles except that in rows a and
b first emergence occurred in follicles 1 a and 1 b so that in these rows whiskers
emerged last in follicles 2 a and 2 b.

This same pattern of whisker appearance in the vertical rows has been ob-
erved in the unoperated follicles of sixteen rats, of both sexes, used in other
Whisker regeneration

experimental series which were under observation over far greater periods of time than 2 months.

Whisker emergence throughout each vertical row in the young male rats was completed within about 9–11 days.

The time for a phase of growth for each of the vertical rows was calculated either from the successive presentation of the same number of newly emerged whiskers in a particular row, or similarly, from the complete appearance of whiskers throughout a row to the appearance of the next generation of whiskers throughout that row. Row f demonstrated some 14–17 days between the successive appearance of new whiskers; row e about 3 weeks; row d about 4–5 weeks; row c about 5 weeks. For rows b and a the times for a phase of growth were calculated from the patterns presented by club loss. These times may be slightly less than the undisturbed times since frequent handling of the clubs at observations may have loosened their attachments and hence led to their premature loss. Row b required approximately 6½ weeks to complete a phase of growth and row a about 7 weeks.

Table 1. *Tabulation of average club lengths (mm) for each follicle position as obtained from four male rats during their third month of life*

Figures are presented as if on the right lip of a rat

<table>
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</tr>
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</table>

The club lengths of whiskers in the five vertical rows a–e were measured, when they presented themselves at intervals on both lips of these two and two other male rats over a period of a month (during their third months of age) as shown in Table 1.

There was an antero-posterior gradation in club lengths in each horizontal row, with the longest whiskers in the most posterior follicles. The horizontal row 4 contained, as a whole, the longest clubs along its length, and row 1 the shortest.

With the exception of the follicles in the horizontal row 1, each vertical row contained clubs of about the same order of length; row a 52–55 mm, row b 40–45 mm, row c 27–30 mm, row d 18–22 mm, and row e 9–12 mm.

The rates of growth of whiskers in each follicle position were determined in two male rats during their third month of life and are shown in Table 2.

In general the results showed a gradation in the rates of whisker production along any horizontal row, with the highest rate in the most posterior follicle.
The follicles in each vertical row produced whiskers at about the same rate: 1·2 + mm/day in row a, 1·2 mm/day in row b, about 1 mm/day in row c, just under 1 mm/day in row d, and perhaps 0·7 mm/day in row e.

It would appear that there is a period of some 5–10 days between the cessation of growth, i.e. club formation, and the emergence of the next-generation whisker, since this period of time was recorded in several follicles during which the same club length was present before the appearance of the new whisker. It was also noted that the clubs were retained until the growing whiskers were about three-quarters grown.

Table 2. Tabulation of average rates of growth of whiskers (mm/day) as obtained from two male rats during their third month of life

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<td>—</td>
<td>1·3</td>
<td>1·1</td>
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</table>

2. Removal of dermal papillae

Material from four of the eighteen follicles operated on was either lost at removal or badly damaged. The dermal papillae from the remaining fourteen follicles were examined directly after removal and stained; whole mounts were prepared of these specimens. Eleven of these were dermal papillae with intact 'bodies' and a good length of apex (five also had the basal stalk and were thus complete dermal papillae); in a further two the complete body and a short length of apex were present; and one apparently consisted of a portion of papillary material and epidermal tissue. All of the dermal papillae had varying amounts of matrix attached to them (Plate 1, figs. A, B).

All 18 follicles deprived of these dermal papillae subsequently produced generations of whiskers.

The first whiskers appeared between 15 and 24 days in 14 of the follicles and were first recorded at 27, 30, 38 and 45 days in the other four.

Fourteen follicles, including the five from which complete dermal papillae had been removed, produced generations of whiskers within 3 mm of the approximate expected length for their follicle position. A further follicle first produced two clubs shorter than the whisker present in the follicle at operation, then in subsequent generations produced clubs of approximately the expected length. Two follicles consistently produced generations of whiskers 5 and 11 mm respectively short of normal. Recordings for the 18th follicle were inadequate to make a comparison of club lengths.
Figs. A, B. Whole mounts of dermal papillae removed from follicles which subsequently produced generations of whiskers of normal length. The dermal papilla in fig. A consists of a long apex, entire body, and the basal stalk. Some matrix is attached to the papilla and melanocytes are present on the surface of the neck of the papilla. Mayer’s haemalum. Fig. A, x 85; fig. B, x 75.

