Journal of Medical Genetics (1973). **10**, 201.

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The Development of the Epidermal Ridges

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In man, and in his arboreal ancestors, the skin on the palmar and plantar surfaces of the hands and feet has a peculiar linear formation which is believed to help the animal to obtain a firm grip, particularly on branches of trees. The structure was first described by Nehemiah Grew, in 1684, as composed of very numerous 'ridges of equal bigness and distance and everywhere running parallel with one another'. He pointed out that, in certain places, 'triangles' and 'ellipticks' were formed and that there were pores, which excreted sweat, situated along the tops of the ridges. A new significance was given to the subject when the importance of finger-prints for purposes of personal identification began to be realized in the period from 1880 onwards. Much work was done on the problem by Francis Galton but the methods now most widely used by the police were those recommended by E. R. Henry (1900). This function of finger-prints depends upon two basic facts. The first is that, in detail, the ridges are slightly different for every finger of every person. The second is that they do not change throughout life and survive superficial injury. The precise patterns and minutiae are determined at a very early embryonic period, that is at about 10 weeks.

The origin of the medical uses of 'dermatoglyphics' nearly 50 years ago is closely associated with the work of H. Cummins who invented this new name for the science of epidermal ridges in 1926. There are differences in the arrangement of 'triangles', now called triradii, and 'ellipticks', now called loops, between individuals and there are also frequency differences which distinguish, to some extent, one ethnic group from another.

In certain abnormal conditions there are characteristic distortions of pattern. These occur whenever the abnormality affects limb growth at an early stage of development. Disturbances can be caused environmentally by diseases such as fetal rubella or by thalidomide poisoning. Specific peculiarities are sometimes the results of single abnormal genes which alter the growth of the hands and feet, as in the 'lobster claw' deformity. Consistent peculiarities occur in association with chromosomal aberrations. The effects are produced by generalized disturbances of growth of the whole body. One important example is Turner's syndrome, in which a female has only one X chromosome in place of the normal two. The main peculiarity consists in a decrease of ridge width. On the finger-tips this is shown by a significantly increased number of ridges as compared with the normal and corresponding pattern alterations. At the present time nothing is known definitely about the immediate causes of these abnormal reactions although there is likely to be a connection between the fetal oedema which occurs early in Turner's syndrome, and which subsides later, and the excessive number of ridges formed (Penrose, 1967). Consequently, there is need for precise study of the processes which take place during the period of ridge formation, that is from the second to the fifth month of fetal life. Much work has been done using the light microscope, but the electron microscope can also help this particular investigation.

The stages in normal development can be demonstrated by a series of light microscope sections. Fig. 1 shows a sagittal section of a finger of a fetus, 4 cm long from crown to rump, which corresponds to an age of 9 weeks. The section is about 2 μ in thickness, stained with 1% toluidine blue in a 1% solution of borax in H_2O. The primary magnification of the photograph shown here was 100 diameters. The developing bones, in the form of a cartilaginous matrix, are clearly seen, and also some fibrous structures, especially the flexor tendons. The skin is in the nature of a smooth thick layer of which the outer surface is irregular.

Of great interest is the volar pad, a bulge in the skin, which is situated above the proximal end of the most distal (the third) metacarpal bone. Pads like this occur on each finger and they were much studied by Bonnevie who, in 1925, thought that their presence at this early stage is in some way

Received 24 April 1973.

This paper was sent to the Editor by Professor Oliver Penrose after the death of his father, Professor L. S. Penrose, F.R.S.

