ОГЛЯДИ ЛІТЕРАТУРИ

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ANATOMICAL BASIS OF BIOMECHANICAL PROPERTIES OF SUPERFICIAL TISSUES OF THE ANTERIOR ABDOMINAL WALL

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Biomechanics is a science that studies the mechanical properties of tissues, individual organs and systems and the body as a whole. The unique mechanical properties of the skin provide the function of support and protection of internal organs through the skin mobility and elasticity. This feature of the skin is determined by its microstructural organization and arrangement of connective tissue fibres. The mechanical properties of the skin are mainly determined by the collagen-rich dermis. The mechanics of the dermis, in turn, depends on the structure, density and direction of collagen fibres. Each biological tissue is able to acquire deformation properties i.e. stretching or contraction. At each stage of deformation in the tissues of different topographic and anatomical areas there are changes in histoarchitectonics (within the plastic characteristics, and outside these parameters). Different structural interactions are expressed by different mechanical factors, which are adequate to the magnitude and direction of tensile forces (deformation vectors), form the typical features of the connective tissue matrix of abdominal wall tissues. Normalization of the direction of tissue stress vectors, uniform distribution of the direction and force of deformation prevent microstructural rearrangement of the surface tissues of the abdominal wall. Dynamic changes in the histological structure and biomechanical behaviour of the skin are closely related to the aging process, hormonal background, mechanical factors: physiological stretching of the skin during rapid growth in adolescence, pregnancy, overweight (or rapid weight loss), under the influence of physical load and wound healing. All these factors lead to connective tissue remodelling. Thus, the skin has a complex three-dimensional morphological structure; it is subjected to prolonged exposure to internal and external factors that determines its mechanical properties.

Key words: biomechanics, anterior abdominal wall, skin

The importance of mathematical analysis as an objective method of planning in plastic surgery on the anterior abdominal wall (AAW) was stressed on in 1946 by A. A. Limberg, who was the first in developing and introducing a list of theoretical norms aimed to facilitate the planning of local plastic surgery [10, 16]. The successful outcomes of operation require well-planned technical approach including a clear understanding of the biomechanical properties of living tissue, susceptibility to physiological and pathological changes [9]. A. K. Langer in 1861 concluded that human skin can withstand a certain degree of tension, and when a skin sample is taken from the body, it then always shrinks to a smaller size relative to the initial area [18, 33].

Biomechanics is a branch of natural sciences that studies the mechanical properties of tissues, individual organs and systems, and the body as a whole. The unique mechanical properties of the skin provide the function of support and protection for internal organs through the skin mobility and elasticity. These peculiarities of the skin are determined by the microstructural composition and arrangement of connective tissue fibres [6], therefore, mechanical studies are to some extent a "functional biopsy" of the skin.

For the surgeons, three mechanical properties of the skin are of the great practical importance: contraction, displacement, and stretching. In terms of biomechanics, the term "elasticity" , i.e. the ability of a body or material to withstand significant reverse deformation without destruction, at relatively low loads, is used [9, 20]. While many publications have been devoted to the study of human skin elasticity, the process of skin relaxation, as well as the possibility of its prediction according to studies with skin stretching in clinical practice is insufficiently covered [17, 23].

From the perspective of biomechanics, the skin is a material that has non-linear, anisotropic, viscoelastic properties and is subject to a certain initial tension (preload) in vivo [5, 6].

Nonlinearity is manifested in static tests on uniaxial tension, which enables to obtain data of the "stress-strain" interdependence [12, 17]. When stretching the skin on the curve of stress versus deformation, the initial section I is detected, while small loads cause significant stretching at low stress in the samples. In the next section II there is an increase in the stiffness of the biological tissue, and in the final stage III the deformation is accompanied by an even faster increase in stress. It is possible to notice that if for a site I elastic deformation is characteristic, the sites II and III demonstrate expressed viscoelastic properties of skin [6, 17]. This deformation behaviour is due to the orientation and straightening of collagen fibres during stretching (fig. 1).

