Defects in the Existing Theory of Skeletal Muscle Contraction and Postulation of a New Theory

O. Sasikumari

ABSTRACT

In 1954, two independent research teams, one consisting of Andrew F. Huxley and Rolf Niedergerke from the University of Cambridge, and the other consisting of Hugh Huxley and Jean Hanson from the Massachusetts Institute of Technology proposed the theory of skeletal muscle contraction [1]. They used electron microscopy to study the details of muscle filaments. The structure was studied in detail by them, but the mechanism of skeletal muscle contraction was not defined. Based on various assumptions about the actin and myosin filaments of muscle, later they postulated a theory called “sliding filament theory”. When this theory is scrutinized in detail, I find that there are a lot of defects in this theory, which I have pointed out and I have made an attempt to postulate a different mechanism for the skeletal muscle contraction.

Keywords: Muscle contraction theory; skeletal muscle; Actin; Myosin; sarcomere; cross bridges.

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I. INTRODUCTION AND REVIEW

The skeletal muscles are composed of numerous fibers ranging from 10 to 80 micrometers in diameter. These fibers have smaller myofibrils, and each myofibril is made up of about 1500 myosin filaments (thick filaments) and 3000 actin filaments. These actin and myosin filaments are actually responsible for the process of skeletal muscle contraction [2]. The actin filaments are attached to other sides of an Z disc as shown in (Fig. 1).

Fig. 1. The structure of a myofibril.

The portion of the myofibril between two successive Z discs is called a sarcomere. So, a muscle fibril is made up of hundreds of sarcomeres. The myosin filaments are seen interdigitating between the actin filaments. There are hundreds of cross bridges extending from the myosin filament to the actin filaments. The heads of the cross bridges attach to the actin filament. The cross bridges arising from the myosin filaments run in the opposite direction on either ends, i.e. for example, at the right end of myosin the cross bridges attach to actin in the rightward

direction and at the left end of myosin, the cross bridges attach to actin in the leftward direction.

II. PRESENT THEORY OF MUSCLE CONTRACTION

All the detailed molecular changes occurring in the muscle fibrils during the process of a nerve impulse have not been discussed here. Only the defective portion of the theory has been highlighted. The present theory of muscle contraction is known as the sliding filament mechanism [2]. According to this theory, whenever there is a nerve impulse, by a series of molecular reactions, the heads of the cross bridges extending from the myosin filaments attach to the actin filaments on either side and pull them closer, so that the Z discs also come closer and the length of the sarcomere reduces, thus reducing the size of the muscle on contraction. (Fig. 2).

Fig. 2. Contraction of muscle:

a) Sarcomeres before contraction; b) Sarcomeres after contraction.

A. Defects in the Present Theory

The defect in this theory can be understood if we consider a series of adjacent sarcomeres, named as A, B and C for convenience. Let the Z discs between them be named as Z1, Z2, Z3 and Z4 (Fig. 3).

Fig. 3. Sarcomeres before contraction.

When a nerve impulse is given to this segment, if the cross bridges of all the myosin filaments pull the actin filaments towards the center, there will be a tug of war at the Z discs. If B has to contract, then Z2 and Z3 should be brought closer. Similarly, if A has to contract, Z1 and Z2 should be brought closer and if C has to contract, then Z3 and Z4 has to be pulled closer. In short according to the sliding theory, there will be a tug of war between B and A for Z2, so also between B and C for Z3. If at all, A and C succeed in contracting then there will be corresponding stretching of the sarcomere B (Fig. 4).

Fig. 4. Sarcomeres after contraction.

Then how will the length of the muscle decrease on contraction?

Isn't it like $\frac{1}{3} / \frac{1}{3} / \frac{1}{3}$ on contraction gives $\frac{1}{2} / \frac{5}{2}$, both on addition gives 9°.

