Leucine's Effects on Muscle Growth and Body Composition – Questions / Answers and Practical Applications

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Related Articles

The following faq / summary of leucine research is based on the papers listed below

Wilson, J. (2006) Leucine's General Effects on Muscle Growth and Protein Balance.

Wilson, J. (2006) Leucine's Effects and Interaction with Insulin and Muscle Growth

Wilson, J. (2006) The interaction between Leucine and Exercise on Muscle Growth

Wilson, J. (2006) The role of leucine and Anabolic Resistance

Wilson, J. (2006) The Effects of leucine and fat metabolism

For an in depth and referenced discussion on leucine, refer to those papers. The following paper is meant to summarize key points and practical applications, in a mildly technical manner.

Introduction

The branched chain amino acids, leucine, isoleucine, and valine are three of the essential amino acids which have the perfect capability for acting as signaling molecules to control muscle growth. This is because the liver lacks the enzyme responsible for initiating their breakdown. Therefore, while a large amount of the other amino acids are degraded and taken up by the liver and other tissues of the gut, the BCAAs enter into peripheral circulation, where skeletal muscle tissue is relatively unscathed.

It has been known for some time that consuming a complete meal stimulates protein synthesis. The components of a meal have now been analyzed in depth by the research. This research has revealed that amino acids are responsible for 80 % of the protein synthesis which occurs after feeding. It also reveals that out of all the amino acids only one is able to stimulate protein synthesis by itself→ The BCAA leucine. Leucine also has several other functions including regulating the hormone insulin, controlling protein breakdown rates, stabilizing blood glucose levels, along with a host of other functions. The following paper will be formatted in a questions and answers format in order to address these particular roles.

How does leucine effect protein synthesis?

Protein synthesis refers to the process of constructing new proteins. It is accomplished by first copying instructions from DNA onto an mRNA molecule (transcription). Following the mRNA is taken into the cells interior and attached to complex machinery known as the Ribosome, and its accompanying ribosomal proteins. Once attached a new protein is constructed, and this process is known as translation.

Protein synthesis can change rapidly during exercise, after feeding, and during fasting conditions such as when you sleep at night. The evidence is clear that these rapid changes occur at the beginning stages of translation, known as translation initiation.

Translation is controlled by a family of proteins known as initiation factors. For example they are responsible for binding mRNA to a ribosome (e.g. attaching the instructions for building a protein to the machinery responsible for building the protein). Increased leucine concentration leads to an increase in the formation of these initiation factors. Leucine also activates a protein known as ribosomal protein S6 (S6), which actually stimulates production of more initiation factors and other ribosomal proteins. In other words S6 increases the capacity of a cell to produce proteins.

Leucine does not directly stimulate any of these processes. Instead increased concentrations of leucine activate a molecule known as Mammalian target of rapamycin (mTOR). This cellular machine ends out activating the initiation factors and increasing a cells capacity to increase protein synthesis.

The amazing thing is that mTOR is sensitive to leucine concentration, growth factors released from exercise, energy status in the cell, and insulin concentrations. Therefore for protein synthesis to act optimally it requires an interaction between all of these factors.

In summary increased leucine concentration activates mTOR, which activates protein synthesis, and increases a cells capacity to produce new proteins.

Summary: Leucine → mTOR → Protein Synthesis → Skeletal Muscular Growth

What is Leucine's Role in regulating protein degradation (breakdown)?

Leucine's primary role appears to be increasing protein synthesis. But recall that muscle growth is the difference between protein synthesis and breakdown (degradation). Leucine appears to decrease protein breakdown. For example leucine has lowered markers of muscle damage in both resistance training and endurance conditions. There are a number of theories as to why this occurs.