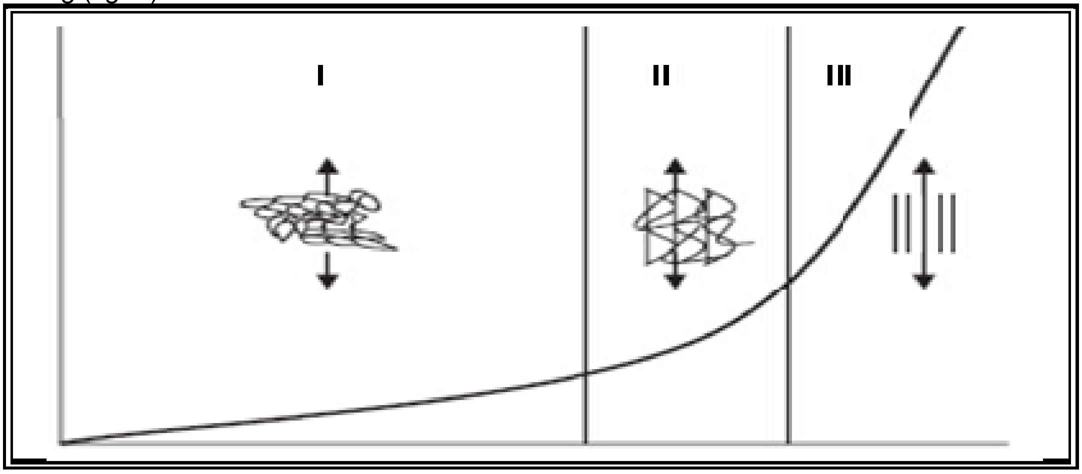

Fig. 1. Stages of skin deformation.

Anisotropy is the ability of the skin to stretch and contract differently in different directions. This property is due to a certain location of collagen fibres in the dermis, according to the Langer lines [6, 33].

The term viscoelasticity embodies the property of the skin to demonstrate a combination of elastic and viscous mechanisms, when stress and strain depend on the course of the deformation process over time, and is characterized by energy absorption in a closed deformation cycle with gradual reduction of deformation with complete loss of load [5, 34]. The property of the skin viscosity is observed at rather large deformations, i.e. at abdominoplasty, injuries [21].

Preload is a phenomenon associated with the fact that human skin is in a certain state of tension, which varies with age and the intensity of the growth of subcutaneous fat. This property is manifested by the fact that the thickness of the skin increases, and the size of the skin flap decreases after incision [5]. That is, from the perspective of biomechanics, the reduction of skin area after liposuction and lipectomy is also associated with the elimination of preload [6, 8-10].

The mechanical properties of the skin are mainly determined by the collagen-rich dermis. Biomechanical studies performed on full-skin and dermal collagen separately give almost identical results. The mechanical properties of the dermis, in turn, depend on the structure, density and direction of collagen fibres [6, 22, 23].

Collagen is the main component of connective tissue, which determines its strength. A characteristic feature of collagen fibre is the tendency to spiral twist at all levels of the organization. This structure limits the sliding of the components relative to each other under tension, which provides rigidity and strength. However, collagen fibre is not a completely rigid rod, and is capable of some reverse deformation, so the stretching of dense collagen-containing tissues is not only due to the straightening of wavy areas [6, 8].

Mylytsya K.M., examined patients with postoperative ventral hernias and other AAW defects in order to study the structural features of tissues. Based on histological studies, the authors concluded that in the altered skin and musculoaponeurotic layer of the AAW, type II and III collagen predominated, and in healthy individuals type I collagen dominated. The researchers have found out that these patients demonstrated the prevalence of destructive-dystrophic and disintegration changes in the tissues of all layers of the AAW. The analysis of collagen structure revealed a decrease in the number of fibroblasts involved in the formation of collagen, a decrease in its synthesis with a predominance of type II-III collagen. Thus, we can conclude about the existence of systemic structural lesions of the AAW tissues [13].