The defects in the present theory were pointed out in 1989 when I was a second year medical student, in Government Medical College, Thiruvananthapuram. I communicated this to Mr. Arthur. C. Guyton who was the author of the Physiology textbook and was in the Department of Physiology in the University of Mississippi Medical Center. He agreed to this argument (Appendix A).

In 1993, there was a National conference on Physiology in India Appendix B) where I presented the defects, and I proposed a new theory of skeletal muscle contraction. No further progress occurred.

III. PROPOSAL OF A NEW THEORY OF SKELETAL MUSCLE CONTRACTION BY DR. O. SASIKUMARI

For convenience I have divided my theory into many parts-

Part I – All skeletal muscles contract towards their origin.

Part II – All the cross bridges arising from the myosin filaments are projecting towards the same direction and attaching to the actin filaments. (Unlike the present theory where the cross bridges from the myosin are in the opposite direction).

Part III – The heads of the cross bridges are always away from the origin of the muscle, towards its insertion (Fig. 5).

Fig. 5. Arrangement of cross bridges:
a) Present postulate; b) New postulate.

When a nerve impulse occurs, by similar molecular reactions as stated by the sliding filament hypothesis, the heads of the cross bridges attach to the thin filaments and pull them closer, i.e. the Z discs are brought closer without a tug of war. The entire cross bridges move in the same direction i.e. they pull the muscle fibers from the insertion of a muscle, to the origin of the muscle.

By a series of such reactions, maximum contraction occurs, when the cross bridges pull the thin filaments so much that these cross bridges straighten up ultimately. When the slanting cross bridges straighten up, they will require more space between the upper and lower actin filaments, to accommodate themselves. So, they push the upper and lower actin filaments away from the myosin filaments which will result in the straightening up of the Z discs to some extent. i.e. the vertical length of Z discs increases. This can be the reason why the circumference of the muscle increases on contraction (Fig. 6). This aspect is not explained in Sliding filament theory.

The length of muscle decreases and height of muscle increases.

Fig. 6. The contracted myofibril.

IV. CONCLUSION

The sliding filament theory has certain defects. It does not clearly mention how the Z discs move when a nerve impulse activates two adjacent sarcomeres. It also fails to explain how the length of the muscle decreases and the circumference of a muscle increases on contraction. I have made a humble effort to explain this by postulating a new theory for skeletal muscle contraction. This new theory is open for discussion or criticism. There may be better explanations.

ACKNOWLEDGEMENT

My sincere acknowledgement to Late Dr. Malathy Amma, Professor and head of the Department of Physiology, Government Medical college, Trivandrum, who gave me the opportunity to present this theory in the National conference of Physiologists in India, in 1993.

REFERENCES

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- [2] John E. Hall, Guyton and Hall Textbook of Medical Physiology.

Dr. O. Sasikumari was born in Kerala, in India on 25th of November 1971. She did her schooling in different Kendriya Vidhyalayas of India, after which she joined for M.B.B.S in Government Medical College, Thiruvananthapuram, in 1988. During 1989 when she was a second year student, she had serious doubts on the "Sliding filament hypothesis" of skeletal muscle contraction. She conveyed it to Mr. Arthur. C. Guyton who was the author of the Physiology textbook and was in the University of Mississippi Medical Center. He agreed to this argument. In 1993 there was a national conference of Physiologists in India. She presented the defects of the existing theory and postulated a new theory. Further propagation was not done due to lack of professional support.

