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Research Article

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Anatomical Rationale for the Choice of Surgical Intervention for an Ingrown Nail

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BACKGROUND An ingrown toenail is one of the reasons for surgical intervention: it accounts for up to 20% of all operations in clinics. At the same time, conservative and surgical approaches to treatment are not reliable enough: up to 70% of cases are complicated by relapses.

AIM OF STUDY To study the topographic location and ratio of cells in the growth zone of the nail plate, necessary for planning the volume of intervention in the treatment of ingrown toenails.

MATERIAL AND METHODS The material for conducting our own research was samples of the cadaver nail complex, without identified pathologies, from 20 objects of different ages and genders. Studies were carried out using histological, immunofluorescent and microscopic methods.

The results were compared with available literature data, clarifying the most important structural features. The data obtained will make it possible to reasonably plan the volume of intervention during operations for ingrown nails, as well as to reduce the number of unsatisfactory results of operations on the nail complex in case of injury and nail diseases.

Keywords: nail plate, ingrown nail, anatomy, nail matrix

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INTRODUCTION

Ingrown toenail (incarnation of the nail) on the toes is one of the most common surgical diseases. According to various sources, operations for this reason account for from 2.5 to 20% of all operations in clinics [1–3].

Conservative, orthopedic and even surgical approaches are not reliable enough, and therefore from 10 to 70% of cases are complicated by relapses [1, 4, 5].

Considering the prevalence, frequency of relapses after surgical treatment, duration of disability, ingrown toenails currently occupy one of the leading places among diseases in outpatient surgery [1, 2, 4].

The main goals of surgery are to widen the nail bed, remove the nail plate, and excise the growth zone. In various modifications of operations, one of the listed goals or all at once is realized [6, 7]. Obviously, knowledge of anatomy is extremely important for planning and performing such operations, but in the available literature these issues are not sufficiently discussed, in particular, there is no indication of the size of the growth zone. In this case, incomplete destruction leads to relapse of nail growth and unsatisfactory results of the operation [2, 5]. Despite the availability of specialized literature, there is no complete differentiated algorithm for the diagnosis and treatment of this pathology.

The aim of this article was to study the topographic location and ratio of cells in the growth zone of the nail plate, necessary for planning the volume of intervention in the treatment of ingrown toenails.

MATERIAL AND METHODS

Samples of the nail complex for research were taken during a pathological-anatomical study from people of different ages, gender and anatomical external data (age, gender, external dimensions of the finger and nail plate were taken into account). In total, to study the anatomy of the nail complex, the structure of the soft tissues and nail bed of the big toe was studied in 20 random objects.

There was no nail plate separation, ingrown nails, or paronychia in any case. The sampling was carried out using a cutter (in 2 cases) together with a sector of the bone of the nail phalanx and using a sharp scalpel (in all other cases). When sampling with a scalpel, the bone was not excised (Fig. 1).

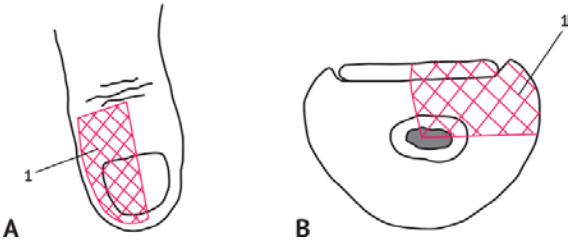

Fig. 1. The collection of material for histological study (shaded area). A – back surface view; B – volume of tissue excised for examination

Preparation of histological preparations: isolated samples of the nail bed along with the nail plate were fixed in a solution of 10% formaldehyde for 3–5 days, taking into account the density of the nail plate. In two cases, decalcification was performed; the

remaining tests were performed without decalcification. Next, the cassettes with tissue samples were placed in a carousel-type histoprocessor, where, after a standard procedure of dehydration and paraffin embedding, paraffin blocks were formed. From the prepared blocks, 88 longitudinal serial sections with a thickness of 8–10 μm were prepared, including the nail bed, nail folds, root and tubular bone fragments. Deparaffinized sections were stained with hematoxylin-eosin according to standard methods.