So far, 29 types of collagen have been described [32]. Histological organization of collagen types corresponds to the functional load and determines the functional features of connective tissue types. More than 90% of all tissue collagen belongs to type I - IV collagen. The combination of collagen I (resistance to stretching) and III (flexibility, ability to stretch in all directions) is optimal for the skin. Macro- and microheterogeneity of the primary structure of collagen determines its morphological properties at all biostructural levels (fibrous, filamentous and others) and the nature of interaction with other components and cellular elements of connective tissue. The literature highlights the data that collagen has tissue and immune specificity [32, 38].

Each biological tissue is able to acquire deformation properties to stretch or contract. At each stage of deformation changes in histoarchitectonics (reversible - within the plastic characteristics, irreversible - outside these parameters) are revealed in the tissues of different topographic and anatomical areas, which to some extent affect the physiological and functional mechanisms of the tissue [22, 24].

Figure 2 shows the dependence of the degree of deformation on tension in the form of three stages of deformation. In the first stage (x1), the tissue sample is deformed, but the tension (μ) remains constant. Such a deformation is called plastic. At stages x2, x3 - pathological changes occur in the tissues that leads to additional scar deformation in the area of surgery or to necrotic changes in the skin and fat flaps, due to changes in tissue tension. [1, 3].

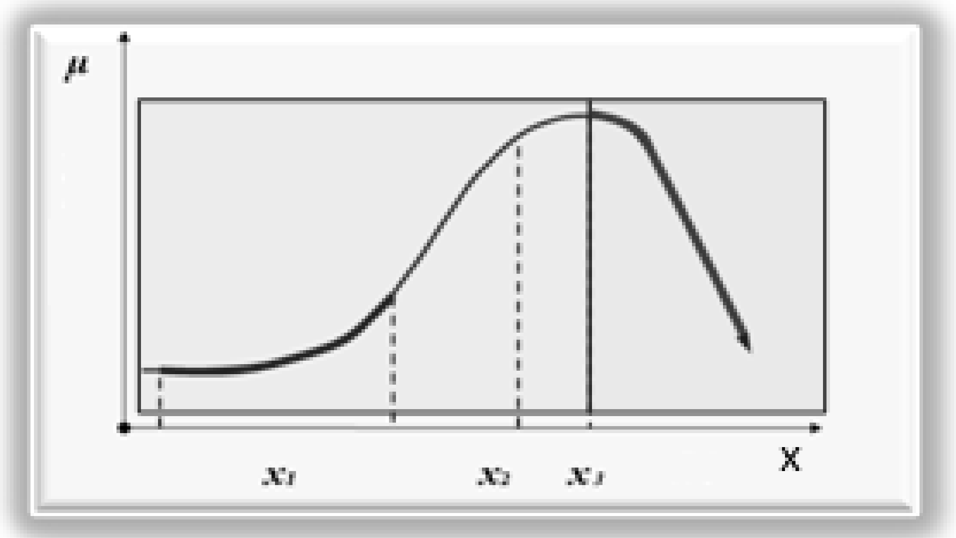

Fig. 2. Graphic representation of the stages of deformation of connective tissue structures during uniaxial linear stretching: μ – tension; x – deformation; x_1, x_2, x_3 – deformation stages.

The techniques used in plastic and reconstructive surgery create conditions of deformation of the surrounding soft tissues of the skin. Initially, the degree of tissue tension is a purely mechanical parameter. Later, against the background of deformation, reactive processes occur in the tissues of arteriolo-venular anastomoses, elements of the microcirculatory tract, connective tissue components, and structures of innervation with the involvement of cellular mechanisms in response to a certain tissue stress [1, 7].

Today, the properties of the dermis and hypodermis in uniaxial linear stretching have been studied and it has been established that these surface layers of the AAW have significant volumes of plastic deformations, which vary considerably and depend on the shape of the body, age, and sex [1, 13]..