In 1999 she entered the Health service of Kerala, as Assistant surgeon. During her tenure, she had received an award from the government of Kerala for her meritorious role in the flood relief activities. She took a diploma in Public Health in 2001, from Chennai, Tamil Nadu. Later her career deviated to the administrative sector of the Health Service. She was the Joint Director of KSACS (Kerala State AIDS Control Society). She

served the Health service for 10 years. Her interest in Medical Education and research made her resign the job and she joined as the junior most faculty in the Medical Education department of Kerala with a grossly diminished salary. In 2009, she joined as Lecturer in Microbiology. She did her Post graduation (M.D.) in Microbiology from Government Medical College, Kottayam in 2013. Now she is the Associate Professor of Microbiology in Government Medical college, Kollam. Her field of interest is Clinical Microbiology and she is doing PhD under KUHS (Kerala University of Health Science) When she found that the theory of muscle contraction is taught to the M.B.B.S students even now, with all its defects, she decided to put forth her findings once again, for open discussion. She has eight international publications to her credit. She is a research guide to the postgraduates in Microbiology and also students of Medical Laboratory technology. She has done research under the State Board of Medical Research (SBMR) of the government of Kerala. She is also a trained mentor of the Medical council of India for the implementation of CBME (competency based Medical education).

Dr. O. Sasikumari is also an active member of ACM (Academy of Clinical Microbiologists of India).

APPENDIX

APPENDIX I

THE UNIVERSITY OF MISSISSIPPI MEDICAL CENTER
2500 North State Street
JACKSON, MISSISSIPPI 39216-4505

School of Medicine
Department of Physiology and Biophysics

Area Code 601
984-1820

November 27, 1989

Mr. O. Sasikumari
Sree Parthasarathi Mandhiram,
Monvila, Kulathoor P O,
Trivandrum 695583
Kerala, INDIA

Dear Mr. Sasikumari:

You are very correct to raise the issue that you have regarding muscle contraction. This is a problem that still has not been solved by the research workers.

However, if both ends of the muscle can be shortened, contraction of all sarcomeres will occur. However, if the two ends of this muscle are fixed so that they must contract isometrically, then if one sarcomere contracts another must elongate.

You might look in my textbook at the curve which shows the strength of contraction of the sarcomeres when they contract beginning at different lengths. As long as the length of the muscle is shorter than 2.05 microns, the sarcomeres will all contract equally. The reason for this is that if one of the sarcomeres contracts more than the other, it begins to lose strength. Furthermore, if the other sarcomeres have been stretched by the first one contracting, then they gain strength. *This is the normal situation.*

Yet, if the length of the sarcomeres is greater than 2.2 microns, exactly the opposite effect occurs, and this is the effect that you have drawn in your diagrams in your letter. That is, at these longer lengths when a sarcomere begins to contract it becomes stronger. In addition, the stretched sarcomeres become weaker. Therefore, the stronger sarcomere will continue to contract until the weaker ones pull out to a longer length.

What I have written above is theoretically what would happen. When research workers perform the actual experiments, they do not find, except in a few instances, one sarcomere contracting more than the others. Therefore, there is something wrong with the theory. Actually, I posed this same problem to Professor Huxley, one of the persons who first proposed the sliding filament model, and I found that he had only a partial answer to the problem.

I hope that this helps to answer your query, and I am sorry that there is not a complete answer at present.

Yours very sincerely,

Arthur C. Guyton

Arthur C. Guyton, M.D.

ACG:ih

APPENDIX II

THE ASSOCIATION OF PHYSIOLOGISTS
&
PHARMACOLOGISTS OF INDIA

39th ANNUAL NATIONAL CONFERENCE
DECEMBER 27-29, 1993
Medical College, Thiruvananthapuram

CERTIFICATE

*This is to Certify that Dr. (Miss) O. Sasi Kumari,
M.B.B.S Student, Medical College, Trivandrum
attended the 39th Annual National Conference of the Association of
Physiologists and Pharmacologists of India, held at Medical College,
Thiruvananthapuram from 27-29 December, 1993 and actively participated
in the scientific deliberations of this conference.*

*She has also presented a paper in the Guest lecture/Symposium/
Free Communication session ~~and chaired a scientific session.~~*

It has been a pleasure to have ~~him~~/her with us.

P. Premakumari

Dr. P. Premakumari Devi
Chairperson, Scientific Committee

R. Malathi Amma

Dr. R. Malathi Amma
Organising Secretary