

HYPOTHESIS

NEW HYPOTHESIS FOR MECHANISM OF SLIDING FILAMENT THEORY OF SKELETAL MUSCLE CONTRACTION

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Key Words

Sliding Filament Theory; Muscle Contraction; Actin; Myosin; Z Disc

Background: Current understanding of skeletal muscle contraction is based on the sliding filament theory proposed independently by A.F. Huxley and H.E. Huxley (1954). The sliding filament theory very well explained shortening of skeletal muscle during contraction with reference to a single sarcomere with movement of Z discs toward center of that particular sarcomere. However, when we consider shortening of multiple sarcomeres in a myofibril arranged in series, the sliding filament theory fails to justify the movement of Z discs as each Z disc is being pulled in opposite direction by myosin heads of adjacent sarcomeres.

Aims & Objectives: To find out alternate possible mechanism of Z disc movement on either side of A band if movement toward center by both sides is not possible.

Materials and Methods: We have prepared a simulating model of sliding filament theory and observed mechanism of contraction on it.

Results: The sliding filament theory fails to explain the movement of Z discs when all sarcomeres in a myofibril are contracting simultaneously. Therefore, we proposed a new hypothesis that Z discs and actin filaments in the half part of each sarcomere, which is toward origin end of muscle fiber, are not pulled toward center of myosin filament instead myosin filament slide toward origin end, and in the other half of each sarcomere (which is toward insertion end) actin filaments slide over myosin filament toward origin end of the muscle.

Conclusion: This study adds a new insight into the sliding filament theory of muscle contraction and needs further confirmation on electron microscopic studies.

INTRODUCTION

Current understanding about skeletal muscle contraction is based on the sliding filament theory proposed independently by A.F. Huxley and R. Niedergerke^[1] and H.E. Huxley and J. Hanson^[2] in 1954. Since then many scientists are working on unresolved aspects of this theory.^[3] In 1973, Sir Andrew Huxley, himself addressed some unexplained issues of this theory.^[4] The sliding filament theory was based on the observation that there are two separate sets of filament actin and myosin located differently with myosin filaments in A band, and on electron microscopy there are two interdigitating sets of filament and length of A band does not change during contraction.^[1,2]

According to the sliding filament theory, during

contraction the sets of thin filaments in each half of sarcomere are drawn toward the center of A band and subjected to sliding forces oriented in opposite directions.^[5-7] The sliding filament theory very well explained the shortening of skeletal muscle during contraction with reference to a single sarcomere with movement of Z discs toward center of that particular sarcomere. However, when we consider shortening of multiple sarcomeres in a myofibril arranged in series, sliding filament theory fails to justify the movement of Z discs as each Z disc is being pulled in opposite direction by myosin heads of adjacent sarcomeres. Thus, this study was undertaken to see whether movement of Z discs on either side of A band toward center of sarcomere is possible during contraction or any new insight can be proposed in the sliding filament theory.

The aim of this study is to review and analyze sliding filament theory in context of the movement of Z discs on either sides of A band during contraction of all sarcomeres in single muscle fiber.

Objectives: (1) To see whether movement of Z discs on either side of A band toward the center of a sarcomere is possible when contraction is occurring in two adjacent sarcomeres simultaneously. (2) To find out another possible mechanism of movement of Z discs on either side of A band if movement toward center by both sides is not possible.

MATERIALS AND METHODS

This study was carried out at Department of Physiology, Dr. Shankarrao Chavan Government Medical College, Nanded, Maharashtra, India. To review and analyze the sliding filament theory, we have prepared a simulating model, which is explained with the help of figures in the later sections.

In this model, we have prepared three consecutive sarcomeres arranged in series to show movement of Z discs during contraction in all sarcomeres simultaneously. In our model, actin filaments can be manually slid over myosin filaments as is given in the sliding filament theory of muscle contraction and Z disc also move along with movement of actin filaments.

Initially, we have slid actin filaments on either side of A band in a single sarcomere toward its center. Then we have tried to slide actin filaments of two adjacent sarcomeres toward centers of respective sarcomeres as described in the sliding filament theory.

RESULTS

In the above-mentioned simulating model, when we slid actin filaments present on both sides of a myosin filament toward center of A band in a single sarcomere as it occurs during contraction, two Z discs on either side of A band moved toward center of the sarcomere, as shown in Figure 1.