Immunofluorescence studies were carried out on deparaffinized sections using primary antibodies produced by *Abcam* : rabbit monoclonal antibodies to keratins 14, 15 and mouse monoclonal antibodies to keratin 10. Treatment with antibodies was carried out in accordance with the manufacturer's recommendations, after which, to visualize the binding sites, the sections were incubated with a solution of the second antibodies conjugated to fluorochromes: *anty-rb Alexa Fluoro* 488 and *anty-mouse Alexa Fluoro* 555 for an hour in the dark. Nuclei were stained with *DAPI dye*.

Photography and examination of the preparations were carried out using a fluorescence microscope (*Olympus*) at wavelengths of 380, 480–495 and 540–595 nm.

Since there was no data in the available literature on the sizes of the elements of the nail complex (in particular, the thickness of the matrix), it is impossible to give reasonable recommendations about the depth of destruction during operations of anatomical structures. In this regard, during microscopic studies of histological preparations, morphometric measurements of the most important, from the surgeon's point of view, structures of the nail complex were carried out using an optical micrometer. The results obtained were compared with the available literature data, clarifying the necessary information. The elements of the nail complex were examined step by step and the most important data necessary for performing surgical intervention were revealed (Fig. 2).

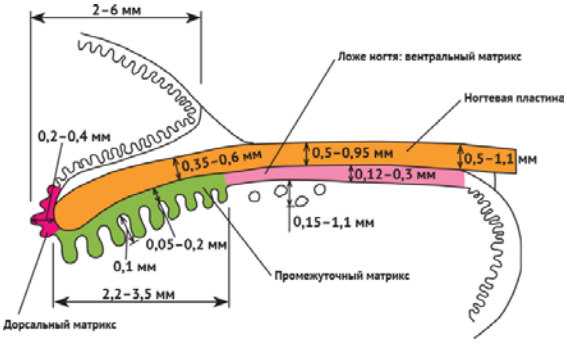

Fig. 2. Morphometry of tissues of the nail (scheme)

Data sources. The *PubMed* literature search was conducted using topic queries using the key terms "ingrown toenail," "onychocryptosis," and "embodied toenail." The search included meta-analyses, randomized controlled trials, clinical trials and reviews.

REVIEW OF KNOWN DATA ON THE ANATOMICAL STRUCTURE OF THE NAIL COMPLEX AND THE RESULTS OF OUR OWN RESEARCH

The term "nail complex of the finger" refers to the combination of the nail plate and the soft tissues surrounding it (nail folds and bed) (Fig. 3).

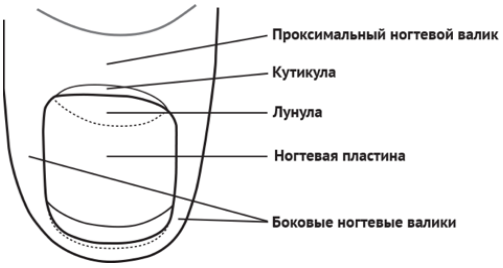

Fig. 3. The nail unit structure

The nail, being a derivative of the germ layers of the epidermis of the skin (basal and spinous), is a plate lying on the nail bed of the distal phalanx of the finger. Its strength is due to the fact that it is formed by horny scales, which contain solid alpha-keratin. The thickness of the nail plate changes: in the proximal part it is 0.35–0.6 mm, and in the distal part it becomes thicker – 0.5–1.1 mm [8].

The nail plate is heterogeneous and consists of three layers: a thin dorsal layer, which grows from the most proximal part of the matrix, a thick intermediate layer, which is formed by the cells of the middle (intermediate) layer of the matrix, and a thin ventral layer, which is formed in the area of the cells of the nail bed (Fig. 4) [9].

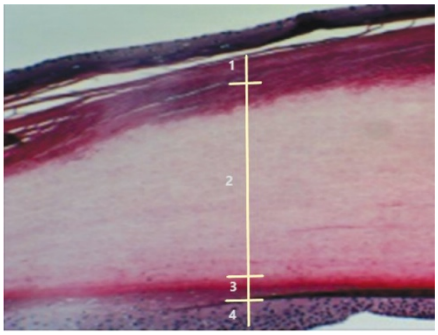

Fig. 4. Epithelium of the nail bed and nail plate. 1 — dorsal layer of the nail plate; 2 — intermediate layer of the nail plate; 3 — ventral layer of the nail plate; 4 — epithelium of the nail bed. Magnification ×100, hematoxylin-eosin staining

The proximal part of the nail plate is hidden under the skin fold (eponychium or proximal nail fold), along the lateral edges it is limited by the lateral nail folds and ends with a free (distal) edge that is not fused to the nail bed.