In a recent paper my colleague Gabriel Wilson and I submitted for publication, we discussed the possibility that because leucine is the precursor to HMB, that its conversion to HMB may explain some of leucines effects on protein breakdown. For those not familiar with HMB, this is a metabolite of leucine which is mainly known as an inhibitor of protein breakdown. It has been demonstrated to decrease muscle loss in both exercise and clinical conditions. The only problem is that only 2-10 % of leucine is converted to HMB. Yet, if you analyze a bodybuilder's diet, which frequently consists of 200 to 300 grams a day of protein, it is conceivable that this is how it is eliciting some of its effects. This would amount to 20 to 30 grams of leucine. If the average of 5 % were converted then this would give a range of 1 to 1.5 grams of HMN, and if the maximum were converted it would give a range of 2-3 grams of HMB daily. If an individual is supplementing with EAAs rich in leucine the numbers can increase.

A second theory is that leucine can directly decrease pathways which initiate the breakdown of tissues. There is a great deal of evidence for this as well.

In summary leucine probably acts through both indirect (HMB) and direct mechanisms.

I should also bring up another point. Muscle tissue is made of 80 % BCAAs, and these are preferentially broken down (in terms of amino acids) during exercise. Thus, by supplying an outside source of BCAAs such as leucine, you can spare your own muscular stores. The same applies to dieting conditions

How do Diets Rich in Leucine Stimulate Net Positive Protein Balance?

As stated protein balance must be positive for muscle growth to occur. Protein Balance is summarized by the following equation:

Protein balance = Protein synthesis – Protein degradation

During the course of a day human beings constantly cycle from positive to negative protein balances, and these correspond to post food consumption and fasting conditions. Post food consumption periods last 2-3 hours after a meal when nutrients and amino acids are rich in the blood stream. If an individual has consumed a leucine rich meal, then they can maximally stimulate protein synthesis during this time frame. Once nutrients lower to fasting levels, individuals enter into a state of net protein breakdown.

For this reason bodybuilders first approach to maintaining a positive protein balance is to consume a leucine rich meal every two to three hours, thereby avoiding catabolic states.

Muscle growth however is a small process when viewed from a day to day basis, and on average most people neither gain nor loose muscle tissue in a single day. This is summed by an excellent quote by by Combaret and colleagues (2005):

> "*Skeletal muscle protein synthesis decreases in the postabsorptive (PA) state and increases in the postprandial (PP) state, while protein breakdown follows the inverse pattern. In adults,* ***net positive protein balance in the PP state and net negative protein balance in the PA state cancel each other.***

They conclude on exactly how this cancellation process occurs:

> *"In humans protein mass increases in daytime and decreases overnight so that muscle protein mass does not change throughout the day and night cycle*. "

In article one I argued that the night time sleep cycle is one of the most critical keys to muscle growth in a bodybuilder's arsenal. There are two steps to fighting turning what amounts to a potentially catabolic period to an amazing period of growth.

The first step is by consuming a slow digesting protein source prior to bed time. However this will only last at best the first half of sleep. The typical bodybuilder is in a state of net protein breakdown for at least 4 hours a night. If you add that up over 365 days this accumulates to approximately 1500 hours or a 60 full days of time! Therefore you can experience 60 days worth of muscle tissue loss a year or replace that with 60 days worth of muscle tissue gain.

I will discuss the pre bed and mid sleep meals briefly.

How much leucine should an individual consume in a given day?

The problem here is that protein requirements are hardly established, especially for athletes. For example if you look at the RDA for leucine, you roughly need 2-4 grams a day of it. But this is based on leucine's function as a building block for proteins. The situation is much more complex then this, because leucine has many other metabolic roles. In fact in non exercising individuals leucines metabolic use has been calculated to be up to 12 grams daily. Yet, it appears that its function as a regulator of protein synthesis, and breakdown are proportional to its levels in the diet.

It's important to understand that leucine is about 10 % of high quality proteins. Thus if we only analyze leucine's role in protein synthesis, we see that the standard gram per pound of bodyweight of protein for a bodybuilder amounts to at least 20 grams of leucine per day. We have also provided evidence that protein needs may be higher than this. I highly suggest reading article one's section on dietary reference intakes to fully understand the situation.

In summary however, leucine intake per day for athletes may be optimized at 20-30 grams a day, but in reality it is the timing, and pattern of leucine ingestion that is critical.

