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On the Impossibility of Optimal Hypertrophy of Biarticular Muscles: A Theoretical Support for Lengthened Partials

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Abstract: ***Biarticular muscles possess a multifaceted significance in the context of exercise selection. This is due to their ability to perform functions across two joints. This paper aims to investigate the underlying factors that render the achievement of optimal hypertrophy in biarticular muscles unattainable. It is posited that the conditions of peak contraction and stretch, while under active tension, are imperative prerequisites for achieving optimal hypertrophy. In this paper, we shall focus on three biarticular muscles: triceps brachii (long head), rectus femoris, and hamstrings group. We shall also analyze why the common compound movements fail to provide adequate hypertrophic stimulus to the target biarticular muscle. The reductio argument explored in this paper provides a theoretical basis for the superiority of lengthened partials in providing hypertrophy.***

Keywords: Biarticular muscles, Muscular hypertrophy, Maximization of Hypertrophy, Resistance Training, Com pound Movements

1. Introduction

Biarticular muscles

Biarticular muscles are skeletal muscles that cross two joints in a series unlike mono-articular muscles that only function over a single joint.

The functions of a biarticular muscle largely depend on its proximal and distal attachment.

In this discourse, we shall look at three biarticular muscles commonly incorporated in generic resistance training (RT).

Triceps brachii (long head)

The long head of the triceps brachii (TB) has a proximal attachment at the infra glenoid tubercle of the scapula. It inserts at the posterior surface of the olecranon process of the ulna.

It functions to extend the elbow (strong), but because it also crosses the glenohumeral joint, it functions in extension and adduction of the arm (weak).[8]

Rectus femoris (RF)

It originates from anterior inferior iliac spine (AIIS). It inserts along with other muscles of the quadricep group at the patella via the quadriceps tendon.

It functions to extend the knee (strong), but because it also crosses the hip, it functions in hip flexion along with the iliopsoas (weak).[5]

Hamstrings group (HS)

All three muscles of the hamstrings group are biarticular muscles. The semitendinosus, semimembranosus and biceps femoris, all originate at the ischial tuberosity, and insert at the medial tibial condyle, except the bicep femoris that inserts at the lateral tibial condyle.

All three functions in knee flexion and hip extension. Nevertheless, the lever arms associated with the proximal and distal attachment, unlike other biarticular muscles, do not exhibit any biases. They are equally strong in hip extension as they are in knee flexion.[9]

Biceps brachii and Gastrocnemius

Two biarticular muscles that are prominent in RT, which have not been considered in the current discussion, are the biceps brachii (BB) and the gastrocnemius. The rationale behind the exclusion of the gastrocnemius is that its moment arm, responsible for knee flexion, is considerably smaller than its remarkably substantial change in length through plantar flexion. The gastrocnemius for all relevant ideas can be considered only nominally biarticular.[4] The exclusion of the BB is based on two reasons:

1) Multiple weak functions at the glenohumeral joint (extension, abduction, horizontal adduction)
2) Within the context of the ideas presented in this discourse, the hypertrophy of the biceps brachii is already optimized.

Conditions for optimal hypertrophy

In the current discussion, we will focus on the variables associated with the muscle's length.

To ensure an optimal stimulus, it is essential that an exercise induces a contraction of the specific muscle being targeted. It is important to note that this contraction should not involve an isometric contraction, but rather a change in the length of the muscle in question. This is because dynamic movements incorporate both active and passive tension.[3]

Brad Schoenfeld[2] has demonstrated that for maximization of hypertrophic stimulus, a combination of mechanical tension, metabolic stress and muscle damage is a necessity. However, it is imperative to ac- knowledge that the mechanical tension must be evenly distributed between the shortest and longest length of muscle across various positions to ensure optimization of muscular hypertrophy. This is done so that all unique muscle fibers are taken into consideration.

Additionally, there exists some evidence that the lengthened position component offers a superior stimulus through muscle damage, and the shortened position component provides a better pump (increased blood flow), mind-muscle connection, and ischemic and metabolic stress.

