Characteristics of connective tissue fibres

Agnieszka Michalczewska[1] $_{AEFG}$, Agnieszka Pedrycz[2] $_{AEFG}$, Lilianna Kostecka[3] $_{FG}$

[1] Vincent Pol University in Lublin, Poland
[2] Medical University of Lublin, Poland
[3] High School No. 2 in Chełm, Poland

Abstract

Connective tissue connects, supports and protects other tissues of the body. It is composed of cells and the intercellular substance. The important elements of the latter are fibres, which are divided into collagen fibres and their variety- reticular fibres as well as elastic fibres and their varieties, i.e. oxytalan and elaunin fibres.

The present paper describes the proteins forming the individual types of fibres presents a review of the literature regarding the connective tissue, particularly the fibres.

Key words: elastic fibres, reticular fibres, collagen

Introduction

Connective tissue comprises manifold varieties that differ in structure and function. It develops predominantly from mesenchyme; the connective tissue located in some head and neck areas develops from neuroectoderm. The major function of the connective tissue is to connect, support and protect other tissues in the body, i.e. muscular, nervous and epithelial tissues. Its mechanical capabilities result from the abundance and physical properties of the intercellular substance.

The second element of the connective tissue is cells whose function ensures the formation of intercellular substance and decides about the protective mechanisms of the body. The connective tissue cells store extra substances (lipids) and produce numerous mediators regulating the function of other cells.

There are many varieties of connective tissue, differing in structure and adaptation to various functions. The specialised varieties of connective tissue are cartilages, bones and blood.

The intercellular substance of connective tissue is composed of two main components: the ground substance and fibres. The ground substance is amorphous and is composed of proteins and proteoglycans (protein-sugar compounds). It is highly hydrated, which enables the diffusion of gases and nutrients to the cells scattered over its surface. The fibres forming the intercellular substance of connective tissue comprise collagen fibres and their variety- reticular fibres as well as elastic fibres and their varieties, i.e. oxytalan and elaunin fibres.

The aim of the paper was to describe the fibres of connective tissue, their types, structure and function.

Collagen fibres (collagenous)

The collagen fibres are stained with acidic dyes (eosin staining – pink, aniline blue according to the Mallory-Azan method - blue). They are highly resistant to stretching (by about 5% at most) and breaking. A collagen macromolecule is composed of three spirally coiled polypeptide chains, which form a helix α.

The collagen fibres are composed of a fibrilar protein – collagen (from Greek – colla- glue; gannan- produce). It is the most abundant protein occurring in the body and constitutes about 25% of all proteins.

Each molecule of collagen consists of three left -handed polypeptide chains rotating clockwise [1]. Both terminal fragments- telopeptides do not form a spiral and contain the majority of sugar residues in the form of short, branched chains. The terminal fragments are the major place of forming the bonds stabilizing the system of collagen particles into fibrils. This system is extremely regular, which results in the formation of a characteristic transverse striation in fibrils with 67 nm periodicity.

The ends of fibril-forming collagen molecules are not connected (the interval - 0.6 of the period), resulting in the formation of fragments in which the molecules overlap (a bright stripe- o.4 of the period) and fragments with intervals (a dark stripe - 0.6 of the period). Different colouration of stripes results from easier penetration of contrast substances within the loose areas of fibrils and from the different content of electric charges in the terminal fragments of collagen molecules that do not form spirals. The striation of fibrils, including additional finer lines of both types of stripes, is particularly distinct in negative staining.

Collagen has an extremely characteristic composition of amino acids; every third amino acid in polypeptide chains is glycine, almost 1.4 of residues is proline and hydroxyproline; moreover, lysine and hydroxylysine occur in high amounts.

About 25 various collagen α chains have been identified, which differ in the composition of amino acids and their glycosylation (the site and amount of sugar residues bound with them). Each chain is encoded by a different gene. Thus, 25 types of such polypeptides can theoretically result in over 10 000 various types of collagen helixes composed of three polypeptide chains. To date over 20 types of collagen have been identified.

A macromolecule of collagen is called tropocollagen; it is 1.5nm wide and 280nm long and each polypeptide chain consists of about 1000 amino acids.