What is the role of other Essential Amino Acids in Stimulating Protein Synthesis?

If you administer leucine alone, protein synthesis rises for only 30 minutes, but if you provide other essential amino acids then protein synthesis remains elevated for at least 2 hours. Thus, they play a supporting role. Also leucine administered alone can lower the concentration of other amino acids, particular other BCAAs. This is because leucine stimulates the enzyme which degrades all BCAAs. If given in the absence of other BCAAs, they will lower in concentration, and protein synthesis will lower with their decrease.

How much leucine is optimal in a single setting?

Protein synthesis appears to be fully restored at around 2.5 grams, but can most likely be maximized at 3 to 4 grams per serving. If calculating based on bodyweight, the highest amount would be 0.048 grams of leucine per kg of bodyweight per serving.

Assuming that most high quality proteins such as whey and meats are approximately 10 % leucine then roughly 30 to 40 grams of protein will meet the 3-4 gram leucine standard in a single setting, which is roughly 150 to 220 calories. If consuming an essential amino acid supplement such as the Essential Amino Acid shooter, one serving administers 3 grams of leucine at 45 calories per serving.

What should I consume in my Pre Bed Time Meal?

Before bedtime an individual will want to maximize protein synthesis, while minimizing protein degradation. Casein appears to only slowly increase protein synthesis, but markedly enhances protein degradation. It also contains approximately 9 % leucine content. One cup of cottage cheese will deliver approximately 28 grams of protein, if it is low fat, and 2.5 grams of leucine. Protein synthesis may be able to be increased with a higher leucine content. In fact, evidence suggests that increasing whey protein from 22 grams to 33 grams increased protein synthesis. Whey is higher in leucine and so the participants in this study went from 2.2 to 3.3 grams of leucine.

In casein the leucine is delivered very slowly into circulation, which is most likely why protein synthesis is not increased to a great extent, as compared to whey protein which rapidly and drastically increases protein synthesis.

Remember, it is the extracellular increases in leucine which stimulate protein synthesis. Therefore a slow release will only expose cells to a moderate levels of leucine and so not cause maximal protein synthesis. Casein stays in the gut for quite some time. The main reason is because it contains opioid peptides which slow gastric emptying rate and motility. Therefore in the case of consuming casein, I recommend the upper upper range of leucine intake which amounts to about 0.048 grams of leucine per kg of bodyweight. For a 200 pound man this amounts to about 4.4 grams of leucine.
What an individual can do pre bed is to consume more than a cup of cottage cheese so as to get more leucine, or consume a high leucine containing product along with the casein. I would opt for the latter. One scoop of the amino acid shooter contains 1 gram of leucine and is only 15 calories. In contrast you would have to consume over 100 calories more of cottage cheese to match that amount. Because of the opioid peptides released, the leucine from the shooter, even though it is rapidly digested on its own, should be slowly released if consumed as a chaser to the cottage cheese. The hope here is to optimally stimulate protein synthesis and degradation.

To avoid storing fat a fibrous green vegetable should be consumed such as broccoli, which itself is antiestrogenic, and so should assist athletes in not holding water and attaining a more tight appearance.

At this time I also recommend consuming essential fatty acids in the form of fish oil pills rich in EPA and DHA. EPA has been demonstrated in muscle wasting conditions such as starvation to actually hinder muscle loss!

Glutamine also is critical in this meal. Glutamine makes up over 60 % of intramuscular amino acids. It is also the preferred amino acid for gluconeogenesis during fasting conditions such as sleep, or when carbohydrates are low such as before bedtime. Therefore administration of glutamine can serve a number of functions.

1. If the intracellular and extracellular pools of glutamine levels are low, the intracellular pool will be depleted, causing muscle tissue to be broken down to replace these losses

2. Glutamine draws water into the cell and hydrates it, which may improve protein balance.

3. Glutamine can actually be used to increase glycogen synthesis in muscle tissue in the absence of insulin, and because it is a very gluconeogenic amino acid it can assist the liver in maintaining stable glucose levels throughout the night.