But when we tried to slide actin filaments in two adjacent sarcomeres toward centers of respective sarcomeres as it is described in the sliding filament theory, the Z disc that was common to both sarcomeres was not able to move toward the center of either sarcomere (Figure 2).

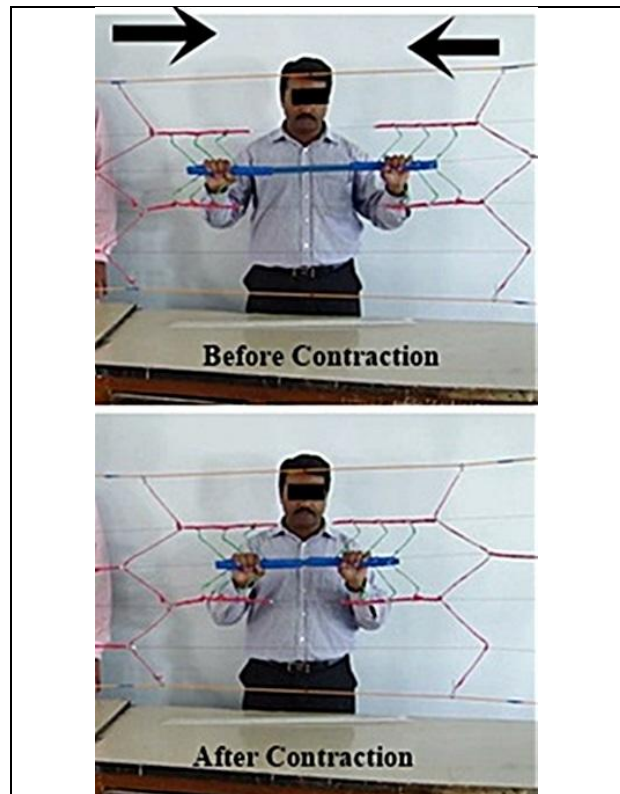


Figure 1: Positions of Z discs in a single sarcomere before and after contraction

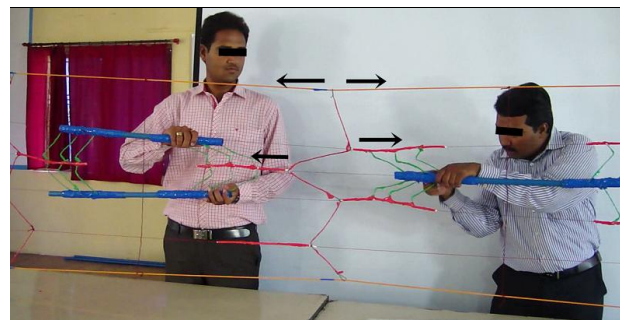


Figure 2: No movement of Z disc when actin filaments of adjacent sarcomeres were tried to slide toward the centers of respective sarcomeres

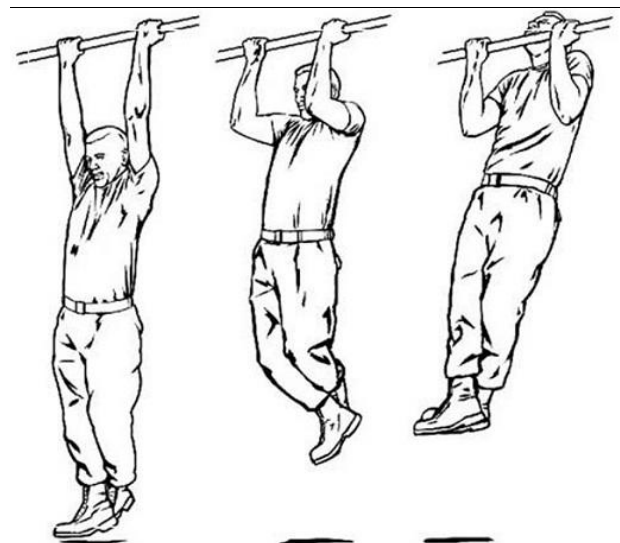


Figure 3: A sportsperson pulling single bar downward but instead his body going upward

