COMPLETENESS OF POSTTRAUMATIC REGENERATION OF THE SKIN IN WARM-BLOODED ANIMALS

A. A. Braun and E. A. Efimov

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Large defects on movable areas of skin in warm-blooded animals are covered mainly by concentric contraction of their edges and intercalated growth of the tissues around the wound. The central parts of these defects and wounds on immovable skin heal either as the result of the development of a more or less perfectly formed regenerating organ, characterized by restoration of its principal structures, or by scar formation. The outcome of the repair depends primarily on the species of animal and the size of the defect, but also on its situation.

The view was held for a long time in the literature that in mammals and man posttraumatic regeneration of the skin results in a scar of fibrous character, covered by epidermis and not possessing hair or glands. However, in recent years evidence has been obtained that during healing of skin wounds in mammals it is possible not only for a scar to be formed, but also for a more perfect restoration to take place, giving a result close to the characteristic structure of normal skin [2-5, 8, 9-11, 15, 19, 21]. Studies of posttraumatic regeneration of the skin in birds (hens, ducks, pigeons) demonstrated its high power of regeneration [7, 12, 16, 20]. Analysis of these facts conclusively proves that the conflicting views expressed on the outcome of healing of skin wounds in mammals and birds can be explained by differences in the course of regeneration depending on many factors and, principally, on the species and age of the animals, the situation of the defect, and, very considerably, on the size of the defect.

The mechanism of healing of large defects on movable parts of the skin in mammals and birds is a complex problem. Besides the concentric contraction of the skin edges already familiar [1], Soviet and Western investigators [6, 17, 18, 22] have shown that skin grows around a wound defect as a rection of the organ to local trauma. In movable parts of the skin, 80-90% of a large wound defect is covered by concentric contraction of the skin edges and intercalated growth, and the healing takes place more rapidly than it would for an area of regenerating skin or a scar of the same size to be formed. In such cases, the scar is formed only in the center of the wound.

In immovable areas of skin, on the outer surface of the concha auriculae of the rabbit, for example, wounds heal by the formation of new tissues in the defect itself. In this case the outcome of the skin repair is the regeneration of adequate skin,* with a basic structure close to that of the original (Fig. 1A); its connective-tissue basis is predominantly dermal in structure, with the characteristic binding of the collagen fibers; groups of hairs of typical structure and sebaceous glands are well developed in the regenerating skin. Stimulation by various means may lead to pronounced hyperregeneration of the hair cover (Fig. 1B) [14]. This type of regeneration is described as adequate but atypical. Regeneration in which the chief structures of the skin are restored in an atypical arrangement is found in the center of large skin defects

* Adequate regeneration is the term applied to regeneration in which the principal structures of the skin are restored, but to different degrees quantitatively, i.e., the regeneration is incomplete.

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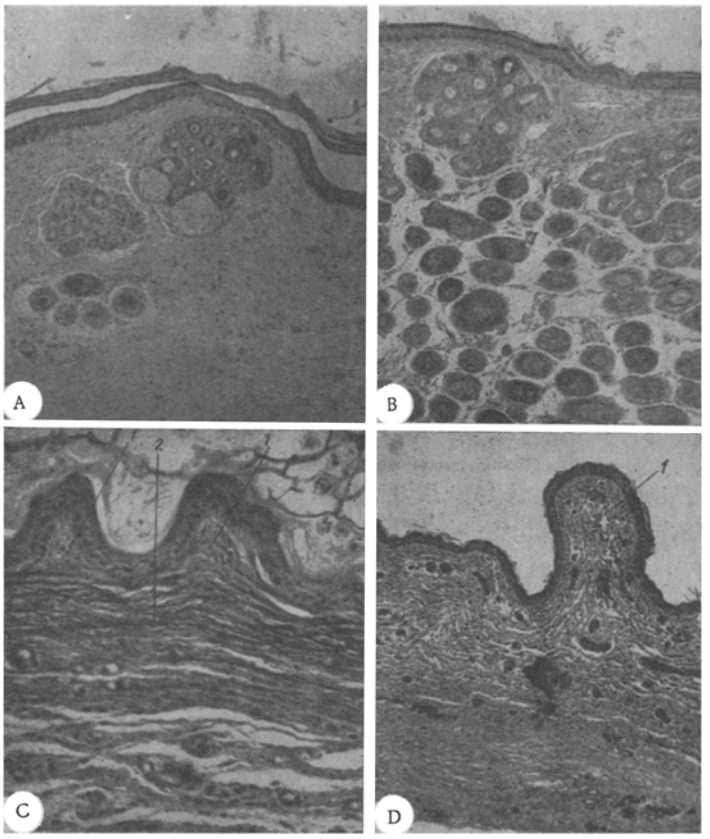

Fig. 1. Formation of organ structures in regenerating skin in various warm-blooded animals. A) Skin complexes in center of regenerating area on concha auriculae of rabbit (hematoxylin-eosin, 90×); B) numerous skin complexes in regenerating skin on concha auriculae of rabbit after rejection of homograft (hematoxylin-eosin, 90×); C) folds and elastic fibers in peripheral part of regenerating skin on mouse's head: 1) fold, 2) elastic fibers (orcein, 90×); D) specific folds in regenerating skin below cock's wing, typical of the skin of the domestic fowl; 1) fold (hematoxylin-eosin, 90×).

on the dorsum in rabbits and sometimes in mice. Adequate, atypical regeneration (hyperregeneration of the sweat glands, thinness of the bristle, coarseness of the collagen binding of the newly formed dermis) occurs during the healing of defects in immovable skin on the dorsum in young pigs [5].