Fig. C. Rat II, 15 weeks after removal of root ends from follicles 4b–4f on the left lip. Short club-length whiskers (2nd generation after operation) are present in follicles 4b and 4c.

Fig. D. Vertical section of the root end removed from follicle 1a, rat VI. The dermal papilla has no attenuated apex. The follicle subsequently produced generations of whiskers 46% of the normal length. Weigert’s haematoxylin, alcian blue and Curtis’s Ponceau S. x 65.

Fig. E. Vertical section of the root end removed from follicle 1b, rat V. The distal termination of the papilla apex can be seen. A whisker of approximately 30% of the normal length was produced after operation. Weigert’s haematoxylin, alcian blue and Curtis’s Ponceau S. x 65.

Fig. F. Vertical section of the root end removed from follicle 2a, rat V. No whisker was produced after operation. Ehrlich’s haematoxylin and eosin. x 65.
In general, however, there was no indication of a gradual attainment of normal whisker length with successive generations; several follicles produced clubs 4 mm or more longer than the first post-operatively produced club, but as the rats were still growing an increase in club lengths would normally be expected.

Fourteen of the growing vibrissae present at operation were lost by the time of the first observation (i.e. between 0 and 20 days). Of the other four, a complete dermal papilla had been removed from one follicle, yet the shaft present at operation had persisted. Damaged material had been removed from the other three; they may have been in catagen at operation allowing club formation to be successfully completed.

Fifteen of the follicles were definitely in some stage of anagen at operation, and contained quarter-grown to over three-quarter-grown fibres.

3. Removal of root ends

Since vibrissae of normal, or nearly normal, length were produced after the removal of dermal papillae alone, it was necessary to perform more drastic removals of root material in order to investigate the extent of the regenerative potential.

Twenty-eight of the 37 follicles from which root ends were removed produced whiskers; generations of whiskers were observed to grow (Plate 1, fig. C) from 25 of these follicles (one rat died at 38 days after operation).

The first post-operative whisker appeared between 20 and 30 days after operation in 26 of the follicles and after a longer period of time in the other two.

Club lengths ranged from 10 to 90 % of the club lengths normally produced in the same follicle positions, with the majority (15) in the 25–50 % range. Expressing the actual club length as a percentage of the normal club length provides a measure of the degree of regeneration in terms of whisker lengths produced (Table 3).

The dermal papilla, including its apex, was present in its entirety in all 13 of the root ends sectioned (Plate 1, figs. D, E and F). Nine of the 13 follicles from which they had been removed produced whiskers, ranging from 29 to 50 % of the normal length.

Part of the sensory nerve supply to the follicle was also removed with nine of the 13 root ends and probably severed in other follicles in their preparation for root end removal.

There was a correlation between the length of root end removed at operation and the subsequent degree of regeneration. If the lengths removed are expressed in terms of 'matrix diameters', which in some measure compensates for the disparity in follicle size according to the follicle position on the lip, this correlation is even closer (Table 4). These observations are highly indicative that the greater the length of root end removed the shorter the fibre produced with, apparently, a level of approximately 1 mm or a third of the total follicle length above which fibres are not regenerated (Plate 1, figs. D, E, F).
Table 3. Tabulation of average club lengths recorded after removal of root ends, club lengths expected for these follicles normally, and % of recorded lengths against expected lengths

<table>
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<tr>
<th>Animal and sex</th>
<th>Follicle</th>
<th>Average club length (mm)</th>
<th>Approx. expected length (mm)(^1)</th>
<th>% of recorded against expected club length</th>
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\(^1\) Club measurements obtained from the non-operated lip.
\(^a\) Lengths produced by 38 days when rat died. These are probably nearly club lengths.
W = whisker produced but rat died prematurely.
Comparatively longer lengths of whisker were present at 31 days in the five follicles of the rat which were plucked at operation.

