THE STRUCTURE OF THE MUSCLES OF THE LOBSTER.

By M. L. HOLBROOK, M. D., New York City.

When we read the history of those scientific investigations which have been made by our most excellent observers during the last forty years, we can hardly fail to be convinced that even the simplest facts of natural philosophy are established only after long-continued and patient research. Truth is rarely or never reached in a straight line, but by a tortuous and zigzag course. At times we seem to have it almost within our grasp, and then it becomes lost to view and we are compelled to seek for it in a new direction. All this is true when applied to the researches of muscular structure, as we shall see.

The muscular system, as we know, constitutes the motor apparatus of all complex animal bodies. By it all movement from place to place, all change of shape and form, are accomplished. In the most highly developed animals we find two kinds of muscles. The first is the smooth, unstriped variety, composed of relatively small granular spindles, which together form bundles. The second variety is composed of relatively large spindle-shaped fibers which exhibit more or less distinct striations, from which they are called the striated muscles. The smooth, unstriped muscles are the involuntary, and act independently of the will; while the striped ones are subject to volition. The heart is a notable exception, being composed of striated muscles and yet involuntary in its actions.

All motions of the body are based upon the contraction of these two varieties of muscle fibers, for they possess in the highest degree the same property seen in every portion of living matter in every simple organism, in every *plastid*, the power to contract. From this it is fair to conclude that muscle must also be living matter.

The subject which I wish to consider here is the structure of the striated muscle of the lobster. I shall use the nomenclature adapted by Dr. Louis Elsberg (Science, Dec. 10, 1881), who suggests the term *bioplasson* for living matter, or *protoplasma* and *plastid* for the word "cell."

Our modern views on the structure of striated muscle date back as far as the year 1839, when Th. Schwann* in his celebrated researches on the identity of the structure of the animal and plant, maintained that the striated muscle is composed of innumerable, extremely delicate, fibrillæ of a beaded or rosary-like appearance. A number of such fibrillæ, the beads of which stand in one line close together would, according to his view, form a muscle bundle. If we look at a muscle-fiber we notice alternating light and dark lines of a definite width, and these, according to Schwann's view, originate in the regularity in which the thick and thin portions of the fibrillæ are placed side by side. W. Bowman† demonstrated that the fibers sometimes break up, when subjected to mechanical injuries or chemical re-agents, into transverse discs. The cleavage of the fiber lengthwise gives us the fibrillæ, while a transverse cleavage gives the discs. By splitting the fibers in a longitudinal and transverse direction, this investigation obtained innumerable small cylindrical or square pieces which he called the *sarcous elements*. He maintained with great positiveness that the striations in the muscle-fiber are due to a difference in the refracting power of the intermediate substance, and that the longitudinal and transverse splitting are not essential properties of the muscles, but are due to mechanical or chemical injuries.

The next investigator who has thrown light on this subject is E. Brücke‡. This observer maintains that the *sarcous elements* are

*Untersuchungen über die Uebereinstimmung, etc. Berlin, 1839.
†Todd's Cyclopedia, etc., 1848.
‡Untersuchungen über den Bau der Muskelfasern, 1857.

by no means invariable and unchangeable formations in the living muscle, but that they are rows of corpuscles differently arranged at the moment of death. On examining the fiber with polarized light, he came to the conclusion that the *sarcous elements* are constructed of very small invisible particles which he named *disdia klasts.* Upon the grouping of these minute bodies, he believed, depended the varying formation of the *sarcous elements.* Brücke argues that the rows of *sarcous elements* are double-refracting, while the spaces between them are only simple-refracting. As to the nature and consistence of these intermediate layers he offers no opinion. C. Heitzmann* in 1873 asserted that a muscle is constructed on exactly the same principle as every other protoplasmic body, as for instance, the amœba. He believed that the *sarcous elements* of the muscle were analogous to the granules seen in the body of the amœba. He pointed out an inter-connection of the *sarcous elements*, both longitudinal and transverse, by means of delicate filaments of living matter, in the same manner as the granules of *bioplasson* in the amœba are connected. My own observations point strongly to the correctness of this assertion.

