CELL BIOLOGY AND WOOL PRODUCTION AND PROPERTIES

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SUMMARY

The cell biology of the wool follicle/fibre system is briefly reviewed. Emphasis is given to the cellular basis of wool production, nutrient uptake, and some wool properties.

CELL BIOLOGY

Most people think of wool as a homogeneous fibre. Some differences in physical characteristics or properties are usually recognized: wool may be fine or coarse; crimped or lacking in crimp; sound or tender.

The wool fibre and the follicle from which it is derived are cellular structures and it is the activities of their cells which determine the rate of fibre growth and the properties of the fibre produced. By studying the cells and their activities, the cell biologist works towards an understanding of how a fibre is formed, what variations, especially genetic, exist for a given fibre component, and how these variations may be manipulated to improve wool production or quality. Fibre formation has so far received the most attention.

The cellular nature of the follicle and the fibre it is forming is depicted in Fig. 1 (Orwin, 1979), in which the black lines represent cell margins. There are a number of different cell types in the follicle and the fibre, and all of them are necessary for fibre production. Up to five of the 10 cell types formed may be found in the fibre: one forms the outer cuticle, up to three cell types constitute the cortex (the main part of the fibre), and one forms the medulla (which is usually present only in the coarser fibres).

During fibre formation, some generalized events take place. From the population of dividing cells at the base of the follicle sufficient cells pass towards the skin surface to allow the differentiation of all cell lines. Initially, most cells increase in size and undergo changes in shape. This is followed by a period of structural protein synthesis for some cell lines. In the cortex,