All but one of the 23 follicles for which the stage of cycle at operation was determined were in anagen, ranging from just before whisker emergence above skin level to 0.5 grown fibres. One follicle was in early catagen. There was no apparent correlation between the stage of cycle at operation and subsequent follicle behaviour.

Table 4. Comparison of the % of regeneration after root end removal (derived from Table 3) with the actual length of root end removed and with the ratio of the length removed over the diameter of the matrix, which helps to compensate for disparity in follicle dimensions according to their position on the lip.

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<th>Animal and follicle</th>
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<td>50</td>
<td>1.2</td>
</tr>
<tr>
<td>VI, 1a</td>
<td>0.44</td>
<td>46</td>
<td>1.6</td>
</tr>
<tr>
<td>VI, 1b</td>
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<td>40</td>
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</tr>
<tr>
<td>III, 2b</td>
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<tr>
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<td>30</td>
<td>2.5</td>
</tr>
<tr>
<td>V, 1b</td>
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<td>31+</td>
<td>2.5</td>
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<tr>
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<td>0.73</td>
<td>27+</td>
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<tr>
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<td>24</td>
<td>2.7</td>
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<tr>
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<td>W</td>
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<tr>
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<td>10</td>
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</tr>
<tr>
<td>III, 3c</td>
<td>1.75</td>
<td>0</td>
<td>5.8</td>
</tr>
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</table>

1 Length derived from number of transverse sections.

W = Very short whisker produced, but rat died before club formed.

Cycle times were calculated for seven of the follicles which produced whiskers after operation and compared with the approximate normal cycle times of the corresponding unoperated follicles on the opposite lip. The experimentally induced cycle times were also compared with the cycle times of normal follicles producing similar lengths of whisker. These comparisons showed that three of these seven follicles had cycle times of approximately normal duration for their positions on the lip, even through two of these produced clubs 17 mm (57%) and 9 mm (45%) short of normal, and four of the seven follicles had cycle times longer than the club lengths produced would seem to warrant. The rates of growth of whiskers from the seven follicles were 0.1-0.2 mm/day slower than the normal rate for the same follicle positions, but faster by 0.1-0.2 mm/day than follicles naturally producing whiskers of similar length.

Of the 16 root ends implanted in ear skin, four produced generations of whiskers above skin level (4–6 mm long), and a further five produced whiskers below skin level.
DISCUSSION

Normal growth

The arrangement of the major vibrissae within the mystacial region of the hooded rat is essentially the same as the arrangement in the mouse, which has been described by Danforth (1925), Grünberg (1943a, b), and Davidson & Hardy (1952), except that Davidson & Hardy's diagram indicates extra follicles in the most ventral horizontal row.

Dry (1926) observed that the shortest vibrissae present on the upper lip of the mouse at birth became clubs by two weeks and the longer ones completed their growth in turn, the longest becoming clubs in the fifth to sixth week. He also observed that by 4 months more generations of short vibrissae in the anterior follicles had been produced than long vibrissae in the more posterior follicles. The present work extends these observations in relation to the rat.

The prominent gradation in times for each of the vertical rows to complete a phase of growth demonstrates that phases of growth must be entered into by the vertical rows individually and without reference to the behaviour of adjacent rows. Thus there can be no overall waves of growth on the lip. Dry also commented on the fact that the mode of succession of the vibrissae is in striking contrast to the overall progression of waves of hair growth on the main body area.

In the young male rats the time between the first appearance of a whisker in the most ventral follicle of each of the three anterior vertical rows c, d and e, and the appearance of a whisker in the most dorsal follicle was about 10 days. (The sequence was 5, 4, 3, 2, 1.) Similarly, in the two posterior vertical rows a and b the time between the appearance of whisksers in the first and last follicles was also about 10 days, although the order of presentation was different; the first whisker appeared in the dorsal follicle, followed progressively from the ventral follicle dorsally (1, 5, 4, 3, 2).

The time of 10 days for whisker emergence throughout each of the vertical rows e–a compares with the phase times of 2, 4–5, 5, 6 and 7 weeks for these rows. This behaviour in each of the vertical rows appears to merit the description of synchronal growth, according to the definitions offered by Mercer (1961) and Chase & Eaton (1959); however, these authors were referring to waves of growth in populations of hairs with appreciable resting periods. Similarly, Durward & Rudall (1958) have observed that in animals exhibiting regular waves of hair growth the duration of the growing period in neighbouring follicles is about the same, a situation paralleled in each vertical row of vibrissae in which the follicles appear to have growing periods of similar duration.