A corollary to mechanical tension at the shortest and longest length of the muscle is peak contraction and peak stretch. However, these extreme lengths of the muscle should be reached through dynamic movement and not isometrically as discussed above. Additionally, tension implies a resistance to the tension by the target muscle. In other words, the target muscle should be actively functioning to reach peak contraction and working in the eccentric portion of the exercise while reaching peak stretch.

Thus, we have two conditions for optimal hypertrophy:
1) Peak contraction of the target muscle under active tension.
2) Peak stretch of the target muscle under active tension.

Aim

Aim: To explore the impossibility of optimal hypertrophy of biarticular muscles assuming conditions of peak contraction and peak stretch as necessary.

In this paper, we shall analyze the problems in achieving the maximum hypertrophic stimulus for biarticular muscles, especially the long head of TB, RF, and the HS. With the assumption that optimal hypertrophy is necessarily dependent on peak contraction and stretch of the target muscle under active mechanical tension. We shall also examine the failure of common compound movements in providing hypertrophic stimulus and the impossibility of simultaneous peak contraction and stretch of biarticular muscles. Lastly, we shall also examine the inability of biarticular muscles to obtain hypertrophic stimulus from the peak contraction component and the possible solutions to these problems.

2. Background

Peak Contraction and Stretch

Let us begin by examining the exact position of peak contraction and stretch for the biarticular muscles in consideration.

Triceps brachii (long head)

The function of the muscle at the elbow joint is elbow extension and at the glenohumeral joint is weak shoulder extension and weaker adduction. The long head contracts to produce these functions. Hence, the peak contraction of the long head will occur when the elbow is terminally extended and the shoulder is terminally extended and adducted.

The peak stretch will occur at the exact opposite position. Hence, the peak stretch occurs when the elbow is terminally flexed and the shoulder is terminally flexed as well.[8]

Rectus femoris

The function of RF at the knee joint is knee extension (strong) and at the hip is hip flexion (weak). It contracts to produce these functions. Hence, the peak contraction of RF will occur when the knee is terminally extended and the hip is terminally flexed.

The peak stretch will occur at the exact opposite position. Hence, the peak stretch will occur when the knee is terminally flexed and the hip is terminally extended.[5]

Hamstring group

All three biarticular muscles of the hamstring group i.e. semimembranosus, semitendinosus and the long head of the biceps femoris, contract to function in knee flexion and hip extension. The peak contraction occurs at terminal knee flexion and terminal hip extension.

The peak stretch component will occur at the exact opposite position. Hence, peak stretch will occur at terminal knee extension and terminal hip flexion.[9]

Failure of compound movements

Before we proceed to substantiate the impossibility of optimal hypertrophy of biarticular muscles, we must first discuss the need to do so.

One of the major reasons why the discussion about the hypertrophy of biarticular muscles is required is because, the major and common compound movements fail to elicit adequate hypertrophic stimulus for them.

In accordance with the consideration of these three muscles, we shall proceed to examine the two prevalent compound movements that generate stimulus for their agonist muscles.

Triceps brachii (long head) and Bench press

In the concentric phase of the bench press, there are three primary movements that transpire, namely horizontal shoulder adduction, shoulder flexion, and elbow extension. Similar conclusions can be drawn from exercises that possess comparable movement patterns. For instance, the overhead press, dip, and push-ups will all yield similar outcomes.

Due to the presence of the elbow extension element, TB will exhibit a high level of activity throughout the motion. The long head of TB will contract during the concentric phase of the motion to generate elbow extension. However, because of the shoulder extension component inherent in the bench press, the long head of TB will expand during the concentric phase of the bench press.

The simultaneous contraction and expansion of the long head during the concentric phase of the bench press suggests that the length of the muscle barely changes. As discussed earlier, the change in the length of the muscle is a necessary condition for an adequate hypertrophic stimulus. Hence, the bench press does not provide adequate hypertrophic stimulus for the long head of the triceps brachii.