It was also found that in response to the action of plastic deformation (load within normal limits) of the tissues of each topographic anatomical area are able to reduce in the range of certain rotational angles depending on body constitution and biomechanical properties of skin and fat flaps and this range of angles can be used to optimize mobilization and fixation of rags from the surface layers of AAW in order to minimize the uneven distribution of stress in the tissues, due to the relaxation that occurs in the postoperative period due to changes in the force of the load [2, 13].

Thus, different structural interactions are expressed by different mechanical factors, which are adequate to the magnitude and direction of tensile forces (deformation vectors), form the typical features of the connective tissue matrix of AAW tissues. [2, 4]. Qualitative and quantitative parameters of fibrous structures (collagen and elastin) in the formations of the connective tissue framework of AAW tissues are directly dependent on the indicators of deformation and stretching of tissues of different topographic and anatomical areas [25, 26].

Normalization of the direction of tissue tension vectors, uniform distribution of the direction of deformation and its force prevents microstructural rearrangement of the surface tissues of the AAW [3, 10, 12].

In addition to genetically determined morphological heterogeneity, the skin undergoes constant changes due to physiological and pathological processes, as a manifestation of dynamic heterogeneity. Changes in collagen types occur during the development of organs and tissues, as well as in pathological conditions. Type III collagen synthesis occurs mainly in rapidly developing tissues (embryonic skin, young granulation tissue, keloid scar, etc.), and type I collagen predominates in mature tissues. The aminoacid composition of collagen also changes with age [8, 17, 31, 38].

Tensile strength and Young's modulus of individual collagen fibres, different tissues, differ insignificantly [31]. The main reason for mechanical differences is the geometry of the location of fibres and bundles, as well as the nature of the interaction of collagen with other components. Human skin undergoes significant changes in length without any damage due to the interaction of collagen fibres, which in themselves are weakly prone to stretching.

The main factors that determine the architecture of the fibres are the strength and topographic distribution of the load on the tissue. It is experimentally proved that the direction of the Langer lines corresponds to the orientation of the collagen network of fibres [28, 33].

The final individual morphology of collagen structures in different types of connective tissue, which determines the diversity of functions and mechanical properties, affects the interaction of collagen with proteoglycans, which play the role of interfibrillar cementitious substance, significantly [18].

The distribution of collagen fibres by thickness is one of the most important factors influencing the mechanical properties of tissues. Thus, the resistance to plastic deformation to bending and torsion is directly related to the percentage of small-diameter fibres, due to the significant interaction of the fibres with other components of the tissue matrix. At the same time, large-diameter fibres are able to withstand high levels of tensile stress, which is associated with an increase in the number of intermolecular "firmware". The coincidence of the direction of stretching of the fibre and the vector of applied force provides tension and tensile strength of the tissue. Accordingly, the spatial orientation of the fibres differs in certain tissues [8].

The presence of elastic fibres in the connective tissue also determines its elasticity and stretching. They are based on globular scleroprotein, elastin, which is characterized by very high plasticity and strength. Elastic structures are found in the form of fibres in tissues (skin, sclera, veins, elastic ligaments, and cartilage) and membranes (arteries) [27, 28].

There is no direct relationship between collagen and elastin fibres. Collagen fibres are twisted around an elastin rod. When stretched by about 1.3 times, the collagen helix is straightened. Thanks to an elastin network the normal arrangement of fibres changed under the influence of external forces is restored, and mechanical durability at small loadings is provided [8, 17].

The biomechanical properties of the skin are also affected by the hormonal background [31, 37]. Deficiency of female sex hormones accelerates skin aging, and hormone-dependent skin aging is independent of photoaging and is manifested mainly in skin thinning and degradation of elastin and collagen fibres. Histological analysis of the skin of the lower abdomen (where photoaging is less severe) shows that the collagen content in the skin decreases sharply after 40 years and after menopause, the latter trend is less severe in women receiving hormone replacement therapy [31, 36].