Passing posteriorly from the most anterior vertical row, the vibrissal follicles within each vertical row demonstrate progressively longer cycle times, correlated with the production of longer fibres as well as faster rates of growth.

It is possible that the prominent gradation in behaviour in the vertical rows
Whisker regeneration

is correlated with the mode of follicle development as described by other workers in the embryo rodent (mouse) (Danforth, 1925; Grüneberg, 1943a; Hardy, 1951). Hardy states that 'There is a ventro-dorsal gradient in the time of development of the rows, and also a latero-mesial gradient in both time of development and size of follicles'.

The most posterior row, the first to appear in ontogeny, displays the longest phase time, associated with the growth of the longest whiskers, at the fastest rate, while the follicles in successively more anterior rows reflect, in their gradation in phase times, lengths of whisker produced, and rates of growth, the progressive appearance of their follicles in development. Moreover, the ventro-dorsal gradient in time of development is apparently faithfully repeated at each phase of growth in the vertical rows, especially c, d, e and perhaps f, since emerging whiskers in a phase of growth appear in the ventral follicles first, then progressively in the more dorsal follicles.

The time of 5–10 days observed between club formation and the emergence of the next-generation whisker suggests that a resting phase in the cycle, if existent, is of very short duration, especially since Ebling & Johnson (1964) report a time of 6 days between the initiation of anagen and fibre emergence from the much shorter pelage follicles of the rat. Sections of vertical rows of vibrissae in which club formation was occurring reveal no dramatic shortening of the vibrissal follicle nor the formation of papilla ‘rests’ such as occur in pelage hair follicles at telogen; the dermal papilla, though diminished in size, was always at least partly contained by the epidermal component. Similarly, in the mouse, Dry (1926) and Melaragno & Montagna (1953) describe no telogen stage in the vibrissal cycle. Since there is very little shortening of the follicle at catagen the club vibrissa may be positioned by a distal movement of at least part of the outer root sheath. This would be consistent with the suggestion by Straile (1962) that in hair follicles the upward movement of the club hair may be associated with a corresponding movement of the outer root sheath cells.

Whisker regeneration

Montagna & Van Scott (1958) have defined the dermal papilla of hair follicles as ‘the connective tissue element which is enclosed by the bulb of the follicle during anagen, and which forms a compact ball of dermal cells underneath the ‘hair germ’ during telogen. The dermal papilla is attached to the connective tissue sheath by a basal stalk’. Structurally the dermal papilla of large vibrissa follicles of the rat at anagen differs from the papilla of pelage hairs in that it has an apical region which may extend beyond the confines of the bulb of the follicle (Text-fig. 1; Plate 1, fig. E), and also, as mentioned above, does not form papilla ‘rests’.

Examination of removed dermal papillae showed in most cases that they were complete but that part of the basal stalk may be left in the follicle. It is also possible that the cut shafts in some of the follicles from which root ends had
been removed at, or just above, the end bulb level contained papillary apex material. However, conclusive evidence that fibres can regenerate in the absence of any traces of the original papilla, which may otherwise have effected restitution of a new papilla, is provided by the fact that all of the thirteen removed root ends examined contained the entire dermal papilla, yet nine of the follicles from which they had been removed subsequently produced generations of whiskers.

These findings contrast with the observations of Lillie & Wang (1941) on the feather follicle. Whether this discrepancy is due entirely to differences in the intrinsic properties of the vibrissa and feather follicle or arises from differences in details of local anatomy such as availability of blood supply, etc., cannot be determined yet.

Vincent (1913) reported that after severing the sensory nerve supply to the nose and vibrissae in white rats, trophic changes occurred in the hairs; they became curled and brittle, then eventually broke off. However, no obvious correlation could be found between the length of fibre produced, after the removal of root ends, and the incidence of removal of part of the sensory supply to the follicle; no trophic changes in the fibre were apparent, even up to 400 days after operation, in follicles from which the nerve supply was known to have been removed with the root end.