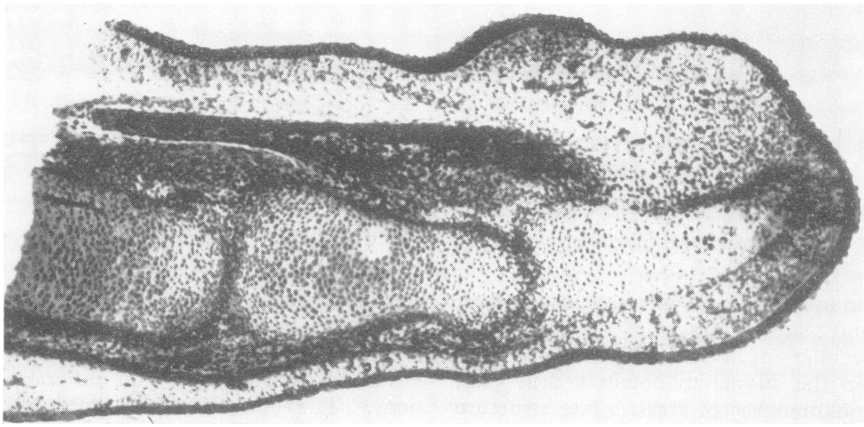

FIG. 1. Sagittal section of finger (9 weeks). ×58.

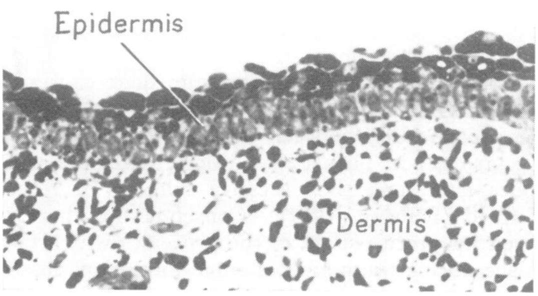

FIG. 2. Section of skin (9 weeks). ×275.

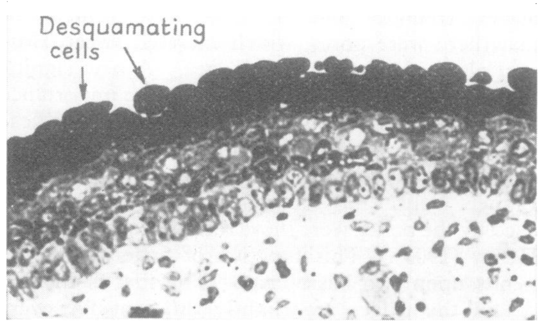

FIG. 3. Section of skin (12 weeks). ×275.

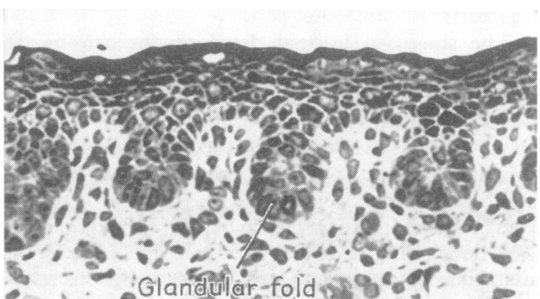

FIG. 4. Section of skin (16 weeks). ×275.

responsible for the development of the finger-print patterns, arches, loops, and whorls. This view is still widely held. Some details of Bonnevie's theories which she published later are less credible.

Later in the development of the bud, the volar pads almost disappear though the ridge system remains. Figs. 2, 3, 4, and 5 are light microscope sections, cut longitudinally in the same direction as that in Fig. 1 and similarly prepared, but they are shown under much greater primary magnification of 400. They demonstrate the progressive development of the ridge system. In Fig. 2, a section is shown from the palmar surface of the finger of the same 9-week old embryo as in Fig. 1. The most superficial layer has darkly stained cells. In Fig. 3, from a 12-week embryo (crown–rump length 8 cm), the same layers are seen with increased thickness and the outermost cells are tending to desquamate. No ridges are yet visible but there is undulation in the basal layer of the epidermis. However, in Fig. 4, from a 13-cm (16 weeks old) fetus, periodic down-growths from the basal layer are clearly defined. They are folds which here are seen sectioned at right angles to their