In patients with hypopituitarism, the skin often loses normal turgor and becomes waxy, and often there are an increased number of wrinkles and stretch marks. The growth hormone affects the amount, distribution and accumulation of subcutaneous fat, which gives the oval female shape. When an adult's growth hormone production decreases, skin nutrition is disrupted and it becomes atrophic: it becomes pale, cold, dry, sweat and fat secretion decreases, small wrinkles appear, its elasticity is lost. At the raised level of somatotropic hormone, the skin thickens, roughens, the expressiveness of skin folds amplifies, the number of sweat glands increases and a real thickening of all layers of the skin occurs [35-37].

In Cushing's syndrome or after treatment with glucocorticoids in appropriate pharmacological doses, there is often the appearance of stasis, overflow of skin vessels with blood, thinning of the skin, a tendency to bruising [39].

Thus, dynamic changes in the histological structure and biomechanical behaviour of the skin are closely related to the aging process, which occurs due to external and internal factors and has different biological, biochemical and molecular mechanisms, and affects its morphofunctional properties. The stretching and thickness of the skin remain the same until the seventh decade, but the elasticity and ability to recover progressively decreases from an early age. Over time, the skin becomes thinner, firmer, less elastic and the ability to stretch decreases [23, 39].

Internal mechanisms of aging include atrophy of the dermis due to loss of collagen, degeneration of the network of elastin fibres and decreased hydration, which is clinically manifested by a network of fine wrinkles, atrophy of the dermis and loss of subcutaneous fat. The decrease in collagen mass is due to a decrease in its synthesis and increased breakdown of collagen fibres. At the molecular level there is the formation of cross-links and modification of the side chains of collagen, which leads to a violation of the normal interaction between cells and extracellular structures, loss of flexibility of molecules [29, 30].

External photoaging involves a massive accumulation of altered elastic fibres known as elastosis in the upper and middle layers of the dermis, which are more responsible for the elasticity of the skin and are clinically manifested by coarse wrinkles, folds, and thickening [29, 30].

Along with the changes in the skin over time, mechanical action can lead to its restructuring, due to physiological stretching of the skin during rapid growth in adolescence, during pregnancy and overweight (or rapid weight loss), under the influence of physical load and wound healing. All these factors lead to connective tissue remodelling [19, 20].

The biomechanical properties of the skin are affected by its preconditioning - a term used to describe the tolerance of tissue to the action of traumatic agent due to previous exposure to stressors, and different types of loads (static, cyclic, stretching, compression, torsion, etc.) cause different microstructural changes , affecting both fibrous structures and the intercellular matrix. This, in turn, affects cellular metabolism by altering the biomechanical properties of the skin. Proof of this is the behaviour of the skin during prolonged stretching by tissue expanders, i.e. dermotension. It is known that with the gradual stretching of the skin, its mechanical properties change, and then return to the previous ones [9, 17].

Certain groups of scientists devoted their work to the study of skin retraction and, on the basis of the obtained data, created mathematical models and programs for predicting and modelling the behavior of the surface layers of the skin during certain surgical interventions [12, 14, 15].

Thus, the skin is a complex three-dimensional structure and is subject to prolonged exposure to internal and external factors, which is reflected in its mechanical properties. It is not possible to assess the influence of internal and external factors on the individual features of the patient's skin biomechanics, so in practice, studies of individual biomechanical properties of the patient's skin depending on the purpose and objectives of treatment are conducted.