The majority of fibres produced after the removal of the dermal papilla attained normal club length and presumably had cycle times of normal duration; after the removal of root ends either whiskers shorter than normal were produced with, in some follicles, cycles tending to approach normal, or no whisker at all.

It was determined that the greater the length of root end removed, the shorter the whiskers subsequently produced. Measurements of the root ends removed from three of the follicles which did not produce whiskers after operation indicate that there is a certain level, about one-third of the distance up the follicle, beyond which whiskers are not produced.

Apparently that part of the follicle remaining which is competent to regenerate fibres cannot readjust to the normal pre-operative state since, in general, particular follicles consistently produced post-operative generations of clubs of about the same length and did not eventually produce whiskers of normal length. It is possible that part of the proximal extent of the follicle, and hence part of the lower extent of the potential regenerative system, was removed with the dermal papilla in the three follicles which produced shorter than normal whiskers after removal of the dermal papilla.

Further studies will report on the histological changes which occur during whisker regeneration and present an analysis of the importance of various follicular structures in this process.
SUMMARY

1. The arrangement and mode of growth of the major vibrissae on the upper lip of the hooded rat has been studied.
2. There was an antero-posterior gradation in rates of growth and club lengths produced in each of the vertical rows. The longest vibrissae were produced at the fastest rate in the larger follicles in the posterior vertical rows.
3. There was a similar antero-posterior gradation in the times for a phase of growth throughout each of the vertical rows.
4. There are no overall waves of growth on the upper lip; phases of growth are entered into by the vertical rows individually.
5. The suggestion is made that the above behaviour may be related to the mode of development of the vibrissae in the embryo.
6. A method has been described for the removal of the dermal papilla *in situ* and the removal of dermal papillae and various lengths of whisker root ('root ends') have been performed to determine the effects of these operations on whisker growth.
7. After removal of dermal papillae, all 18 follicles produced generations of whiskers; 15 of these follicles produced vibrissae of normal or nearly normal length.
8. After removal of root ends, whiskers of shorter than normal length were produced from 28 out of 37 follicles.
9. Conclusive evidence was obtained that generations of vibrissae can be produced after complete removal of the dermal papilla.
10. The degree of regeneration, as expressed by the length of post-operative whiskers produced, was apparently dependent on the amount of proximal follicle root removed.

RÉSUMÉ

*Croissance des vibrisses après extérèse de la papille dermique et du follicule sur une certaine longeur, chez le rat de la lignée ‘mantelé’ (*‘Hooded’*)

1. On a étudié la disposition et le mode de croissance des vibrisses principales de la lèvre supérieure du rat ‘mantelé’.
2. Il y a une variation graduelle antéro-postérieure des taux de croissance et des longueurs formées dans chacune des rangées verticales. Les vibrisses les plus longues se sont formées le plus rapidement dans les follicules les plus grands des rangées verticales postérieures.
3. Il y a une variation graduelle antéro-postérieure semblable dans le temps, pour une phase de croissance considérée, à travers chacune des rangées verticales.
4. Il n’y a pas de vagues de croissance générales sur la lèvre supérieure; les phases de croissance commencent individuellement dans les rangées verticales.
5. On suggère l’hypothèse que le comportement précédent puisse être en rapport avec le mode de développement des vibrisses chez l’embryon.
6. On a décrit une méthode d'exérèse de la papille dermique in situ, et on a réalisé l'exérèse des papilles et de diverses longueurs de la racine des vibrisses ('extrémités radiculaires') pour déterminer les effets de ces opérations sur la croissance de la vibrisse.

7. Après l'exérèse des papilles dermiques, les 18 follicules au complet ont produit des générations de vibrisses ; 15 de ces follicules ont produit des vibrisses de longueur normale ou presque normale.

8. Après exérèse des 'extrémités radiculaires', des vibrisses de longueur inférieure à la normale ont été produites par 28 follicules sur 37.

9. Il est manifeste que des générations de vibrisses peuvent se former après exérèse complète des papilles dermiques.

10. Le degré de régénération, tel qu'il s'exprime par la longueur des vibrisses produites après l'opération, dépend apparemment de la masse de racine folliculaire proximale éliminée.

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REFERENCES


Whisker regeneration


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