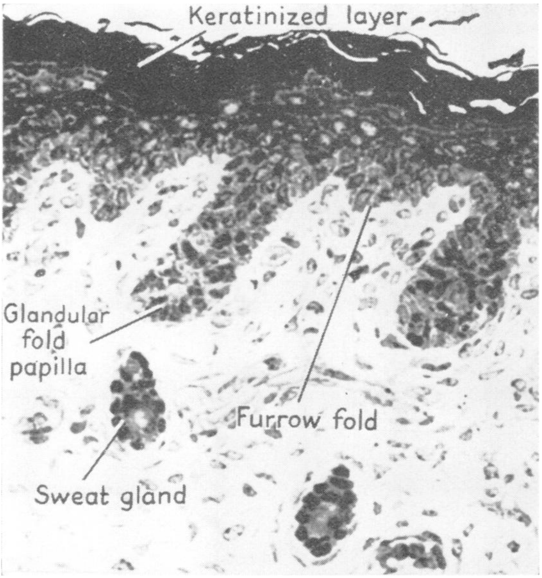

FIG. 5. Section of skin (23 weeks). × 275.

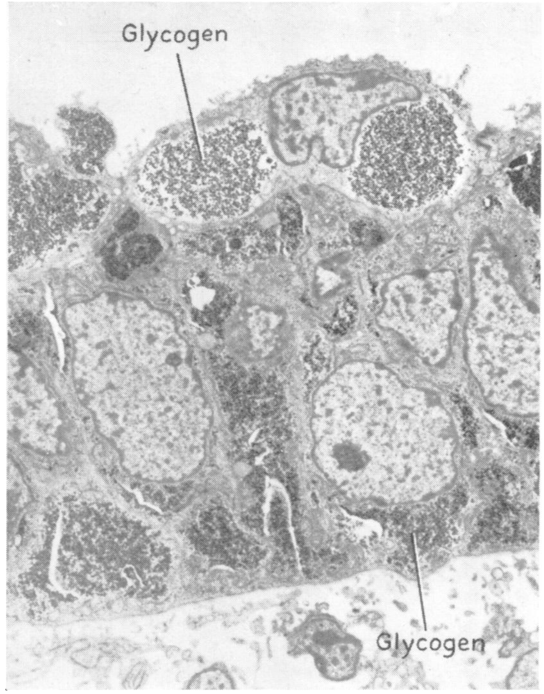

FIG. 7. EM skin section (8 weeks). × 4750.

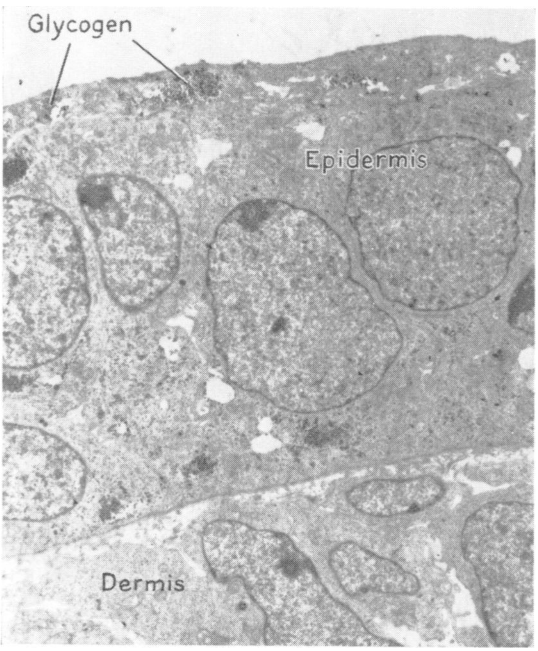

FIG. 6. EM skin section (7 weeks). × 4750.

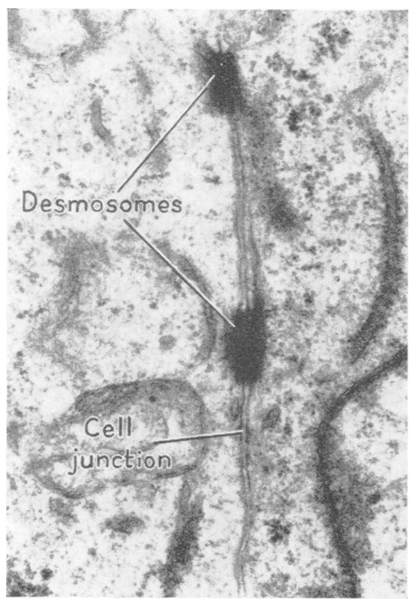

FIG. 8. EM primitive desmosomes (8 weeks). × 28,900.