The proximal ridge is a wedge-shaped fold of skin on the dorsum of the distal part of the finger, from under which the nail plate protrudes [7, 9]. The proximal nail fold consists of two surfaces (parts): dorsal and ventral. About a quarter of the total surface of the nail plate is located under the ventral part of the proximal nail fold (Fig. 5).

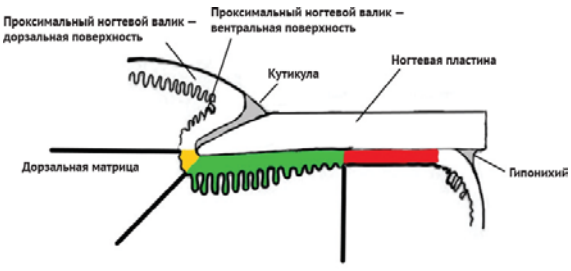

Fig. 5. The nail unit structure, sagittal plane

The dorsal portion of the proximal nail fold consists of a continuation of the epidermis and dermis of the dorsal finger with sweat glands, but no follicles or sebaceous glands.

The ventral part is thickened, without appendages, tightly adjacent to the dorsal surface of the nail plate (Fig. 6). The epithelium of the ventral surface of the proximal nail fold is called eponychium [10, 11]. Diseases that affect the ventral portion of the proximal nail fold may also affect the newly formed nail plate. For this reason, some authors believe that the proximal nail fold contributes to the formation of the superficial layer of the nail plate [12]. In particular, the appearance of pits and trenches (Beau's line) on the nail is associated with a parakeratotic phenomenon and a growth retardation phenomenon, respectively, in the ventral part of the proximal nail fold. The keratic layers of the epidermis of the proximal fold creep onto the body of the nail, forming the skin of the nail (cuticle), which isolates the space between the nail plate and the proximal nail fold from foreign bodies (Fig. 6). Its function is to protect the nail base, especially the germinal matrix. The loss of the cuticle often leads to damage to the nail matrix by acute and chronic inflammatory and infectious processes (paronychia), which leads to secondary dystrophies of the nail plates.

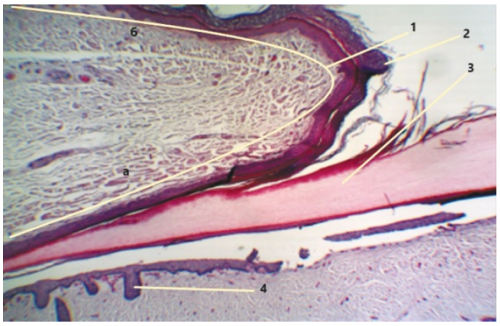

Fig. 6. Proximal fold and cuticle. Magnification ×40, hematoxylin-eosin staining. 1 — proximal ridge, ventral (a) and dorsal (b) part, 2 — cuticle, 3 — nail plate, 4 — matrix

The lateral folds limit the nail plate, but are not connected to it. Due to the presence of space between the nail plate and the lateral fold, fixation by the lateral folds of the nail plate is possible. By hooking the folds with clamps (for example, wire), you can change the direction of growth of the nail plate.

The nail over its entire area is tightly fixed to the matrix and nail bed, and its separation is quite traumatic. The removal of the nail plate in the absence of growth pathology is possible only after detaching it from the underlying nail bed using a flat and sharp instrument (the jaw of Cooper scissors is often used).

The growth rate of the nail plate is known: it increases by 1.9–4.4 mm per month [3, 6]. The growth of the nail plate on different fingers is uneven: fingernails grow faster than toenails. While the nail plate on the hand takes approximately 6 months to fully grow, the nail plate on the foot takes 12 to 18 months to grow to the edge of the nail bed [13].

The nail matrix (matrix or germinative matrix) is the zone of the nail complex where the formation of the nail plate occurs. The matrix is divided into three parts: dorsal, intermediate and ventral (Fig. 5) [9, 11, 12]. For surgeons, this section of the nail complex is the most anatomically significant, since removal of this zone determines whether the nail will re-grow. It is believed that the intermediate matrix makes the main contribution to the formation of the substance of the nail plate. For this reason, in most works, when discussing the histology of the matrix, they mainly mean its intermediate part, using the term “true matrix” [9]. In this regard, the importance of determining the boundaries of the matrix becomes clear, but this is not very easy to do, since macroscopically these sections do not differ.

