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Journal of Surgical Case Reports and Images

Mehmet Rami Helvaci *

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Short Communication

Chemical Composition of Smooth Tonic Muscles

Mehmet Rami Helvaci

Specialist of Internal Medicine, MD, Turkey.

***Corresponding Author:** Mehmet Rami Helvaci, Specialist of Internal Medicine, MD, Turkey.

Received Date: March 02, 2026; **Accepted Date:** March 10, 2026; **Published Date:** March 26, 2026

Citation: Mehmet R. Helvaci, (2026), Chemical Composition of Smooth Tonic Muscles, *J, Surgical Case Reports and Images*, 9(2); **DOI:10.31579/2690-1897/302**

Abstract

The smooth musculature of vertebrates, of mesenchymal origin, is one of the key tissue types enabling the function of internal organs, the vascular wall, and specialized sphincter apparatuses. The fundamental differences between smooth muscles and striated skeletal musculature are evident both at the level of histological organization and in the features of their contractile activity.

Keywords: smooth muscle; tonic contraction; chemical composition; myofibrillar proteins; actomyosin; tropomyosin; paramyosin; ATPase activity; stromal proteins; collagen

Introduction

The smooth musculature of vertebrates, of mesenchymal origin, is one of the key tissue types enabling the function of internal organs, the vascular wall, and specialized sphincter apparatuses. The fundamental differences between smooth muscles and striated skeletal musculature are evident both at the level of histological organization and in the features of their contractile activity [1, 2].

Despite the significance of smooth musculature, its chemical composition and, in particular, the organization of its contractile apparatus have been studied to a lesser extent compared to skeletal muscles [3, 4].

Analysis shows that smooth muscles are characterized by a number of fundamental features. In addition to proteins, their composition includes glycogen, lipoids, nitrogenous extractive substances, nucleotides, and creatine phosphate; however, the concentration of ATP and other high-energy compounds in smooth musculature is significantly lower than in striated muscles [5]. The same applies to the content of the dipeptides carnosine and anserine, which are present here only in trace amounts. However, the most characteristic and important differences are revealed when studying the protein fractions of smooth muscles [6, 7].

The ratio of fractions extracted at different ionic strengths of the solution exhibits a pronounced uniqueness. The actomyosin complex of smooth muscles differs in its characteristics from the classical actomyosin of skeletal tissue, and the ATPase activity of the isolated proteins is reduced by an order of magnitude [8]. A characteristic feature is the increased concentration of tropomyosin and its variants, as well as a significant proportion of stromal elements, represented mainly by collagen, which impart mechanical stability and elasticity to the muscle [9, 10].

This work is devoted to the analysis of the chemical composition of smooth tonic muscles, with an emphasis on the uniqueness of their protein components, which is necessary for understanding the molecular organization of the contractile apparatus and its regulatory mechanisms [11].

Main Part

Smooth muscles of vertebrate animals of mesenchymal origin differ from striated skeletal muscles both in their tissue structure and in the nature of their contractions [1, 12].

The chemical composition of smooth muscles has been studied less thoroughly than that of skeletal muscles. The composition of smooth musculature, like that of striated muscles, includes, in addition to proteins, glycogen, neutral fats and lipids, small amounts of phosphorus esters of monosaccharides, phosphotrioses, glucose, nitrogenous extractive substances, adenosine triphosphate and other purine and pyrimidine nucleotides, creatine, creatine phosphate, creatinine, carnosine and anserine, amino acids, urea, and many other compounds. Nucleoside triphosphates, particularly ATP and other acid-soluble organic phosphorus compounds, are present in smooth musculature in significantly lower concentrations than in striated muscles [5].

The same can be said about the content of extractive substances like carnosine and anserine in smooth muscles. In most cases, only traces of these dipeptides are found in smooth musculature [3]. However, the most characteristic and important features of the chemical composition of smooth musculature can be discovered by studying its protein fractions [6].

Proteins of Vertebrate Smooth Tonic Musculature

The total protein nitrogen content in smooth muscles is lower than in skeletal muscles. Data on the fractional composition of contractile

(myofibrillar) proteins, which are extracted from muscle tissue with salt solutions of high ionic strength after prior removal of easily soluble sarcoplasmic proteins, are of the greatest importance [4]. The total content of contractile proteins in the smooth musculature of the stomach is approximately two times lower than in skeletal muscles [13].

It has been established that contractile proteins, in turn, can be divided into two groups: proteins soluble in salt solutions with high ionic strength, and proteins soluble in salt solutions with low ionic strength [14]. The ratio between these two groups of proteins differs in different types of musculature. For fast skeletal muscles, this ratio is approximately 3.5, whereas for smooth tonic muscles it ranges from 1/1.5 to 1/3.

The so-called "actomyosin fraction" of smooth muscles differs sharply in a number of properties from the typical actomyosin of skeletal musculature [8].

It is likely that the so-called "readily soluble" contractile proteins play the most important role in the tonic locking function of smooth muscles [11]. They represent heterogeneous systems, which include tropomyosin, water-soluble contractile protein, globulins, and a number of sarcoplasmic proteins more or less firmly bound in the muscle fibers into a single functional complex with myosin. Some of these proteins readily undergo spontaneous denaturation [6].

The uniqueness of the fractional composition of proteins in different muscle types is closely related to the nature of their physiological activity. In locomotor, i.e., rapidly contracting muscles of invertebrates, the proteins of the actomyosin complex differ little in their properties from the actomyosin of skeletal striated muscles and are present in significantly greater quantities than in the tonic muscles of vertebrate internal organs [7, 8].