This conclusion is evidenced by a study done by Brandao et al.[7] As per findings, the long head of TB saw significantly low increase in cross-sectional area when only the bench press was employed (2.1$\pm$ 29%) as compared to isolation movements (17.5 $\pm$ 7.3%). On the other hand, the lateral head of TB saw more CSA increment in programs with the bench press as opposed to Isolation movements. Essentially, of the three heads of TB, only the long head lacked significant increase in CSA through bench press.

Rectus femoris, Hamstrings and Squat
The two main component movements of the squat during the concentric phase are knee extension and hip extension. Exercises with similar movement pattern are hip thrust, leg press, as such the conclusions of the squat shall follow for these exercises.

Because of the knee extension component, the quadriceps group will be highly active during the movement. RF will contract to produce knee extension during the concentric phase. HS will expand because of the knee extension component. But because there also exists a hip extension component, RF will expand during the concentric phase and HS will contract.

The simultaneous contraction and expansion of RF and HS during the concentric phase of the squat, suggests that the length of either muscle barely changes. As discussed earlier, the change in the length of the muscle is a necessary condition for adequate hypertrophic stimulus. Hence, the squat does not provide adequate hypertrophic stimulus for RF or HS.

This conclusion is evidenced by a systematic review by Ribeiro et al. [14] The finding of difference between MRI-assessed MIV increased for vastii (8-11%), for RF (4%) and HS (0%) suggests that the squat does not provide adequate hypertrophic stimulus to either RF or HS.

Simultaneity of Peak contraction and stretch
We have previously examined the two essential prerequisites for achieving optimal hypertrophy, which are attaining peak contraction and peak stretch while maintaining active tension. To implement this in practical resistance training (RT), it is imperative to determine whether these two prerequisites must be met simultaneously or if meeting each of these prerequisites individually yields comparable outcomes.

In the subsequent section, we will examine the attainability of achieving optimal hypertrophy for both alternatives. Within this sub-section, we will deliberate upon the rationale behind the notion that the occurrence of peak contraction and peak stretch concurrently should yield a superior and therefore, optimal stimulus.

The primary evidence supporting this assertion resides in the fact that a complete range of motion consistently outperforms a limited range of motion. For example, if one were to choose two distinct exercises that offer peak contraction and peak stretch individually, it becomes evident that the range of motion would inherently be restricted. Conversely, if one were to select an exercise that simultaneously facilitates peak contraction and peak stretch, only then can a biarticular muscle effectively engage in its full range of motion. A systematic review by M. Wolf et al. [12] on range of motion seems to indicate that full range of motion provides better results for hypertrophy. The study also posits that additional evidence is required since the studies that involve partial range of motion analyze the identical exercises but with variations in their ROM. A more precise depiction will only be illustrated if alternate exercises were selected.

For instance, if the range of motion of a standard barbell bicep curl was differentiated and reduced to two halves, then it would lead to inferior results as opposed to using full ROM. However, we cannot say with certainty that these results would be replicated if two different exercises that specialize in emphasizing the shortened and lengthened position of the biceps were selected. For example, preacher curl combined with bayesian curl could potentially outperform the barbell biceps curl in providing hypertrophic stimuli.

Thesis
The two different models of incorporating peak contraction and peak stretch can be differentiated by whether these conditions occur simultaneously in a single movement or not. Essentially, the bio-mechanical implication here is whether one joint is fixed or not. In case of simultaneous peak contraction and stretch, both joints over which the target muscle exerts function are not fixed. Meaning, the length of the muscle changes over both joints. In case of non-simultaneity of peak contraction and stretch, the joint associated with the weaker function is fixed.

We shall now explore, why optimal hypertrophy is impossible in either of these cases for the target biarticular muscle.

Simultaneous peak contraction and stretch
The primary reason for the impossibility of achieving optimal hypertrophy through simultaneous peak con-traction and peak stretch is simply mechanical deficiency.

The extreme positions associated with peak contraction and peak stretch, cannot be approached by any exercise such that the load is distributed throughout the movement.

No exercise can effectively provide mechanical tension throughout such a varied double-jointed movement. Exercises fail to do so in three different ways.

Either peak contraction or peak stretch does not occur
This happens when one of the joints is fixed throughout the movement. As such this problem occurs in isolation movements.