Upon external examination of the nail plate, a white crescent-shaped area protruding from under the proximal nail fold is clearly visible. This spot is called a lunula. It is believed that the lunula defines the boundary of the most distal part of the growth layer and determines the shape of the free edge of the nail plate [14] (Fig. 3). The whitish color of the nail plate in the lunula area is caused by the presence of unformed keratin in it [13, 15]. Due to the fact that the color of the lunula is caused by the color of the nail plate and not the nail bed, after removing the nail plate it is impossible to visually determine the boundaries of the true matrix.

Histologically, the matrix is an easily identifiable thick squamous epithelium located immediately beneath the ventral portion of the proximal nail fold (Fig. 7). The matrix has a very active germinal basal layer of immature basaloid cells producing keratinocytes, which differentiate, harden, die to form horny squamous cells and contribute to the formation of the nail plate [14]. The main feature of the matrix is the presence of 8 to 15 sites of epithelial cell penetration into the deeper layers, in the form of peculiar “lacunae” or “pits”. Histologists refer to these formations as “acanthotic processes” (Fig. 8–10). The waviness of the epithelial matrix layer is visible only a few millimeters in the dorsal and intermediate matrix locations. The depth of the acanthotic processes gradually decreases towards the ventral matrix (or nail bed) (Fig. 11). In terms of length, the proximal matrix is located in the projection of the end of the nail plate for 0.4–0.6 mm. The intermediate matrix occupies the entire space of the matrix, covered by the proximal ridge, over a length of 2.2–3.5 mm.

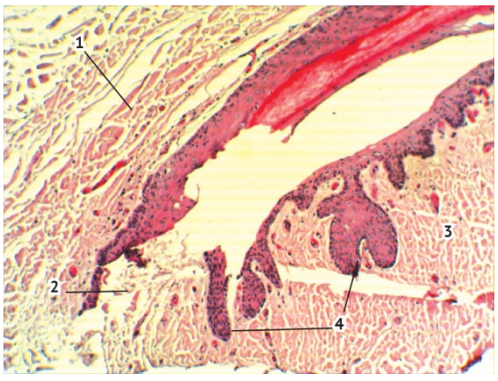

Fig. 7. Nail root. Magnification ×40, hematoxylin-eosin staining.
1 — proximal fold, 2 — dorsal matrix, 3 — intermediate matrix, 4 — acanthotic processes

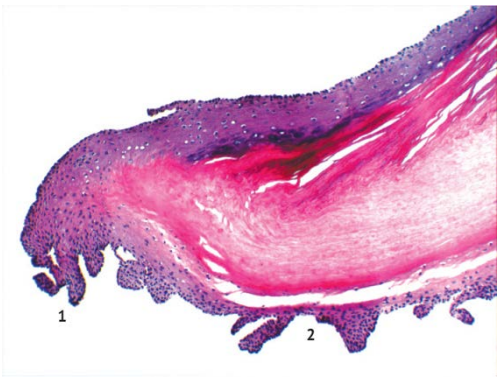

Fig. 8. Nail root. Magnification ×100, hematoxylin-eosin staining. The proximal part of the nail plate and the epithelium of the dorsal and intermediate matrix are shown. It is clearly visible that the main part of the nail is formed from the epithelium of the intermediate matrix. 1 — dorsal matrix, 2 — intermediate matrix, 3 — intermediate matrix, 4 — acanthotic processes