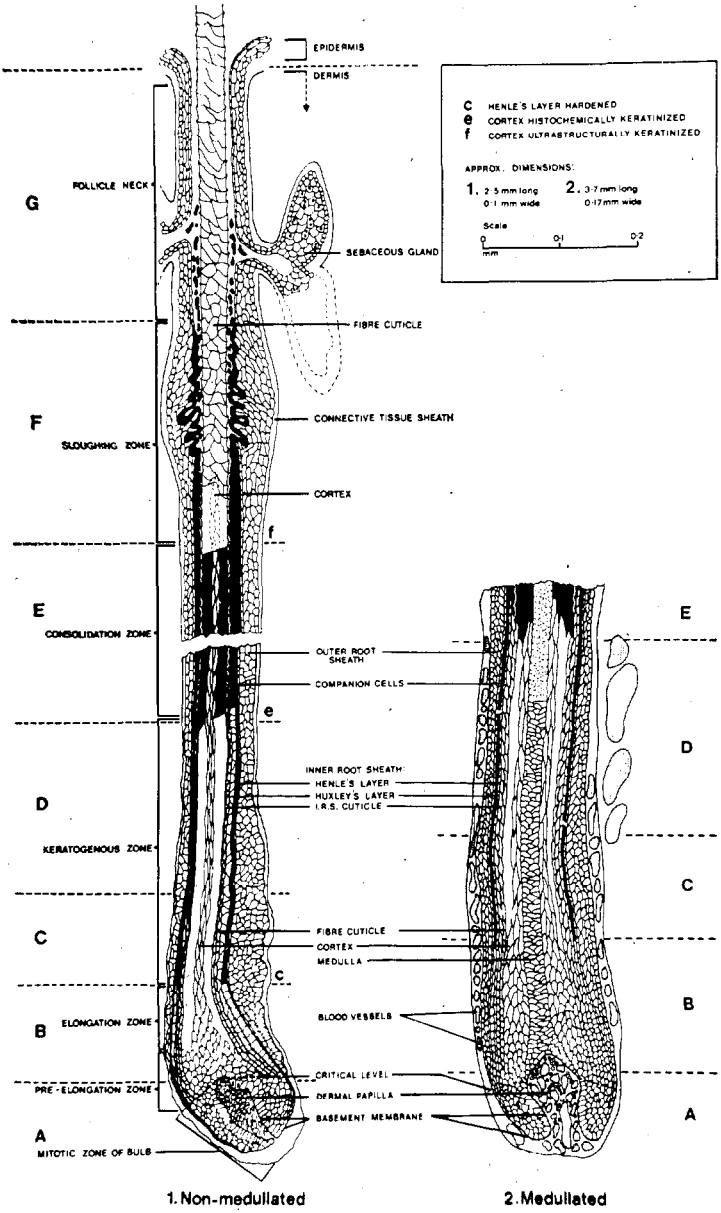

FIG. 1: *Diagrammatic representation of a wool follicle (from Orwin, 1979)*

the structural proteins are called keratins; they are produced in such amounts that they eventually fill the cells. About a third of the way up the follicle (see Fig. 1), the proteins undergo chemical cross-linking or keratinization so that the whole cellular system becomes fixed and very stable, and also non-vital. The fibre is thus fully formed below the surface of the skin. The types of keratin proteins produced in each of the three cell types forming the cortex are very important as they are associated with many fibre properties such as crimp (Kaplin and Whiteley, 1978). More detailed descriptions of follicle and fibre cytology have been published (Auber, 1952; Swift, 1977; Orwin, 1979).

Each cell is itself made up of many components (Fawcett, 1966), and these may be grouped into three major assemblages:

1. The cell surface or plasma membrane is believed to be composed of a lipid bilayer within which proteins may be found; it surrounds the cytoplasm.
2. The cytoplasm is the site of protein synthesis and contains many organelles. These are often membrane-bounded and include mitochondria, lysosomes, and Golgi complexes. Organelles carry out specialized functions within the cytoplasm of the cell.
3. The nucleus usually lies near the centre of the cell. It contains the genetic material or DNA with codes for proteins, including those of the wool keratins.

INCREASING WOOL GROWTH

What is one actually requiring a follicle to do in cellular terms when one attempts to improve wool growth? Wool growth for an individual follicle can be divided into:

(1) the provision of cells for fibre formation, where the rate of cell division is a major factor; and

(2) the size and shape of the cells that ultimately make up the fibre; these determine, in part, the diameter of the fibre formed and its rate of growth in length.

CELL DIVISION

There are two aspects of cell division and fibre production:

(1) the size of the population of dividing cells in the follicle base; a larger population produces a larger-diameter fibre (Schinckel, 1961); and

(2) the actual rate of cell division.

Cells go through a cycle in order to be able to divide (Pardee *et al.*, 1978). This cycle is divided into:

G0 — a period of mitotic inactivity:
G1 — growth of a cell to roughly double its size;
S — doubling of the genetic material;
G2 — a period prior to and preparation for
M — mitosis or actual division of the cell into two cells, each with the normal complement of genetic material.

The two cells formed can either go into phase G1 and commence another cell growth and division cycle, or into G0 where they remain mitotically inactive until stimulated to go into G1.

The proportion of follicle cells in G0 and G1 is not known; it may be expected to vary under conditions which lead to changes in wool production. Another complication results from the numbers of cells which leave the cell-division zone and enter the pathway leading to fibre formation (Wilson and Short, 1979). Many factors such as nutrition and rate of growth affect the length of G1 and the stimulation of cells from G0 into G1 (Pardee *et al.*, 1978). Most of these are unknown for the wool follicle.

Cell Growth

Once a cell has left the cell-division zone a period of cell growth follows. For instance, cortical cells increase in length three to four times (25 μm to 88-106 μm) (Wilson and Short, 1979); this is a significant factor in growth in length of the fibre. Their cross-sectional area also helps to determine the fibre diameter.

What is involved in cell growth? Obviously many factors are important. However, nutrition is the one which is universally regarded as basic to cell growth. This is true for cells preparing for cell division (G1) and for cells during fibre formation.

What sort of nutrients does the follicle cell utilize? In general, there are likely to be three types of nutrient uptake from cytological evidence (Goldstein *et al.*, 1979).

1. Small molecules, such as amino acids, which pass across a cell membrane by active transport. These can be utilized without further change, if appropriate, for such purposes as

protein synthesis. The rapid uptake of labelled amino acids into the follicle is indicative of this type of intake (Downes *et al.*, 1962).