For the long head of TB, consider movement patterns like the overhead triceps cable extension or skull crusher. In this instance, the shoulder is fixed in a flexed position. Although peak stretch occurs, peak con- traction does not. Its converse is true for movement patterns like triceps kickback, wherein peak contraction occurs but peak stretch does not.

For RF, consider movement patterns like reverse nordics. In this instance, the hip angle is fixed in an ex- tended position. Although peak stretch occurs, peak contraction does not. Its converse is true for movement patterns like the seated leg extension, wherein peak contraction occurs but peak stretch does not.

For HS, consider movement patterns like seated hamstrings curl. In this instance, the hip angle is fixed in a flexed position.

Although peak stretch occurs, peak contraction does not. Its converse is true for movement patterns like lying or standing hamstrings curl; wherein peak contraction occurs but peak stretch does not.

Neither peak contraction nor stretch occurs
This happens because contraction of the target muscle relative to different joints occurs in different phases This makes it so that the length of the target muscle barely changes. This problem occurs in compound movements. As discussed in a previous sub-section, the failure of compound movements is apparent in providing optimal or adequate hypertrophic stimulus to the target biarticular muscle.

In the concentric phase of movement patterns like the bench press or dips, the long head of TB contracts at the elbow joint, but elongates at the shoulder.

Similarly, in the concentric phase of movement patterns like the squat or leg press, RF contracts at the knee, but elongates at the hip. On the other hand, HS contracts at the hip and elongates at the knee.

Because the length of the muscle does not change in either of these cases, these movement patterns do not provide adequate or optimal hypertrophic stimulus for their respective target muscles.

Peak contraction or stretch occurs without active tension
In this case, the target muscle is not actively functioning to achieve the contracted and stretched positions and relies on it being a by-product of the movement itself.

To provide active tension during both peak contraction and peak stretch, the direction of the tension must be altered by a larger angle than mechanically possible.

Consider a subject standing upright with a fully flexed shoulder facing right, intending to provide tension in both an extended and flexed position of the glenohumeral joint. In this position, the active tension must be directed towards the left for the arm. If now, the subject proceeds to extend the shoulder and approach peak contraction of the long head of the triceps, the direction of the tension must be shifted to the diametrically opposite right.

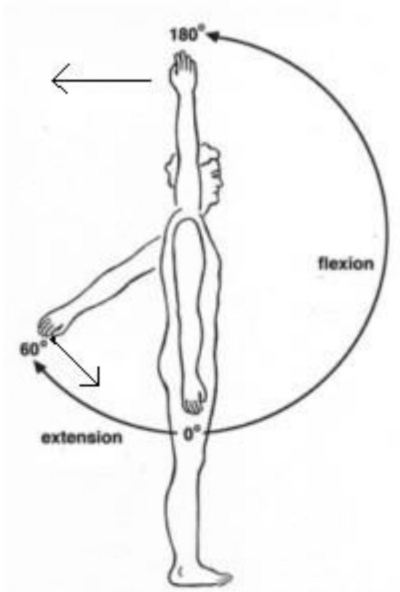

Figure 1: 10The arrows represent the direction of required tension

Similar result is true for both RF and HS.

The 180-degree or more, shift of direction of tension cannot be provided by any exercise or movement pattern currently employed in standard or generic RT programs. Hence, simultaneous peak contraction and peak stretch as employed currently, cannot provide optimal hypertrophic stimulus.

Non-simultaneous peak contraction and stretch
In this case, the joint at which weak function is exerted over, is fixed. The combination of exercises is such that the fixed-joint is done so, in both the shortened and lengthened position. When the joint is fixed such that the target muscle is at its shortened position, an isotonic contraction of the target muscle over the other joint provides peak contraction. When the joint is fixed such that the target muscle is at its lengthened position, the eccentric phase of the movement provides peak stretch.