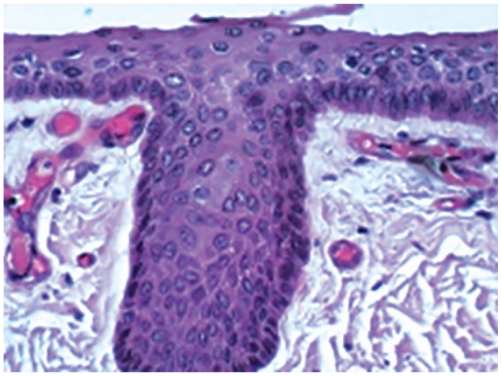

Fig. 9. Intermediate matrix. Magnification ×400, hematoxylin-eosin staining

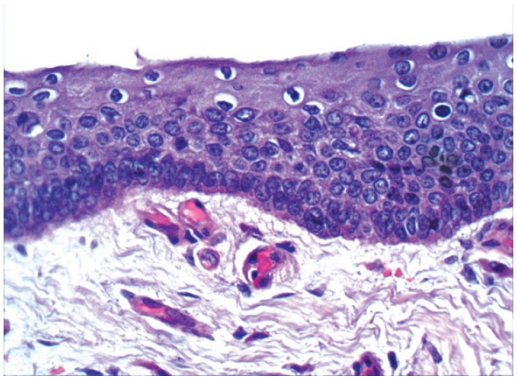

Fig. 10. Intermediate matrix. Magnification ×400, hematoxylin-eosin staining

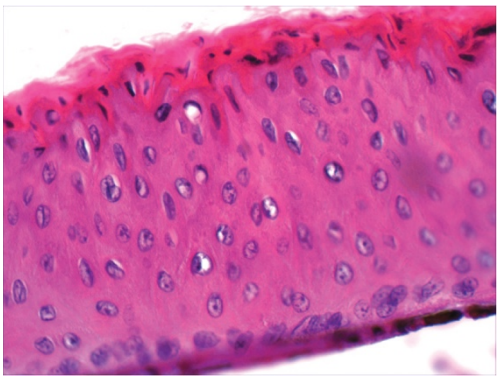

Fig. 11. Epithelium of the nail bed. Magnification ×400, hematoxylin-eosin staining

Thus, the thesis about the coincidence of the border of the lunula and the border of the intermediate matrix is incorrect, as the intermediate matrix mostly ended at the level of the edge of the proximal ridge.

The total thickness of the matrix cells in the proximal and ventral sections ranges from 0.05 to 0.2 mm, but due to the acanthotic processes (which add another depth of up to 0.2 mm), they reach 0.15–0.4 mm.

Typically, tissues are treated with a Volkmann spoon to destroy the matrix. The presence of acanthotic processes leads to the conclusion about the need for deeper destruction of matrix tissue in these sections in order to stop the growth of the nail plate.

As already noted, epithelial cells produce keratin of the nail plate, but we were unable to find information about the role of cells in the acanthotic processes in this.

It should also be noted that the extensor tendon of the digitorum is directly adjacent to the pits of the intermediate epithelium, and therefore it may be damaged.

Distal to the intermediate is the ventral part of the matrix (or nail bed) [11, 15]. Histologically, the area where the intermediate matrix ends and the beginning of the nail bed is located is clearly visible,

acanthotic processes disappear and the appearance of the epithelium changes. The epidermal layer of the nail bed, in contrast to the intermediate section, is a squamous epithelium no more than 3 or 3 cells thick and without melanocytes.

The total thickness of the ventral nail bed matrix, including cambial and keratinized cells, ranges from 0.12 to 0.3 mm (Fig. 2). The zone of transition from living keratinocytes to dead cells of the ventral nail plate is abrupt and occurs in the space of a single horizontal cell layer [16]. Proliferation of the epithelium of the ventral part is less active, with a longer renewal time than in other parts of the matrix and skin [16]. Epithelial cells produce thin parakeratotic keratin, which, together with the upper layers of epidermal cells, is pulled out by the nail plate growing above it. Probably for this reason, the hematoma, which forms under the nail plate, moves along with the desquamated epithelium as the nail grows.

In the area of the nail bed there are also multiple "pockets" of basal epithelial cells, the so-called "epithelial nests" or "crypts" (Fig. 12). These structures are responsible for the rapid epithelization of the nail bed when the nail plate is removed. They are located another 0.15–1.1 mm deeper than the cambial layer. If we take into account the crypts in the ventral matrix, then its total depth ranges from 0.3 to 1.5 mm.