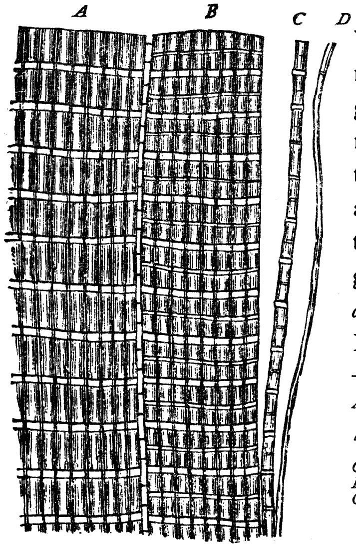
The observations of the investigators now mentioned are the principal sources of our knowledge of the structure of striped muscle. The later researches on this subject, made by Hensen, W. Krause, Engelmann, Heppner and A. Schäfer, have added little to our knowledge, as these authors have explained the structure of striped muscle in a complicated manner, and far differently from what we really see. Perhaps Cohnheim's discovery of the peculiar fields in transverse sections of frozen muscle deserves a remark, as they appear to have been formed by the process of freezing, as we shall see later on.

I will now proceed to give an account of my own investigations in this field of inquiry, which have been mainly with the muscles of the lobster. If we take from this animal a minute piece of perfectly fresh muscular tissue, and transfer it, together with a drop of the blood of the animal, to a glass slide, and cover it quickly with a thin cover-glass, we may see, with moderate powers of the microscope, the fibers composing it of a nearly uniform breadth. These

* Untersuchungen über den Bau des Protoplasmas, 1873.

fibers are separated from each other by exceedingly narrow, light spaces, which, in some places, contain a granular mass. A number of fibers are held together by a delicate fibrous tissue, in which are held the vessels and nerves. These latter features are seen best in a transverse section of the muscle. Within the fiber may be noticed two kinds of substance: one is opaque, and of a dim luster; the other is light, uncolored, not shining. In many places the two substances alternate with each other in such a way as to form rows running in the transverse direction of the fiber; or we may sometimes observe that the opaque substance is distributed, without regularity, in the form of granules, in the light substance. The rows composed of the bright substance vary greatly in their width. Sometimes a line of it is as broad as the light substance; or the shining substance may very much surpass the light one in breadth; or a broad line may be split in the center by an exceedingly light line. In other words, the bright substance varies greatly in its amount in relation to the light substance.

When we come to use higher powers of the microscope, we find that each shining line is composed of a large number of square, cylindrical or prism-shaped pieces, which are the *sarcous elements* of Bowman.



We also see that the light layer between the rows of *sarcous elements* is traversed by extremely delicate grayish filaments connecting all the rows within a muscle-fiber. When the *sarcous elements* are separated so as to render the light interstice between them visible, we again see the grayish filaments connecting the *sarcous elements* in a transverse direction. Lastly, we see that all the inter-

A.—A bundle of striped muscle-fibers composed of single rows of *sarcous elements*.
B.—A bundle composed of rows of *sarcous elements* divided in halves.
C.—Single fibrillæ composed of alternating rows.
D.—Fibrilla nearly solid.
C and *D* are from chromic acid specimens teased out. Magnified 1200 times.

stices between the muscle-fibers are traversed by delicate grayish threads or spokes, connecting the adjoining muscle-fibers, and also connecting the *sarcous elements* with the granules present between the fibers.

From this it is evident that the minute structure of the fresh muscle of the lobster is *reticular*. The nodulations of the *reticulum* correspond to the *sarcous elements*, and vary greatlv in size; while the rectangular connecting-fibrillæ always are exceedingly delicate.

All observers agree that the *sarcous elements* are the active agents in muscular contraction, because they are the formations that change their shape and place during the contraction of the muscle, while the intermediate light spaces are filled with a non-contractile liquid.

C. Heitzmann, in 1873, discovered a reticular structure in the substance hitherto termed *protoplasma*, and acknowledged to be the seat of life. He claimed that only the *reticulum* in the *protoplasma*,—that is, the nucleus, the granules, the connecting filaments, and the investing layer,—are contracting matter proper. He claimed that within the meshes of the *reticulum* is contained a liquid which is lifeless, for the reason that a liquid can never be endowed with living properties, or become the seat of life. According to this observer, all changes of form and place which take place in the lowest organisms with which we are acquainted, are the result of the contraction of a *reticulum* of living matter, and consist in an increase of the size of the granules, a shortening of the filaments which connect them, and a narrowing of the meshes simultaneously with an extension of the *reticulum* in other parts of the body. The discovery of this same observer that even the highest developed animals exhibit a reticular structure in every tissue of the body, was recently explained and corroborated by Louis Elsberg (Science, December 10, 1881.)

Whatever tissue we take, the *reticulum* is living or contracting matter; but in the muscles the contraction is more powerful, and causes great changes of shape and place, on account of their greater size, and the greater accumulation of living matter.