FIG. 9. EM desmosomes (adult). ×28,900.

axes. The tips of papillae, which develop on these epidermal folds, become sweat glands deep in the dermis, as seen in Fig. 5. The papillae elongate and eventually form the ducts of sweat glands. At the stage shown in Fig. 5 (20 cm or 23 weeks) the outer layer of the epidermis has become keratinized. There are also shallow depressions or furrows visible on the surface between the sweat gland exits and below these furrows there are depressions, secondary down-growths, from the basal layer of the epidermis, which are known as furrow folds.

The early developmental processes are seen clearly, especially by use of the electron microscope. For this purpose sections are prepared, $\frac{1}{12}$ μ in thickness, from material fixed in buffered glutaraldehyde and osmic acid, stained with a combination of uranyl acetate in ethanolic solution and lead citrate. The primary magnification of Figs. 6 and 7 is 6900. Fig. 6 shows a section of the palmar surface of a finger-tip on the limb bud from a 2-cm embryo (7 weeks). At this stage the epidermal layer is not more than the width of two cells. Areas of darkly staining glycogen granules are visible in the cytoplasm, particularly near the outer surface. At 8 weeks, a period close to that shown in Figs. 1 and 2, the epidermis, as seen in Fig. 7, has the thickness of about three or four cells. At this stage there is much intracellular glycogen. The cells in the outermost region, at the top of the section, are beginning to desquamate.

The epidermis, even at this very early period, is strongly constructed. The surface membranes of adjacent cells, which are smooth at this time, lie against one another but at some points on these adjoining cell walls there are junctions. At these junctions are structures called desmosomes, and an example of a pair of primitive type is shown (Fig. 8), as two deeply stained bodies lying on the vertical lines where the membranes of two adjacent cell walls have been cut across. As the skin develops, these desmosomes grow larger and the cell junctions become wavy lines and the cell walls interdigitate. The desmosomes penetrate deeply into the cytoplasm of the adjoining cells by means of structures known as tonofilaments. They are seen in

FIG. 10. EM montage of epidermis (19 weeks). ×800.