Triceps brachii (long head)
For the long head of TB, the joint that needs to be fixed is the glenohumeral joint, specifically in flexed and extended positions. A viable combination of exercises is the overhead cable extension and triceps kickback. In the prior, the glenohumeral joint is fixed and the shoulder is fully flexed. At the end of the eccentric phase, the elbow is fully flexed and hence, the long head of TB is at peak stretch. In the latter, the glenohumeral joint is fixed and the shoulder is fully extended. At the end of the concentric phase, the elbow is fully extended and hence, the long head TB is at peak contraction.

Rectus femoris
For RF, the joint that needs to be fixed is the hip joint, specifically in a flexed and extended positions. A viable combination of exercises is the seated leg extension and reverse nordics. In the prior, the hip joint is fixed and the hip is fully flexed. At the end of the concentric phase, the knee is fully extended and hence, RF is at peak contraction. In the latter, the hip joint is fixed and the hip is fully extended. At the end of the eccentric phase, the knee is fully flexed and

hence, RF is at peak stretch.

Hamstrings group

For HS, either of the knee or hip joint can be fixed because the lever arms show no bias. A viable combination by fixing the hip joint, is the lying and seated hamstrings curls. In the prior, the hip joint is fixed and the hip is fully extended. At the end of the concentric phase, the knee is fully flexed and hence, HS is at peak contraction. In the latter, the hip joint is fixed and hip is fully flexed. At the end of the eccentric phase, the knee is fully extended and hence, HS is at peak stretch.

Active insufficiency

At first glance, it seems that incorporating these combinations in an RT program provides a possibility for optimal hypertrophy of the target biarticular muscles. This can be inferred because both the necessary conditions, discussed previously, are met. These exercises do seem to provide peak contraction and peak stretch under active tension. However, this conclusion proves to be fallacious. Although the peak stretch component does occur under active tension, the peak contraction component does not. The concept to consider here is active insufficiency.[1] When a biarticular muscle shortens over both joints simultaneously, it creates muscle slack such that mechanical tension is almost completely lost.

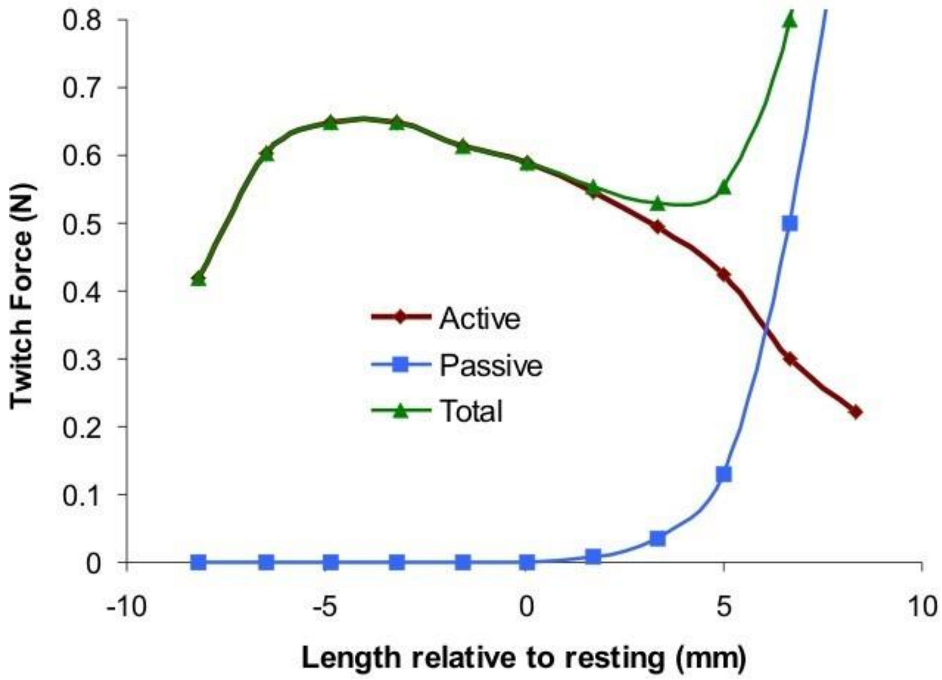

Figure 2: Twitch force against the relative length

Essentially, when a biarticular muscle is shortened over a joint, it cannot shorten over the other joint with active mechanical tension. In our examples, we have selected a component exercise wherein the joint at which weaker function is exerted over is fixed, such that the target biarticular muscle is in a shortened position. Further, the concentric phase of the exercise requires the target muscle to shorten over the other joint. It is apparent by assuming active insufficiency that the mechanical tension across the muscle will be lost and hence, the peak contraction, if it occurs, will not occur with active tension.