Also note that before bed you can consume other slow digesting proteins such as steak.

What should I consume during my Mid Sleep Meal?

I advice setting the alarm in mid sleep, and having a shake next to your bed. I typically mix a mixture of EAAs for caloric efficiency, with a protein powder. To slow digestion I consume EPA in the form of fish oil pills. Further, I include HMB to further hinder protein degradation, as well as glutamine. Shoot for at least 3 grams of leucine here.
If you want to slightly slow digestion, but keep calories low, have EAAs, and consume only a small amount of cottage cheese, such as a fourth cup. The opioid peptides in it should slow gastric emptying.

Sample Pre and MidSleep Meal

Pre Bed

1 cup cottage cheese
1 to 2 scoops of amino acid shooter
fish oil pills amounting to at least a 1 to 1.5 grams of EPA
1 gram of HMB
5-10 grams of glutamine

Mid Sleep

10 grams of essential amino acids, containing at least 3 grams of leucine to restore protein synthesis
¼ cup casein
1 to 1.5 grams of EPA
1 gram of HMB

5-10 grams of glutamine

Does leucine 'alone' stimulate insulin secretion and is this how it exerts its effects on protein synthesis?

Studies are conflicting as some have found no increase in insulin when leucine is administered **alone**, while others have. To clarify Dr. Anthony and colleagues measured insulin levels immediately after leucine administration and found that it increased insulin from 15-45 minutes. Thus it appears that it does increase insulin transiently and that measuring insulin after this time frame will not yield significant increases.

In order to investigate if insulin modulates leucine's effects, scientists will either block the action of insulin, or block insulin release. When this occurs leucine's effects on protein synthesis are partly but not fully hindered. Recall that leucine increases S6, which is the ribosomal protein responsible for increasing the capacity of a cell to conduct protein synthesis. This is completely blocked when insulin is hindered. Leucine also enhances the initiation of translation (the initiation stage of protein synthesis) and this is only partly blocked when insulin is hindered. Thus, leucine has both insulin dependent and insulin independent effects on protein synthesis.

How much insulin is needed in order for leucine's effects on protein synthesis to be maximized?

Leucine can maximally stimulate protein synthesis at fasting levels of insulin, and perhaps at slightly lower levels than this! Therefore spiking insulin levels for the purpose of enhancing leucines effects on protein synthesis do not appear to be necessary. Currently scientists are divided. Either insulin plays a supportive or passive role in supporting leucines effects on protein synthesis, or a direct role. Either way this is maximized at low levels.

Can insulin stimulate protein synthesis independent of leucine and other amino acids?

Insulin administered alone does not appear to have an effect on protein synthesis. The rationale is that insulin increases uptake of amino acids and therefore lowers their concentration in the blood when given alone. Extracellular amino acid levels are critical for protein synthesis to occur. However, when amino acid levels are maintained insulin may be able to stimulate protein synthesis when it is at extremely high levels. This is confirmed in studies which administer either insulin alone, or carbohydrates alone. No protein synthesis is stimulated and the individual remains in a muscle wasting condition. In contrast when amino acid levels are maintained protein synthesis is stimulated when insulin is raised to very high levels.

However, insulin potently decreases protein breakdown, independently of amino acids. In fact it is considered the main player in decreasing protein breakdown, but individuals remain in negative protein balance without aminos.

Can insulin and leucine work together in a synergistic fashion to increase muscle growth?

Like leucine, insulin appears to elicit its actions on protein synthesis through an mTOR dependent mechanism, as well as mTOR independent mechanisms. When leucine and insulin are combined their effects on increasing a cell's capacity for protein synthesis are synergistic. This means that if insulin increases the capacity of a cell to increase protein synthesis 2 fold, and so does leucine, combined their effects are greater than 4 fold.

The current rationale is that insulin actually increases blood flow to muscle tissue, which if combined with increasing levels of amino acids (particularly leucine) would increase amino acid concentrations and delivery to muscle tissue, thereby amplifying their effects.