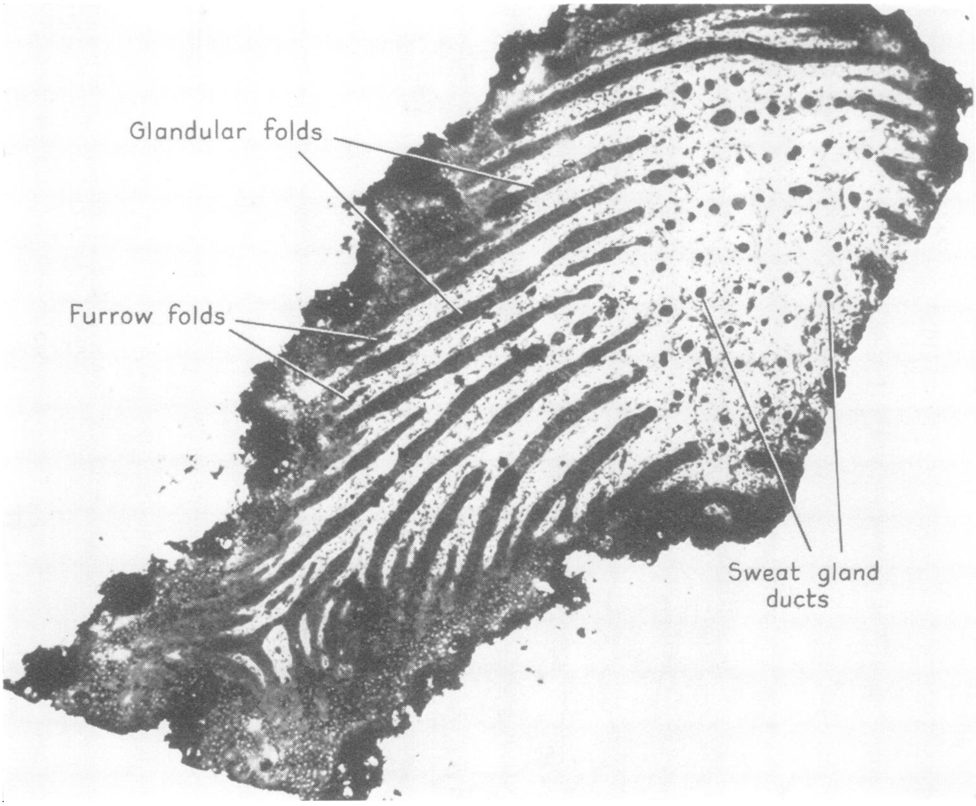

FIG. 11. Tangential skin section (23 weeks). ×40.

Fig. 9 in a section of epidermis taken from an adult. The tonofilaments give the cells an appearance, under a low magnification, which leads to their description as 'prickle cells'.

For comparison with the light microscope pictures in Figs. 4 and 5, a montage of 22 photographs of separate fields from a 19-week-old fetus, seen under the electron microscope, is shown in Fig. 10. The primary magnification was approximately 1200. In the epidermis, the 'prickle cells' are easily observed and also the surface cells which become hardened by the process of keratinization. In central regions of the glandular folds which are formed by the downward growth of the basal layer, there are numerous cells with clear nuclei and cytoplasm. They have been thought to be melanocytes and they seem to have migrated into the epidermis from the neighbouring dermis. At this period of growth, the glandular ducts are not yet formed and, on the outer surface, there is only a very slight suggestion of depressions between ridges which are just starting to develop.

At about 25 weeks, the skin ridges are fully formed and a tangential section of the epithelium, which cuts off a flake of the surface, can show what is happening at a number of different levels. Thus Fig. 11, which presents a section of this kind from the thumb of a 23-week-old fetus (primary magnification ×75) under the light microscope, indicates, in some places, the alignment of the ridges below the surface and, in others, the folds of the basal layers and sweat gland papillae cut across horizontally. Fig. 12 has been drawn to show what the surface of the skin above this section would look like. On the left side there is a ridge pattern formation where three parallel fields meet, known as a triradius and formerly called a triangle or delta. On the right margin, the ridge lines tend to curve more sharply and, if the section had been wider, they would have been seen to form a loop. The pattern, when printed, would have

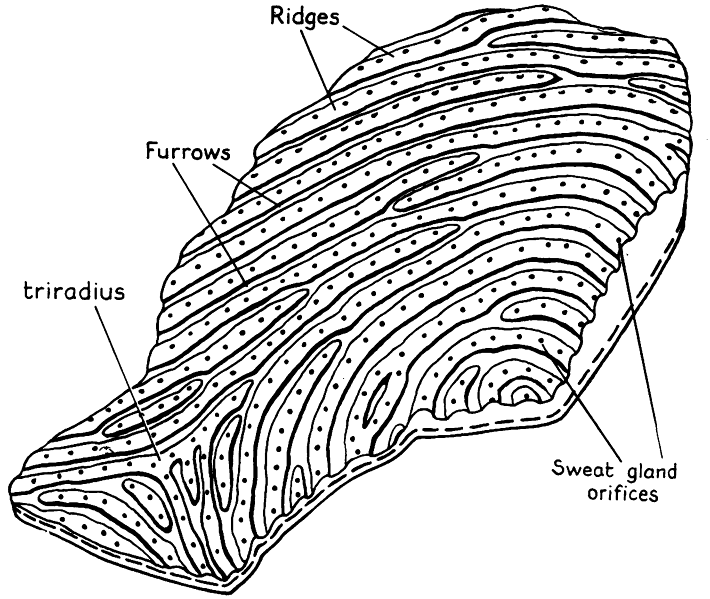

FIG. 12. Epidermal ridge pattern corresponding to that in Fig. 11.