Hence, the second necessary condition for optimal hypertrophy cannot be fulfilled. Therefore, non- simultaneity of peak contraction and stretch obtained from a combination of two exercises cannot provide optimal hypertrophic stimulus.

Possible solutions

The main problem of the model of simultaneous peak contraction and stretch, is a mechanical one. The premise is simply that there does not exist an exercise equipment such that it enables the required movement pattern to be performed under constant tension.

Hence, this problem can largely be resolved from a Bio-mechanical engineering front and not through any framework of exercise science. Due to this reason, I shall reserve this topic for future considerations and shall proceed with a possible solution for the other model.

Problem of active and passive insufficiency

The main problem of the model of non-simultaneous peak contraction and stretch, can be considered under the scope of exercise science. The problem can be stated as follows:

When the joint of the weak function is fixed in a shortened position, further shortening of the target muscle over the other joint lacks active tension component.

The underlying core problem being active insufficiency. The insufficiency of active tension can be characterized as either a complete lack of movement or lack of tension in the target muscle despite movement possibility.

When a biarticular muscle is shortened over a joint, either it cannot be shortened further (further contraction is impossible) or it can shorten further but cannot maintain active tension (contraction occurs without tension). In the latter, other auxiliary muscles take over the brunt of the load.

The identification of which of these cases occurs is based on whether the antagonist muscle group reaches passive insufficiency or not. When a biarticular muscle lengthens over both joints, it prevents the full ROM of each of the joints, essentially it reaches passive insufficiency. [10]

When the target muscle reaches active insufficiency and its antagonist muscle reaches passive insufficiency simultaneously, further movement will be restricted, because the ROM of joints has been reduced.

When the target muscle reaches active insufficiency but the antagonist muscle does not reach passive insufficiency, further movement will occur, but the target muscle will lose tension and the auxiliary muscles will take over.

Solution for the first case

For the first case i.e., passive insufficiency occurs in the antagonist, the main problem is the length of the antagonist muscle. The solution is to increase the muscle length. A large amount of research already exists in increasing longitudinal growth of muscles that should be consulted for the solution.[13] When the muscle length is sufficiently increased, passive insufficiency will no longer be an obstacle, as such, one would end up with the second case.

Solution for the second case

Let us now discuss the second case. When the biarticular muscle is shortened over both joints, it will always reach active insufficiency. Avoiding it, therefore, cannot be a solution if peak contraction is necessary. The problem lies in whether the strong function of the targeted muscle is carried out under active tension or not When the joint of weaker function is fixed, the target muscle is already shortened and it will reach active insufficiency quicker than if it was not shortened. To avoid this, the joint should not be fixed, instead, the exercise that incorporates peak contraction should begin from the position where one joint is in a neutral and the other is in stretched position. The former being the weak function joint and latter being the strong function joint.

The concentric phase of this exercise must first prioritize the shortening of the target muscle over the strong function joint. And as it approaches the full ROM of this joint, the exercise must then shift its focus to shortening of the target muscle over the weak function joint. This makes it so that, the tension is actively present when the strong function is carried out and insufficiency is reached only during the weak function phase.

Anti-thesis

In this section, we will move away from the territory of established facts and focus more on future research in a conjectural space.

We have established that optimal hypertrophy in impossible for biarticular muscles. However, that conclusion holds true only by the definition assumed in this discourse. Optimal, by definition, relates to the maximal possibility. To correct this contradiction, we must assume that the definition for optimal hypertrophy is wrong. Consequently, one of the two necessary conditions for optimal hypertrophy must not be necessary.