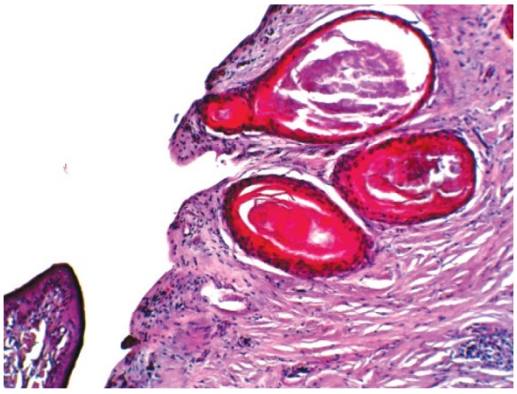

Fig. 12. Epithelial nests in the matrix area. Magnification ×100

The most distal part of the nail bed is the hyponychium, which is the connection between the nail bed and the fingertips. The function of this anatomical formation, like the eponychium, is to isolate the nail bed from foreign bodies and infectious agents [8].

Since the anatomical structure does not always characterize metabolic activity, studies have been carried out to determine the protein content in the cambial matrix cells.

It is known that 90% of the nail plate consists of keratins and proteins associated with keratins [17]. However, each individual pool of keratinocytes is characterized by its own specific set of cytokeratins, which makes it possible to assess the direction and stage of their differentiation. In order to determine the boundaries of the matrix sections and germinal zones of the epithelial layers, we carried out immunofluorescent detection of cytokeratins 10, 14 and 15 (hereinafter referred to as K10, K14 and K15, respectively).

A significant number of cells containing K15 were found in the dorsal matrix (Fig. 13). It is characteristic of stem and early growth cells [18]. In our study, K15 is located in the most proximal part of the matrix, over several millimeters. Its traces were found exclusively in the projection of the end of the root of the nail plate (dorsal matrix). Thus, the dorsal portion of the matrix produces keratin, which predominantly forms the main part of the nail plate. It becomes clear that stopping the growth of the nail plate requires destruction of not only the "true" (intermediate) matrix, but also the proximal one. More distally, K15 was not found on the nail bed; K14 predominated there. This protein is characteristic of basal and suprabasal keratinocytes and epithelial crypts of the nail [18]. Cells containing K14 form the ventral part of the nail plate - when sloughed off, they are fixed to the nail plate and follow the growth of the nail. For this reason, the ventral part thickens distally.

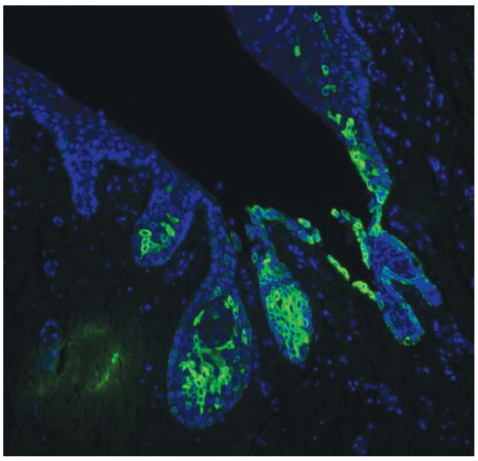

Fig. 13. Immunohistological examination of the nail bed. Magnification ×400. Cell nuclei are stained blue; cytokeratin 15 is stained green. The photo clearly shows that this cytokeratin is released only from the end part of the nail plate, while it is present in the acanthotic processes. The nail plate is removed

As is known, K10 is a mature protein that is found in the superficial layers of the keratinizing epithelium [19]. When analyzing the preparations, we revealed its presence mainly in the ventral part of the proximal skin fold. Cells containing K10 form the cuticle and the dorsal part of the nail plate (Fig. 14).

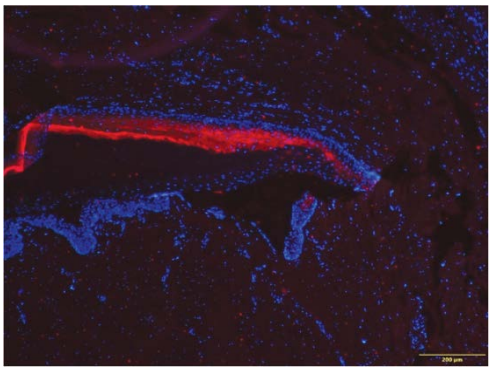

Fig. 14. Immunohistological examination of the nail bed. Magnification ×200. Cell nuclei are stained blue, cytokeratin 10 is stained red. The photo clearly shows that this cytokeratin is formed on the ventral part of the proximal ridge, participating in the formation of the cuticle. The nail plate is removed

As a result of the study, a general scheme of distribution of types of cytokeratins in the tissues of the nail complex emerges (Fig. 15, 16), which indicates the zones where the nail plate is formed: the dorsal part of the nail is formed by the ventral surface of the proximal ridge, the main part of the nail plate is formed in the proximal and intermediate parts matrix, and the ventral part of the matrix (nail bed) forms only the ventral part of the nail plate.