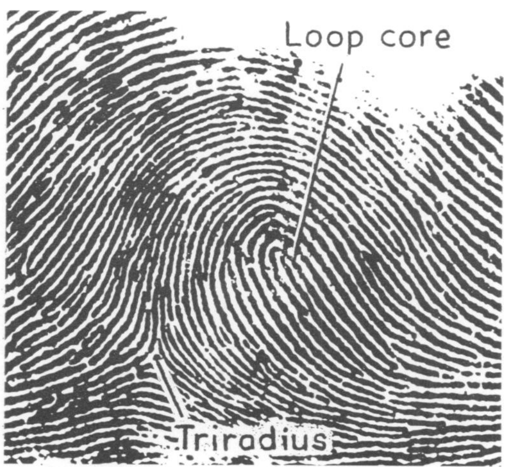

FIG. 13. Loop pattern finger-print (adult). ×3.

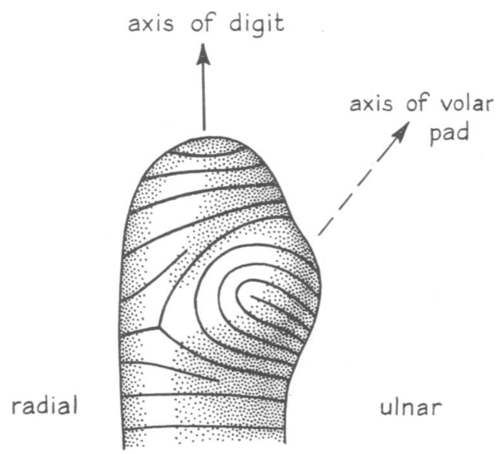

FIG. 14. Generation of fingerprint (ulnar loop) pattern by surface curvature of volar pad.

looked very similar to that on the enlarged finger-print shown in Fig. 13, only, of course, it would have been reversed from left to right.

The mechanism which determines the ridge patterns made out of triradii and loops is at present quite obscure. It is clear that the volar pads have some important function because it is in the areas where they are situated that the patterns develop. Loops and whorls lie on their surfaces and triradii tend to occupy regions between them or at their edges. One of Bonnevie's less credible theories is that the patterns on the finger-tips depend upon the underlying arrangements of peripheral nerves. A nerve developing on the ulnar side would produce a triradius and a radial loop and, correspondingly, a radially placed nerve would lead to an ulnar loop and two equally powerful nerves could make a whorl. It is supposed by other investigators that, in some way, the tensions and pressures set up in the skin growth and subsidence of the volar mounds determine the directions of the parallel systems of lines. One possibility is that the cells in the lower part of the epidermis are, at a very early period, sensitive to curvature and that the slight pressure produced by the concavity in the primitive basal layer induces cells to multiply and to form folds, with rows of papillae, along the lines of pressure rather than in other directions. This would mean that, from the external point of view, the parallel lines would follow the greatest convexity (or least concavity) of the external surface. In favour of such a view is the observation that, in the absence of pattern, ridges tend to run around the limb or digit at right angles to the long axis and in the direction of greatest curvature. The system of lines of greatest convexity on the palmar surface of a finger, at a time when a volar pad is present, are indicated in Fig. 14. The sensitivity of the epidermis to stresses, whether or not they are brought about by curvature, is easy to imagine because it is known that piezoelectric effects are produced by deformation in bone, collagen, keratin and some other biological materials (Bassett, 1968). In the epidermis, the closeness of the component cells to one another and their tight bonding by desmosomes even in the very early stages of development, long before any trace of pattern is observable, may be significant.

The writers wish to thank Mr A. J. Lee for the drawings and Mr N. J. B. Plomley for his helpful suggestions.

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