Insulin increases blood flow + increased leucine → greater concentration of leucine surrounding muscle tissue → amplified effects on protein synthesis.

It is also important to note that as stated, leucine alone either does not or only transiently increases plasma insulin levels. Yet, when combined with insulin, it actually notably increases plasma insulin levels. The rationale is that insulin is cleared primarily through degradation (e.g. it is broken down like other proteins). Because leucine has anticatabolic effects, it may decrease insulin clearance levels.

Can you discuss more of the effects of insulin on protein breakdown?

Yes,

White leucine is the primary regulator of protein synthesis, insulin is the primary regulator of protein breakdown in that it decreases it by hindering pathways responsible for protein breakdown.

In an intriguing study participants were given one of three drinks after exercise. The first was a glucose drink, the second combined whey protein with glucose, while the third added leucine to the glucose / whey serving. Results indicated that protein balance was negative in the first condition, became positive in the glucose / whey condition, and increased again when leucine was added.

Here's the interesting fact. Protein balance appeared to increase with increasing insulin levels. Finally they analyzed the relationship (correlation) between leucine and protein synthesis and insulin and protein synthesis. They found that leucine was positively related to protein synthesis (as leucine increases protein synthesis does as well), while insulin was not significantly correlated. However, insulin was inversely correlated to protein breakdown, meaning when insulin levels rise, protein breakdown decreases.

For practical applications on how to manipulate carbohydrates for insulin release see the following papers

http://www.abcbodybuilding.com/laywindowsemi.php
http://www.abcbodybuilding.com/laywindownon.php

Both exercise and leucine stimulate protein synthesis. Is there any time differences between the two?

Yes, leucine in a mixture of EAAs stimulates protein synthesis for 2-3 hours, where as exercise stimulates protein synthesis for up to 72 hours. The take home message is that you need amino acids with a high frequency.

The second take home message is that even though protein synthesis is elevated with exercise for 72 hours, these effects lower with time. In our publication on Contemporary issues in protein consumption we provided the following graph to demonstrate this

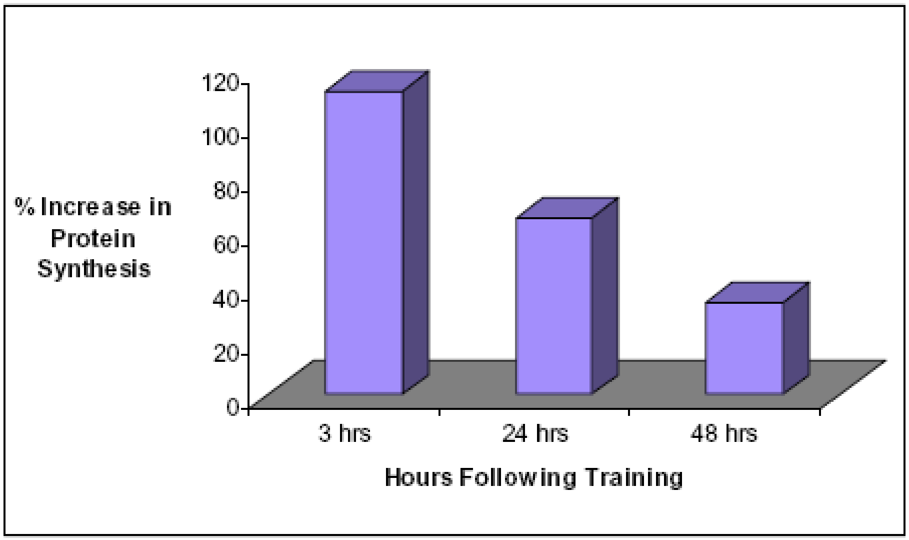

Figure 1.0. The response of protein synthesis to exercise. Adapted from Wilson and Wilson (2006).

This is one of the reasons why HIT training may not be as effective as a higher frequency of training, which is able to maintain higher levels of protein synthesis throughout a 7 day period, then a once a week program, which has diminishing effects.