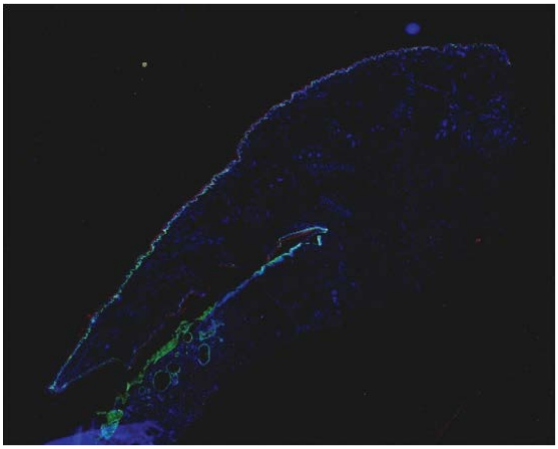

Fig. 15. Immunohistological examination of the nail bed. Increase ×100. Overall view. Cell nuclei are colored blue; cytokeratin 14 is stained green; cytokeratin 15 is stained blue; cytokeratin 10 is stained red

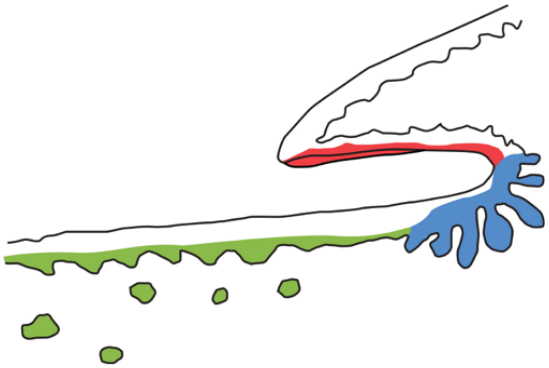

Fig. 16. Scheme of a photograph of an immunohistological examination of the nail bed. Increase x100. Cytokeratin 14 is stained green, cytokeratin 15 is stained blue; cytokeratin 10 is stained red

CONCLUSION

Many methods of surgical correction of nail growth involve removing the growth zone of the nail plate.

In practice, most surgeons, in order to remove the epithelium, perform treatment only of the intermediate matrix with a sharp Volkmann spoon. Studies have shown that this treatment removes only the surface epithelium. However, nail growth continues after such treatment in most cases, since the epithelium remains in the dorsal matrix, acanthotic processes and epithelial pits. The restored epithelium begins to produce keratin of the nail plate

again and the goals of the operation are not achieved. To remove the epithelium in the area of the intermediate and dorsal matrix, it is necessary to remove tissue to a depth of at least 0.4 mm (the maximum length of the epithelium, including the deepest parts of the acanthotic processes) not only under the proximal ridge, but also in the deepest part of the surgical wound.

The established opinion is that the nail plate is formed only from the intermediate and partially ventral matrix. According to the data obtained, the ventral matrix does not actively participate in the formation of the nail plate, for this reason the generally accepted name "nail bed" is quite correct.

RECOMMENDATIONS

1. Based on histological and immunohistochemical studies, it was found that the proximal and intermediate sections of the matrix are of primary importance in the production of keratin. To prevent re-growth of the nail plate, the specified sections of the matrix should be destroyed to a depth of more than 0.4 mm.

2. It is likely that tissue excision with a radio wave or laser dissector will be more technically convenient.

3. When performing the operation, damage to the extensor tendon of the finger should be avoided.

4. The nail bed (also the ventral part of the nail bed) has the ability to undergo relatively rapid epithelization. The source of the epithelium is the epithelial nests (crypts) of the nail bed.

The data obtained make it possible to reasonably plan the volume of intervention during operations for ingrown nails, as well as to reduce the number of unsatisfactory results of operations on the nail complex for injuries and diseases of the nails.

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