According to available data, smooth muscles are characterized by a high content of tropomyosin [11].

The attention of many researchers has been directed to studying the fractional composition of proteins in the locking muscles of mollusks. The pattern of X-ray diffraction spectra of mollusk locking musculature differs from that of mammalian skeletal musculature. Fibers producing such distinctive X-ray patterns are found in especially large numbers in the slowly contracting part of the bivalve mollusk adductor. These fibers were named type I fibrils or paramyosin fibrils [9].

From the smooth, slowly contracting part of mollusk locking muscles, an exceptionally viscous extract can be obtained using 1 M KCl solution, which gives only weak characteristic reactions for myosin and actomyosin [10].

The protein of this extract can be precipitated during dialysis against solutions of low ionic strength in the form of crystalline birefringent needles. The protein obtained in this way is similar in a number of properties to tropomyosin isolated from mammalian skeletal muscles. But, unlike it, this protein is insoluble in water in the absence of salts and is precipitated by ammonium sulfate at a significantly lower degree of saturation [14].

This protein was identified as paramyosin. In the smooth part of the oyster and Pinna adductor, this protein accounts for 25 to 30% of the total muscle protein.

In its amino acid composition, paramyosin is very close to tropomyosin [11].

In addition to water-insoluble paramyosin, which is considered a water-insoluble form of ordinary tropomyosin, water-soluble tropomyosin, which can also be obtained in crystalline form, is found in low concentration in the muscles of cephalopods (Cephalopod) [10].

The ATPase activity of proteins extracted from vertebrate smooth tonic musculature with 0.6 M KCl is significantly lower (10–20 times) than the enzymatic activity of skeletal muscle myosin [5]. Most of the ATPase activity of smooth musculature is associated with water-soluble proteins that are not directly related to the contractile function of muscles [8].

Also characteristic is the high content of myoalbumin and stromal proteins (connective tissue framework proteins) in smooth tonic muscles. In the myometrium, for example, stromal proteins account for up to 40% of all muscle proteins [15]. The stroma of skeletal muscles consists almost exclusively of connective tissue elements. The stromal proteins of the myometrium are represented mainly by collagen. Thus, it can be considered highly probable that the stroma of smooth musculature consists for the most part of relatively inert proteins that do not participate directly in muscle contraction [16].

It is likely that these proteins impart additional mechanical strength and elasticity to smooth musculature and possibly play a certain role in the mechanism of passive return of the muscle to its initial state after active contraction [12].

The existence in smooth musculature of a special protein, originally named nucleotropomyosin, has not been confirmed subsequently. Apparently, there are also insufficient grounds for recognizing the existence of actotropomyosin as an individual protein. At the same time, the possibility of interaction between individual proteins and various other substances, for example nucleic acids, with the formation of unstable complexes of variable composition cannot be denied [2].

Data on the presence of a large amount of free actin (up to 30–40%) in extracts from the myometrium have not been confirmed in subsequent studies [15].

High ionic strength extracts from minced smooth musculature of the uterus, as well as the stomach, do not possess (or possess to an insignificant extent) the ability to interact with L-myosin to form viscous actomyosin. This makes the assumption of the presence of free actin in any significant concentration in extracts from the myometrium or stomach musculature unlikely [13].

There is data suggesting that in smooth musculature, particularly in the myometrium, actin is less firmly bound to myosin than in the actomyosin of skeletal musculature, and separates from this complex upon simple precipitation of proteins with ammonium sulfate. The so-called hysteriomyosin is also apparently a peculiar artifact arising during the process of isolating proteins from muscle tissue [15].

Thus, the chemical composition of smooth tonic muscles is characterized by a number of fundamental differences from skeletal musculature. The key features are a lower total content of contractile proteins and ATP, a specific set of myofibrillar proteins with a predominance of the "readily soluble" fraction and tropomyosin, as well as a high proportion of stromal components such as collagen [17]. These biochemical characteristics directly correlate with the physiological properties of smooth muscles: their slow tonic contraction, high distensibility, efficiency of work, and ability to maintain tension for a long time without fatigue [1, 6]. Further study of the molecular organization of the contractile apparatus and its regulatory mechanisms in smooth muscles is necessary for understanding the pathogenesis of many diseases of internal organs and developing new methods of therapeutic intervention [16].

Conclusion

The conducted analysis of the chemical composition of vertebrate smooth tonic muscles allows us to conclude that their biochemical organization fundamentally differs from that of skeletal musculature. The revealed features of the chemical composition directly depend on physiological parameters: the propensity for prolonged tonic tension, pronounced plasticity, and resistance to fatigue [2, 7].

Summarizing the results of the analysis, the following conclusions should be drawn. It has been established that smooth muscles are characterized not only by a reduced total content of contractile proteins and high-energy compounds (ATP, creatine phosphate), but also by a qualitative uniqueness of the proteome [3, 5]. Significant differences in the actomyosin complex, manifested in low ATPase activity and lability of bonds between actin and myosin components, determine the slow nature of filament interaction and the low rate of force development [8].

Special attention deserves the confirm

ed role of tropomyosin and its analogs (paramyosin), whose concentration in smooth tonic muscles significantly exceeds that in fast skeletal muscles. This forms the morpho-functional basis for prolonged tone maintenance and ensuring the mechanical strength of internal organ walls [14, 17].

Thus, the chemical composition of smooth muscles should be considered as a type of tissue organization, optimized by evolution to perform specific functions in visceral systems. The presented data serve as a fundamental basis for further in-depth study of the molecular mechanisms regulating contraction [4, 10].

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DOI:10.31579/2690-1897/302