Both resistance training and cardio are forms of exercise. Why does exercise trigger protein synthesis, while endurance exercise can decrease it?

First lets give a brief overview of the different responses to exercise.

1. Resistance training does not change protein synthesis much during the exercise session, but causes it to raise up to 72 hours after. However, if you do not consume amino acids, protein breakdown exceeds synthesis, and overall you lose muscle tissue. This means that you will be in a net catabolic state unless amino acids are supplied immediately following training.

2. Endurance exercise lowers protein synthesis during and after exercise. Combined with increased protein degradation, this can be a recipe for disaster!

Now to answer the question!

The difference between the two appears to be related to blood concentrations of leucine. Leucine levels do not lower during resistance exercise, while they lower in endurance exercise. The lowering of plasma leucine levels is correlated with lowered protein synthesis. As further evidence, when leucine is administered after endurance exercise, protein synthesis is fully restored.

Why is the maintenance of leucine levels so important to maintaining protein synthesis?

While the answer is extremely complex, it can be simplified as follows.

1. Recall that mTOR is the machinery that leucine acts on to trigger protein synthesis.
2. It appears that leucine, insulin, and growth factors such as insulin like growth factor increase the activity of mTOR.
3. But, decreased energy stores in the cell, such as occurs during exercise, decreases the activity of mTOR.

When leucine levels are maintained they are able to counter the negative effects of lowered energy stores. But, the combination of lowered leucine, and decreased energy stores in the cell leads to a net decrease in protein synthesis.

Can supplementation inhibit the catabolic effects of cardio?

This question is critical and applies mainly to two situations.

1. Long duration cardio
2. Cardio on an empty stomach, particularly after an overnight fast.

Both are avoided because they are catabolic. But why are they catabolic? Evidence suggests that they may be so due to lowered plasma leucine levels. Thus, supplementing with an essential amino acid mixture prior to endurance exercise that is long duration, or cardio in the morning may negate the catabolic effects seen.

More studies need to be done to examine this, but the implications are great for two reaons

1. Long duration cardio relies on a greater percentage of fat
2. cardio on an empty stomach relies on a greater percentage of fat then cardio closer to a previous meal.

Aging appears to be linked to losses of muscle tissue, and a failure to be able to gain muscle tissue in a number of circumstances. Why is this the case, and is their a point to the elderly bodybuilding?

One of the more frequent questions I receive to my email account and in person is "can I still gain muscle at this age?" Typically my answer is that the evidence supports the efficacy at bodybuilding at any age.

First, the question discusses the link between aging and muscle loss. Statisticallly speaking, after the age of 50 the average loss of muscle tissue is 0.5-2 % per year!

The question however is what is causing this, because if we know then we can reverse these effects. Fortunately science has shed a great deal of light on the matter.

First we need to understand that losses in muscle tissue are again related to overall protein balance. At some point in a 24 hour time period, either protein synthesis or degradation are lower or higher respectively in the elderly than the young.

When measuring normal fasting levels of protein balance, differences between the young and elderly appear negligible. However after a meal is consumed, the young respond with an increase in protein synthesis and a decrease in protein degradation, while in many cases the elderly do not. This suggests signaling deficits to anabolic stimuli, and we think they are related to leucine.

In one study the young and elderly were given 7 grams of EAAs which were 27 % leucine. Only the young responded with enhanced protein balance. Then the experimenters upped the percentage of leucine to 47 %, and found that the anabolic response to the EAAs was restored to youth levels in the elderly! Thus, the amount of leucine ingested is critical for the elderly.

So how can the elderly up their leucine intake? It seems that at levels of 15 grams of essential amino acids no differences are found between the young and elderly in response to feeding. This is because at this dose, the amount of leucine is high enough to saturate protein synthetic machinery. So, the suggestion is that the elderly should consume 15 to 20 grams of EAAs, or 30-40 grams of high quality protein per meal. Interestingly enough, evidence suggests that the elderly may benefit from faster digesting proteins. The reason may be related to the fact that faster digesting proteins can raise extracellular leucine levels high enough to elicit enough of an increase in plasma leucine levels to maximally activate the protein synthetic machinery in the elderly.