2. Larger molecules of unknown type which are presumably derived from blood plasma. These are taken into the cells by membrane-bounded vacuoles and are enzymatically degraded into simpler molecules such as amino acids by the lysosomal system. The resulting small molecules pass across the membrane of the vacuole into the cytoplasm of the cell where they become available for other purposes.
3. Specific molecules, such as hormones and cholesterol in low-density lipoproteins, are bound to receptors in the cell membrane where they are incorporated into coated vesicles. These vesicles pass into the cytoplasm and their contents are utilized in several ways.

The molecules which follicle cell membranes bind are not known. Nor is it known if there are differences between sheep in the way they use these systems or what proportions of nutrients are taken in by each system. All that has been established is that the cytological components of these systems are present (Orwin and Thomson, 1972; Orwin, 1976). It should be pointed out that, because the fibre is made up of cells, supplies of non-protein nutrients such as cholesterol, which is needed for membrane synthesis, are as essential for fibre growth as the nutrients necessary for making keratin proteins.

Nutrient Distribution

Once into a cell, are nutrients confined to that cell alone? Blood vessels are found only around the outside of the follicle and in the dermal papilla.

Supplying regions of high nutrient demand such as the region of keratin-protein synthesis with amino acids from distant blood vessels by the systems described would appear to be a rather inefficient pathway. However, a cytological means of allowing low-molecular-weight molecules to pass directly from cell to cell exists. This is the "gap junction" of the cell membrane, which is particularly common in the wool follicle (Orwin *et al.*, 1973). It is believed that these junctions have pores in them of sufficient size to allow direct exchange of such molecules as amino acids between the cytoplasms of neighbouring cells.

Variations in the distribution of these junctions between follicles, sheep, or breeds are not known.

Nutrient Deficiency

Deficiencies or supplementation of the diet can alter the types of keratin proteins synthesized, and this in turn can cause quite dramatic changes in wool properties. For instance, deficiencies of vitamin-B complex in lambs can cause a change in the distribution of the three types of cortical cells present and the keratin proteins they contain. This results in a marked change in the amount of crimp in the fibres (Chapman, 1976).

"Break" is another wool property which is associated with nutritional changes. Differences in the three types of cortical cell, their distribution, and the proteins they contain have been found between sound and tender wools (Orwin *et al.*, 1980).

Cell Shape

Cell shape also changes in the same region above the zone of cell division where cell growth occurs. This is directed by another cell system known as the cytoskeleton. There are three main components of the cytoskeleton: microtubules (Margulis, 1973), microfilaments and intermediate filaments (Korn, 1978).

Microtubules are present in the follicle cells (Orwin and Thomson, 1973), and there is evidence that microfilaments (Woods and Orwin, 1980) and intermediate filaments are also present. The latter are of interest as they may have similarities to some keratin proteins.

The control of the shape of cortical cells is important because this contributes significantly to growth in length. However, knowledge of the control of cytoskeleton development and its variations between follicles and between sheep must await further research.

The most dramatic changes in cell shape are those associated with the formation of the scale pattern on the surface of the fibre. This pattern is important for such properties as felting. A different basis for change in shape seems to operate here, as it is apparently determined by the neighbouring cell line, the inner root sheath cuticle (Auber, 1952). However, the cytological processes by which these shape changes are brought about are not known.

There are many other cell systems which could be described, such as those concerned with cell adhesion, cortical cell type, keratin-protein organization, and movement of the fibre up and out of the follicle. Most of these have been reviewed recently (Swift, 1977; Orwin, 1979).

This brief review has attempted to portray some of the complexities of the wool follicle/fibre system. While some facts are now known about the cellular basis of wool growth and wool properties, there is obviously much more to be learnt. In particular, further knowledge on how to manipulate the follicle and fibre to improve wool production or desirable properties is required. Cell biology has a vital role to play in this area. It also has the potential to provide new insights into and solutions to current wool problems when allied to work in other fields. The collaborative work of the Whatawhata Hill Country Research Station and WRONZ on fleece tenderness is a start in this direction.

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