The observations which I have made, and which have now been given, it seems to me, confirm in a most striking manner these new views on *bioplasm*.

In order to bring out more perfectly the structure of muscle than could be done in its natural state, I used, with success, a one-half per cent. solution of chloride of gold, which is known to stain living matter violet.

I also tried the freezing of the muscle by means of rhigoline in the Beck microtome, in order to cut the sections more easily and perfectly; but this changed the texture, at times even completely destroying it, and I was compelled to resort to other methods. Here I may state that I suspect the peculiar condition of the muscle described by Cohnheim, and previously mentioned, may have been caused by freezing. I did not succeed in obtaining those peculiar fields described by him, in transverse sections of the muscle of the ox, made while the tissue was slightly frozen.

The next re-agent which I used was a one-half per cent. solution of chromic acid, which is known to preserve and harden living matter, but not destroy its character, or otherwise injure it. The results with the chromic acid specimens were found to be the same as those observed in the fresh muscle. Here too the alternating layers of *sarcous elements* and the interstitial layer were plainly recognized. The power of *sarcous elements* varied greatly in breadth and form. If we tease a chromic acid specimen, we obtain delicate longitudinal fibrillæ, because we break the transverse connections, the filaments of living matter which unite them together. Such an artificially isolated fibrilla may appear beaded, as was asserted by Th. Schwann; or it may exhibit a nearly uniform width throughout its entire length; or the entire fibrilla may appear bright and homogeneous, and show no trace of any difference in its optical properties in any part. This may be explained by the fact that the *sarcous elements* within the muscle-fiber may coalesce or approach each other so closely that the intermediate light substance becomes invisible. We may explain the beaded condition of the fibrillæ either by saying the living matter produces a solid square piece—the *sarcous element*—which above and below is hollowed out, and indicates the interstitial liquid; or by saying that from both edges of a *sarcous element* connecting filaments run to the neighboring *sarcous element*.

In a longitudinal section of a muscle-fiber we not infrequently meet with oblong, solid masses of a highly refracting nature, which are termed by the authors, the *nuclei*. That such formations are present, not only on the surface of the muscle-fiber, but also on its interior, is best demonstrated in transverse sections, where in the center of the fiber we almost invariably observe a more solid mass with stellate offshoots which subdivide the muscle-fiber into smaller fields. The presence of these large bioplasm-masses within the muscle-fiber has a close connection with the history of the development of the muscle, which I do not wish to consider in this place. Similar formations do, however, occur in the muscles of mammals. I have especially observed globular or oblong bioplasm-masses in the center of the muscle-fiber of the ox. In making transverse sections, these masses are very liable to fall out, or perhaps be drawn out by the razor, leaving an empty space behind. This gives the incorrect impression that the muscle-fiber is hollow in its center.

Every muscle-fiber in mammals is known to be ensheathed in an extremely delicate, firm, so-called elastic or hyaline membrane, the *sarcolemma*. This layer is present around the muscle-fibers of the lobster also.

The statement of E. Brücke, which has gained general assent, that the *sarcous elements* are possessed of a double-refracting power, is, I am convinced, incorrect,—at least my own observations on the muscle of the lobster with polarized light are not in accordance with this view. I made a large number of observations on specimens prepared in different ways and also with perfectly fresh specimens, moistened with a drop of blood of the animal, and could only obtain the phenomena of polarization in those of some thickness. In every case where the specimen was very thin, and allowed the light to pass through it freely, there was no evidence of polarization. W. Kühne (1864) failed to obtain polarization with the amœba, and my observation with the muscle-fibers of the lobster coincides with his.

It is Doyère's and Kühne's discovery that the motor nerves which control the action of the muscles never enter tbe muscle-fibers, but terminate on their surface, generally in the form of hills, the so-called *motor hills*. I have observed similar formations in the muscle of the lobster; and further, I have observed a direct connection of the bioplasm of the motor hill with the adjacent *sarcous elements* by many delicate, grayish filaments of bioplasm. Thus it becomes intelligible that the influence of the motor nerve may be transmitted to a number of *sarcous elements* from which it may spread toward the points of the fiber and produce contraction.

As a result of these investigations, I am led to the conclusion that the striated muscles of the lobster are constructed on the same plan as the striated muscles of the highly-developed mammals. It is a formation of living matter of a reticular structure, the points of intersection being the *sarcous elements*, the means of connection being delicate filaments extending in a longitudinal and transverse direction.