The current landscape of empirical research indicates a changing paradigm of focusing on lengthened partials. Consult the following studies for the evidence.[15-22]

From these studies we can infer that hypertrophy is either equal or greater when exercises are performed at lengthened partials instead of full ROM or shortened partials. This corresponds to the condition of peak stretch with mechanical tension.

Hence, we can conclude that the condition of mechanical tension at peak contraction must not be a necessary condition for optimal hypertrophy.

In view of the primary conclusion drawn from this discourse, we can establish a theoretical reason for the superiority of stretch over contraction in producing hypertrophy. It is clear from both theoretical and empirical research that the optimal hypertrophy of biarticular muscles depends on the condition of active mechanical tension at peak stretch. It can be conjectured that this also holds true for single-jointed muscles as well.

Practical recommendation

The most logical practical change is to select exercises that provide peak stretch with active mechanical tension. For the three biarticular muscles in question, exercise selection should be as follows: Reverse Nordics for Rectus femoris; seated hamstrings curls for Hamstrings group; Triceps overhead extension for Triceps brachii (long head).

However, if one is not convinced by the sufficiency of peak stretch for optimal hypertrophy, one can proceed with the solutions provided earlier.

In practice, this warrants a few changes in either exercise selection or exercise performance. In our example above, we considered the combination of overhead cable extension and triceps kickback. A better combination is obtained by replacing the latter with triceps cable pulldown. The difference here is the starting position of the glenohumeral joint. In the triceps kickback, the shoulder is fixed and the long head of the triceps brachii is shortened. Hence, it will reach active insufficiency whilst performing its strong function. On the other hand, in the triceps cable pulldown, the glenohumeral joint is in a relatively neutral position, and before the long head shortens over this joint, it shortens at the elbow. Hence, active insufficiency is reached whilst performing its weak function. A slight change in exercise performance of the cable pulldown is also warranted. A slight lean at the staring position, so that the angle is more neutral and then rocking back after the contraction phase is completed.

For RF, the original combination of seated leg extension and reverse nordics works, as far as exercise selection is concerned. However, a change that can be made is to recline the seat while performing the seated leg extension, which in turn will decrease the hip flexion angle. By using a reclined seat, the hip joint is brought back to a relatively neutral position which in turn makes it so that active insufficiency is reached whilst performing weak function. An even better alternative would be the lying leg extension. After the knee is joint is terminally extended, one can perform hip flexion to further contract RF. For HS, the original combination of seated and lying hamstring curls works well. However, to increase the efficacy of this combination, one must make sure that the lying hamstring curl set-up incorporates a neutral hip position. Otherwise, the exercise can be substituted with standing hamstring curl, in which case, one can freely perform hip hinge. A slight hip hinge will put the hip joint in a neutral position, and active insufficiency will therefore, be reached whilst performing the weak function. Additionally, after the knee is fully contracted, one can perform hip extension to further contract the hamstring group.

3. Conclusion

In this paper, we discussed the problems and possible solutions in achieving maximal hypertrophy of biarticular muscles. By assuming that the necessary conditions for optimal hypertrophy are applicable to biarticular muscles, we can conclude that optimal hypertrophy is unattainable. However, we also discussed the maximization of hypertrophy despite this impossibility. The reason why this topic must be discussed is, the apparent failure of compound movements in achieving the desirable results. The common solution of selecting two exercises that provide either peak contraction or peak stretch by fixing a joint, fails, in the case of biarticular muscles, because of active insufficiency. The theoretical impossibility of optimal hypertrophy guides us towards the contemporary landscape of exercise science. Specifically, about the superiority of lengthened partials over full ROM or shortened partials. This impossibility provides the theoretical basis for the superiority of stretch over contraction in providing hypertrophy. The practical recommendation of this paper is a change in exercise selection. The more aggressive option in exercise selection is to only incorporate active mechanical tension at peak stretch. A conservative option would be selecting at least two exercises, such that one exercise incorporates a fixed joint at the lengthened position and another exercise with a joint fixed at the neutral position. While performing the latter, prioritize achieving full contraction of the target muscle in its strong function and then try to fully contract the muscle in the domain of its weak function.

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