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Реферат

АНАТОМІЧНЕ ПІДГРУНТЯ БІОМЕХАНІЧНИХ ВЛАСТИВОСТЕЙ ПОВЕРХНЕВИХ ТКАНИН ПЕРЕДНЬОЇ ЧЕРЕВНОЇ СТІНКИ.
Драбовський В.С., Кербаж Н.Р., Акєйші А.К., Рибалка Я.В.
Ключові слова. біомеханіка, передня черевна стінка, шкіра

Біомеханіка – наука, що вивчає механічні властивості тканин, окремих органів і систем та організму в цілому. Унікальні механічні властивості шкіри забезпечують функцію підтримки та захисту внутрішніх органів, зберігаючи при цьому її рухливість і розтягнення. Ця особливість шкіри детермінована її мікроструктурним складом і організацією сполучнотканинних волокон. Механічні властивості шкіри головним чином визначає насичена колагеном дерма. Механіка дерми, у свою чергу, залежить від структури, щільності і направлення колагенових волокон. Кожна біологічна тканина здатна набувати деформаційних властивостей – розтягуватись або скорочуватись. На кожній стадії деформації в тканинах різних топографоанатомічних ділянок відбуваються зміни гістоархітектоніки (зворотні – в межах пластичних характеристик, незворотні – поза цих параметрів). Різні структурні взаємодії виражаються неоднаковими механічними факторами, які адекватні величині та направленню сил розтягнення (векторів деформації), формують типові особливості сполучнотканинного матриксу тканин передньої черевної стінки. Нормалізація направлення векторів напруження тканини, рівномірний розподіл напрямку деформації та її сили, попереджує мікроструктурну перебудову поверхневих тканин передньої черевної стінки. Динамічні зміни гістологічної будови та біомеханічної поведінки шкіри тісно пов'язані з процесом старіння, гормональним фоном, механічними факторами: фізіологічного розтягнення шкіри під час швидкого росту в підлітковому віці, під час вагітності, при надмірній вазі (або швидкій її втраті), під дією фізичного навантаження та при ранозагоєнні. Всі ці чинники призводять до ремоделювання сполучної тканини. Таким чином, шкіра є складною тривимірною морфологічною структурою та схильна до тривалого впливу внутрішніх і зовнішніх чинників, що відображається на її механічних властивостях.

Реферат

АНАТОМИЧЕСКАЯ ОСНОВА БИОМЕХАНИЧЕСКИХ СВОЙСТВ ПОВЕРХНОСТНЫХ ТКАНЕЙ ПЕРЕДНЕЙ БРЮШНОЙ СТЕНКИ
Драбовский В.С., Кербаж Н.Р., Акейши А.К., Рибалка Я.В.
Ключевые слова. биомеханика, передняя брюшная стенка, кожа

Биомеханика - наука, изучающая механические свойства тканей, отдельных органов, систем и организма в целом. Уникальные механические свойства кожи обеспечивают функцию защиты внутренних органов, сохраняя при этом ее подвижность и ретракцию. Эта особенность кожи детерминирована ее микроструктурным составом и организацией соединительнотканных волокон. Механические свойства кожи главным образом определяет насыщенная коллагеном дерма. Механика дермы, в свою очередь, зависит от структуры, плотности и направления коллагеновых волокон. Каждая биологическая ткань способна приобретать деформационных свойств - растягиваться или сокращаться. На каждой стадии деформации в тканях различных топографо-анатомических областей происходят изменения гистоархитектоники (обратимые - в пределах пластических характеристик, необратимые - вне этих параметров). Различные структурные взаимодействия выражаются неодинаковыми механическими факторами, которые адекватны величине и направлению сил растяжения (векторов деформации), формируют типичные особенности соединительнотканного матрикса тканей передней брюшной стенки. Нормализация направления векторов напряжения ткани, равномерное распределение направлении деформации и ее силы, предупреждает микроструктурную перестройку поверхностных тканей передней брюшной стенки. Динамические изменения гистологического строения и биомеханического поведения кожи тесно связаны с процессом старения, гормональным фоном, механическими факторами: физиологического растяжения кожи во время быстрого роста в подростковом возрасте, во время беременности, при избыточном весе (или быстрой ее потере), под действием физического нагрузки и при ранозаживлении. Все эти факторы приводят к ремоделированию соединительной ткани. Таким образом, кожа является сложной трехмерной морфологической структурой и склонна к длительному воздействию внутренних и внешних факторов, отображается на ее механических свойствах.