Adequate regeneration of the skin was found in mice after the formation of large defects in the scalp [13]. In this case, a dermis of typical structure was restored, with an abundance of elastic fibers (Fig. 1C). A clear example of adequate regeneration of the skin is healing of skin defects in birds. The end result of repair is a regenerating skin with the folds characteristic of birds' skin (Fig. 1D). The collagen binding of the dermis of the regenerating skin is very little different from the interweaving of bundles in neighboring areas of "old" skin [12]. Ultimately a powerfully developed subcutaneous elastic network, specific for birds, is formed.

Conversely, the healing of large skin defects in rats is inadequate in character: it ends with the formation of a scar (Fig. 2A) in the wound center. However, in the peripheral parts of this inadequately regenerating skin, the collagen bundles begin to interweave with each other and the fibrous tissue gradually becomes dermis-like in appearance (Fig. 2B). Hairs and glands, however, are absent. This is followed by a narrow zone of adequately regenerated skin forming an intermediate area between the scar and the old skin (Fig. 3B, k).

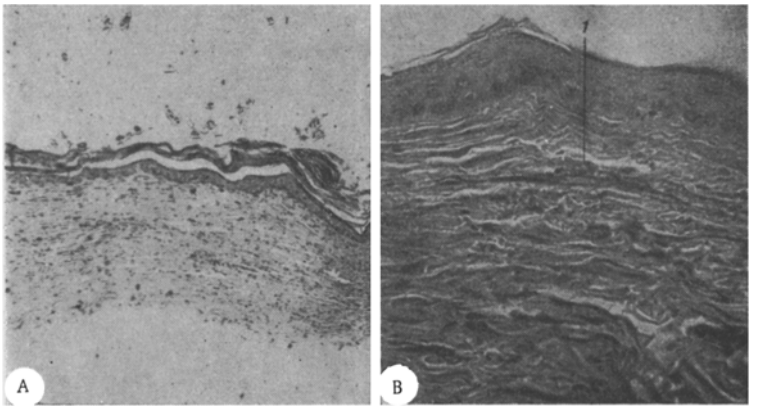

Fig. 2. Inadequate regeneration of dorsal skin in rat: A) central part of defect, consisting of a scar (hematoxylin-eosin, 90×); B) peripheral part of defect: 1) elastic fibers (orcein, 200×).

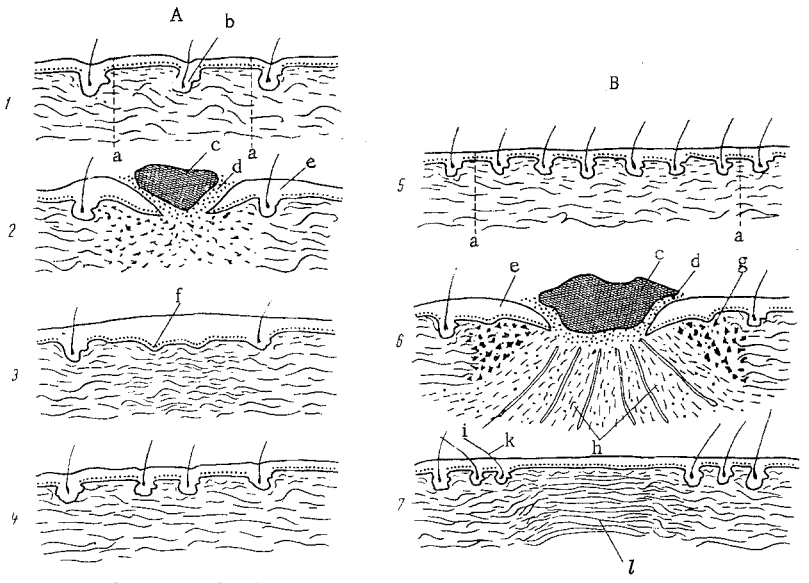

Fig. 3. Schemes of adequate regeneration of skin (A) and healing by scar formation after trauma (B). 1 and 5) Skin before wounding, 2 and 6) first stage of skin regeneration, 3) beginning of second stage of skin regeneration, 4) end of second stage, 7) healing of skin defect by scar; a) boundary of defect, b) hair follicle, c) scab, d) leukocytic barrier, e) tongue of regenerating epithelium, f) rudimentary hair, g) area occupied by fibroblasts, destined to become dermis, h) fibroblasts of nonspecific nature, i) blood vessels, k) newly formed hairs, *l*) scar.

The processes leading to the formation of new skin in wounds on immovable skin or in the central areas of large defects of movable skin can be considered to take place in accordance with the scheme below.

Posttraumatic Regeneration of Skin in Warm-blooded Animals

Filling of wound defect with tissue materials: development, first, of granulation tissue followed by young, dense fibrous tissue in it; epithelization of wound surface – first stage of regeneration (Fig. 3: 2 and 6).

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Prolonged reorganization of young, dense fibrous connective tissue into dermis with specific organ structure and formation of skin derivatives de novo – second stage of regeneration (Fig. 3: 3 and 4).

Reorganization of young dense fibrous connective tissue into fibrous tissue – scar formation (Fig. 3: 7).

It is suggested that a scar forms if invasion of the defect by nonspecific connective tissue takes place before the growth of fibroblasts, destined to become dermal, beneath the regenerating epithelium (Fig. 3: 6). Where such fibroblasts are present, their correlative relationships with the regenerating epidermis leads to the formation of hairs and glands.

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