Overall the take home message is that the elderly can benefit greatly from bodybuilding, as long as they are consuming large doses of leucine per meal.

What are the overall differences between higher protein or higher carbohydrate diets on body composition?

The typical RDA type recommendations, suggest that individuals only need 50-100 grams of protein per day. Or expressed in the ratio of carbohydrates to proteins, the recommendations by the American Health Association (AHA) are 3.5 grams of carbs for every 1 gram of protein. In contrast, when calories are held constant and protein intake is increased to the typical bodybuilding diet which allows for 1 gram per pound of bodyweight or higher the ratio of carbs to protein lowers. Typically studies look at higher protein diets as a ratio of 1.5 grams of carbs per 1 gram of protein.
Evidence suggests that the higher carb diet causes difficulties in controlling blood glucose levels, causes elevated and sustained increases in insulin levels, which leads to decreased use of fat for fuel. Higher insulin levels also drastically lower glucose levels, which leads to greater levels of hunger.

In contrast when protein intake is such that the ratio of carbohydrates to protein is lowered to 1.5, evidence suggests greater fat loss, maintenance of lean tissue mass ,

higher satiety , lower post absorptive insulin levels. Here is a summary of what occurs between groups
Comparing fat loss
For example in a 16 week study by Dr. Layman and colleagues, individuals lost nearly twice the fat (19.4 vs 12.3 pounds) on the higher protein diet, then the higher carbohydrate diet, even though calories were exactly the same (both induced a 500 calorie deficit)! Conversely the loss of muscle tissue was three times greater in the high carbohydrate group than the high protein group!
This suggests that calories are only one factor involved in fat loss diets, while the ratio of carbs to proteins is another absolutely critical variable, which can have drastic effects on fat loss.

Comparing Plasma Glucose levels

Individuals who consume the higher protein diet have more stable blood glucose levels after an overnight fast, and 2 hours after a meal. Those on higher carbohydrate diets are more likely to have low blood glucose levels, which is not only negative in terms of satiety, performance, and mental fatigue, but causes plasma triglyceride levels to rise. Elevated plasma triglyceride levels actually causes insulin resistance!

Plasma Insulin Response

After feeding insulin and glucose levels rise. At about 2 hours following a meal, plasma glucose levels return to normal basal levels, but insulin remains elevated. Remember, insulin is a hypoglycemic hormone. This means that it lowers glucose levels. So, the higher insulin is at the two hour mark, the lower blood glucose levels will be.

Studies show that the higher carbohydrate condition has lower glucose levels and higher plasma glucose levels as compared to the high protein condition.

So how do high protein diets increase fat loss, and spare muscle tissue?

1. Higher protein diets increase satiety. This is most likely related to the fact that higher protein diets maintain a more stable blood glucose level. When plasma glucose levels lower we become hungry. Higher satiety reduces feeding behavior which is counter to fat loss.

2. Higher protein diets stimulate the use of a greater amount of protein for the production of glucose, so as to maintain plasma glucose levels. This occurs in the liver and is known as gluconeogenesis or the formation of glucose from a non glucose molecule. 1 gram of protein converts to approximately 0.6-0.7 grams of glucose, so it is a less efficient energy source. By decreasing energy efficiency during dieting you increase the amount of energy you use in a given day, which is very important in dieting.

3. Further, muscle tissue is extremely metabolically active. Because leucine is able to positively enhance lean mass, it is able to maintain an overall higher metabolic rate for the duration of a dietary intervention.

Leucine is also the major signaling molecule for protein synthesis which is itself an extremely costly process.
How does leucine effect the control of plasma glucose levels?

Both the liver and insulin regulate plasma glucose levels. While fasting, or between meals the liver releases glucose from stored glucose stores and from gluconeogenesis.
Glucoeneogenesis primarily occurs through amino acids. In particular the amino acids alanine and glutamine. Branched chain amino acids, such as leucine are the primary amino acids used to form alanine and glutamine. Therefore increasing BCAAs from diet does one of two things.