Many various cells are capable of synthesising collagen; however, the main producers of this protein are fibroblasts of the connective tissue proper and their counterparts in other varieties of the connective tissue (chondroblasts and osteoblasts in the supportive connective tissue, odontoblasts in the dental pulp).

During the formation of collagen, the synthesis of α chains is initiated, whose proline and lysine residues undergo immediate hydroxylation mediated by respective hydroxylases located in the membranes of the rough endoplasmic reticulum. The chains subsequently undergo glycosylation to bind with disulphide bonds in the molecule of procollagen transported by the Golgi apparatus outside of the cell. Simultaneously, the fibroblast secretes peptidases that truncate the peptide fragments (propeptides) at both ends of the procollagen molecule, which leads to the formation of a final molecule of collagen.

The presence of propeptides enables intracellular aggregation of collagen, while their truncation reduces the solubility of collagen by about 1000 times, facilitating extracellular aggregation into fibrils. The fibroblast is involved in the early binding of molecules coiling them in a groove-like manner. The initial binding of approximated molecules with hydrogen and hydrophobic bonds is followed by deamination (lysine oxidase-dependent) of amino acid residues, which form strong cross bonds connecting the collagen molecules. These bonds provide fibres with structural stability and mechanical properties.

The tissues predominantly contain collagen types I, II, III, IV, V, VI, VII, XI and XII. Collagen types I, II, III,V, VII and XI produce fibrilar macromolecules and fibres of various thickness, from 10 to 300 nm, and of several millimetre-length. Type IV collagen forms multi-angular structures, which are microscopically homogenous. The complexes of type IX and XII collagen bind with various collagen fibres interconnecting them.

Argentophilic fibres (reticular)

Argentophilic fibres are composed of type III collagen. Their name refers to the ability to undergo silver salt impregnation (black colour) and the tendency to create the system of dense networks that support more delicate structures, such as clusters of cells or even singe cells. Unlike collagen fibres, argentophilic fibres do not form bundles and their length does not exceed 2 μm. Microscopically, the fibres building them reveal transverse striation, identical to that observed in collagen fibres yet thinner (about 50 nm). Moreover, higher amounts of the binding substance are found interfibrally, which is responsible for the fibres as the wholes for impregnation with silver salts [2].

Types of collagen

Several genetically different types of collagen have been identified, which vary in primary structure (sequence of amino acids) of polypeptide chains forming the molecule. Moreover, there are differences in their universality and site of occurrence as well as the ability to form fibrils, fibres and bundles.

Type I – the most common. It occurs in the bone, dentine, ligaments, tendons, capsules of fibrosus organs, dermis (the dense part) as well as loose connective tissue and form the systems of thick fibres composed of striated fibrils, frequently creating bundles [3].

Type II – occurring in the vitreous and elastic cartilages, vitreous humour of the eye and nucleus pulposus of intervertebral discs. This type of collagen forms thin, single fibres, sometimes striated and of various periodic patterns.

Type III – occurs relatively commonly and is mainly found in the reticular connective tissue, newly formed connective tissue (healing wounds, embryonic skin), the papillary layer of mature skin, blood vessels and tissues rich in smooth muscular cells. The argentophilic fibres form networks of fine meshes [4].

Type IV – occurs in basilar laminae forming loose networks [5].

Type V – is also common; occurs abundantly in the placenta, muscles and tendon sheaths.

Type VII – is present in basilar membranes, especially those of multi-layer, flat epithelia (e.g. the epidermis) and forms anchored fibrils.

Type IX –is found in the vitreous and elastic cartilage; lies on the surface of fibrils composed of type II collagen and forms inter-fibrin side connections.

Type XI – its occurrence is similar to that of type II collagen; it forms fibrils with type II collagen

Type XII – its occurrence is similar to that of type I collage, predominantly in tendons and ligaments; it forms fibrils with type I collagen.

Type I, II, III, V and XI collagens belong to the fibril-forming group, type IX and XII collagens to the fibril-bound group while type IV and VII collagens to the network-forming group.