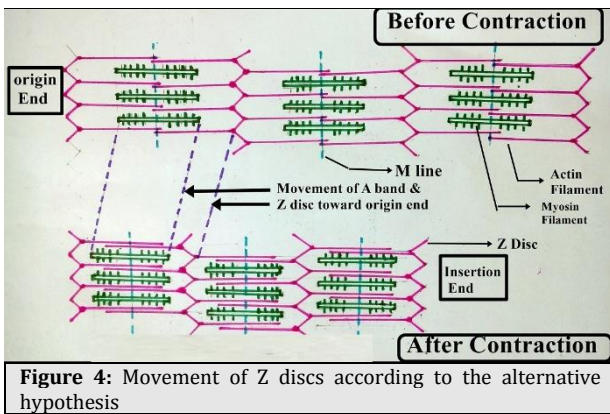


Figure 4: Movement of Z discs according to the alternative hypothesis

DISCUSSION

When we slid actin filaments present on both sides of a myosin filament toward the center of A band in a single sarcomere as it occurs during contraction, two Z discs on either side of A band moved toward the center of the sarcomere. This observation was completely in accordance with the sliding filament theory of muscle contraction under consideration.

But when we tried sliding actin filaments in two adjacent sarcomeres as if contraction is occurring in both the sarcomeres simultaneously, the Z disc that was common to both the sarcomeres was unable to move toward the center of either sarcomere, resulting in no change in length of sarcomeres. This finding was not in accordance with the sliding filament theory of muscle contraction. Considering that the Z disc common to adjacent sarcomeres under contraction was not moving toward the center of either sarcomere, we found the following reasons: (1) Each Z disc is attached to actin filaments on both sides. (2) During contraction, actin filaments on either side of Z disc will move toward the center of the sarcomere in which they are present. (3) Eventually both sets of actin filaments on either side of Z disc will try to pull the disc in opposite direction. (4) It is analogous to tug of war having same power on both sides. (5) It is not mentioned anywhere that actin filaments in different sarcomeres are having different strength. (6) As the Z disc is being pulled in two opposite directions by actin filaments of either sides, it will not move.

Therefore, we tried to find out another possible mechanism in context of the sliding filament theory of muscle contraction. We proposed a new theory that Z discs and actin filaments in the half part of each sarcomere, which is toward origin end of muscle fiber, are not pulled toward the center of myosin filament because if they are pulled, the ultimate pull will be applied on the origin end of the muscle that is not

movable. Instead myosin filament slide toward origin end. In the other half of each sarcomere (which is toward insertion end), actin filaments slide over myosin filament toward origin end of the muscle. This assumption can be supported by Figure 4.2 of *Best & Taylor's Physiological Basis of Clinical Practice*, 13th edition. This study adds a new insight into the sliding filament theory of muscle contraction and needs further confirmation on electron microscopic studies.

To support the above hypothesis, we can consider analogy of a sportsperson doing pull-ups on a single bar, as shown in Figure 3. Here single bar is analogous to the first Z disc toward origin end that is not movable, and hands of the sportsperson are analogous to myosin heads. The rest of the body of the sportsperson is analogous to the body of myosin filament. When myosin heads try to pull actin filaments, which are attached to the first Z disc of origin end side, power generated by myosin heads may be insufficient to pull that Z disc along with actin filaments. Thus, myosin filaments move toward origin end instead of actin filaments along with Z disc moving toward insertion end, this is analogous to body of sportsperson going upward when he tries to pull the single bar downward, as shown in Figure 3. When we consider simultaneous contraction in all sarcomeres, all myosin filaments move toward the origin end, and all the Z discs of insertion end side move toward the center of myosin filaments, which are toward origin end side. Ultimately, Z discs on both sides of A band seem to be moved toward the center of A band but actually myosin filament slide toward origin end, and in the other half of each sarcomere (which is toward insertion end) actin filaments slide over myosin filament toward origin end of the muscle. This is shown in Figure 4.

CONCLUSION

The sliding filament theory of skeletal muscle contraction can explain the shortening of a single sarcomere, but when we consider multiple sarcomeres in a myofibril arranged in series, it fails to justify the movement of Z discs as each Z disc is being pulled in the opposite direction by myosin heads of adjacent sarcomeres. Therefore, we proposed a new theory that Z discs and actin filaments in the half part of each sarcomere, which is toward origin end of muscle fiber, are not pulled toward the center of myosin filament, instead myosin filament slide toward origin end. And in the other half of each sarcomere (which is toward insertion end), actin filaments slide

over myosin filament toward origin end of the muscle. This study adds a new insight into the sliding filament theory of muscle contraction and needs further confirmation on the electron microscopic studies.

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