Elastic fibres

The elastic fibres occur as single fibres (do not form bundles), are up to 1μm thick and are usually arranged in networks. Special dyes are required to visualise them –resorcin- fuchsin stains them steel blue while orcein – brown-brick-red. Single elastic fibres can be stretched by about 100% of their length and return to their previous resilience; hence, they occur in organs undergoing elastic deformations, e.g. blood vessels, particularly in elastic -type arteries, in walls of pulmonary and bronchial alveoli, elastic cartilages. High amounts of elastic fibres are found in the skin (particularly in younger individuals) and loose tissue. They are the basic component of elastic ligaments. connective

Under an electronic microscope, elastic fibres are found to be composed of two elements: an amorphous part located centrally and microfibrils located peripherally, which occur first in the process of fibrogenesis. The amorphous part is formed by elastin, rich in glycine and proline (like collagen) but with a low content of hydroxyproline (unlike collagen) [6].

The characteristic components of elastin are polyamino acids, desmosine and isodesmosine, which are produced from lysine residues due to formation of strong intra- and extra-molecular covalent bonds. Thanks to the tertiary and quaternary structure stabilised by these bonds and hydrophobic effects, elastin is a strong network of randomly coiled molecules, which straighten due to the stretching force; when the stretching is discontinued, the molecules in question return to initial conformation. This ensures the extensibility of elastic fibres and their considerable resistance to boiling as well as the effects of acids, bases and the majority of proteolytic enzymes. The microfibrils of elastic fibres are approximately 10nm thick and consist mainly of glycoproteid, microfibrilin with high content of hydrophilic amino acids, including cysteine. Another component of microfibrils is microfibril-associated glycoprotein, showing the activity of amine oxidase, which is crucial for elastin metabolism.

Some organs, e.g. walls of elastic-type arteries contain **elastic laminae** as well. They are formed by closely adhering elastic fibres and have numerous openings. In the transverse sections of histological specimens, they resemble fibres and show the properties of elastic fibres.

Furthermore, the varieties of elastic fibres have been identified that occur in small amounts, i.e. oxytalan and elaunin fibres.

The oxytalan fibres are particularly resistant to acid hydrolysis. Together with elastic fibres, they occur in the tendons, dental pulp, ciliary zonule and other aggregations of the connective tissue proper. They are composed of 10nm-wide fibres, whose chemical composition remains unclear (almost no elastin).

The elaunin fibres are rarely found in the connective tissue; however, their high amounts occur in the basilar tissue of the epithelium of sweat glands, where they are the only connective tissue fibres. They are composed of 10 nm-wide fibres and small amounts of elastin.

References:

1. Jozsa L, Kannus P, Balint JB, Reffy A. Three-dimensional ultrastructure of human tendons. Acta Anat (Basel). 1991;142:306-12.
2. Schwint OA, Labraga M, Cervino CO, Haffar M, Sequeiros PH, Marcos HJ. A modification of the staining technique of reticular fibres for image analysis of the cardiac collagen network. Cardiovasc Pathol. 2004;13:213-320.
3. Kannus P. Structure of the tendon connective tissue. Scand J Med Sci Sports. 2000; 10: 312-320.

4. Biondo-Simões Mde L, Morais CG, Tocchio AF, Miranda RA, Moura PA, Colla K, Robes RR, Ioshii SO, Tomasich FD.: Characteristics of the fibroplasia and collagen expression in the abdominal wall after implant of the polypropylene mesh and polypropylene/polyglecaprone mesh in rats. Acta Cir Bras. 2016; 31: 294-299. doi: 10.1590/S0102-865020160050000001.
5. Senga K, Kobayashi M, Hattori H, Yasue K, Mizutani H, Ueda M, Hoshino T. Type VI collagen in mouse masseter tendon, from osseous attachment to myotendinous junction. Anat Rec. 1995; 243: 294-302.
6. Baldwin AK, Simpson A, Steer R, Cain SA, Kielty CM. Elastic fibres in health and disease. Expert Rev Mol Med. 2013 20;15:e8. doi: 10.1017/erm.2013.9.

Correspondence address:
Prof. A. Pedrycz
apw4@wp.pl