1. It increases the supply of alanine and glutamine for gluconeogenesis and therefore more stable blood glucose levels

2. It spares muscle tissue which is comprised of 80 % BCAAs!

Higher carbohydrate diets do not provide this amino acid supply and so individuals may break down their own muscle tissue stores.

A second area to analyze is the transition from absorbative feeding periods, which is within 2 hours of feeding and post absorbative periods of feeding, which occurs after the two hours have ended. Recall during this time insulin remains elevated, even though glucose has returned to fasting levels.

If consuming a high carbohydrate diet, that is lower in protein then insulin levels will be higher at this stage. The problem is that if glucose is not supplied by diet (an obvious since this is between meals), then plasma glucose levels must be maintained by the liver. But insulin suppresses the enzymes in the liver which produce glucose and which breakdown glycogen to release glucose. This explains why plasma glucose levels are lower in high carbohydrate / low protein diets.
Leucine not only acts as a precursor to amino acids such as alanine, but it also acts as a signaling molecule which stimulates this process directly. This it controls and participates in gluconeogenic processes.

Practical Applications Summed

Clearly leucine provided by the diet is critical to the bodybuilder. Overall we discussed the following applications of leucine.

1. In high quality protein diets leucine is approximately 10 % of proteins consumed, when averaging typical meat, and whey products.

2. Individuals should consume a minimum of 3-4 grams of leucine per sitting. If consuming whole proteins this amounts to a minimum of 30-40 grams of protein per feeding. This also supplies the critical essential amino acids needed to prolong leucine’s effects.

2. The effects of leucine are mainly on protein synthesis, but it also decreases protein degradation. However, if you want to maximally stimulate protein balance it is important to understand hat carbohydrates stimulate insulin, which is the primary suppressor of protein breakdown. Following training is a good time to take

advantage of insulins effects. During normal feedings, insulin should only be raised by low to moderate GI carbohydrates.

When carbohydrates fade, their anticatabolic effects should be replaced with other anticatabolic agents, including glutamine, HMB, and a reasonable increase in essential fatty acids such as EPA, which is itself directly stops protein breakdown.

3. Leucines effects may only last 2 – 3 hours after ingestion. Thus, frequency of leucine ingestion must be high. I recommend a minimum of 6 meals a day, along with 2 essential amino acid feedings containing 10-15 grams of EAAs, and 3 grams of leucine.

4. Pre bed you are preparing to enter into a state of fasting. You should consume a slow digesting source of protein such as meat or cottage cheese. If consuming cottage cheese, realize that its slow release will not substantially raise leucine levels, even through a cup may contain 30 grams of protein and 3 grams of leucine. This is because at any one point only so much leucine is released and absolute levels are not raised high enough for a drastic increase in protein synthesis. A current, but as of yet unconfirmed hypothesis is to raise the essential amino acid content in cottage cheese, by chasing it with a serving of EAAs rich in leucine. This will mean that the proportion of EAAs released will be higher even though cottage cheese is a slow digesting protein. It may facilitate optimal suppression of protein breakdown and protein synthesis

5. Upon waking in the middle of nighttime sleep you are in a highly catabolic state. Therefore you should have a shake next to your bed which can be quickly consumed followed by going back to sleep. The shake should again contain 10-20 grams of essential amino acids, 3 grams of leucine, and anticatabolic agents previously discussed.

6. During resistance exercise, it is beneficial to provide a rich source of EAAs prior to and after for recovery.

However, during endurance training if you do not maintain plasma leucine levels you will lose muscle tissue. Therefore prior to long duration cardio, or when performing cardio in the morning be sure and first consume EAAs rich in leucine. This should hinder any lean tissue loss

7. The elderly should bodybuild as it not only increases their muscle tissue and functionality, but because they can make improvements that are drastic. The key is that they need to maximally stimulate protein synthesis. If they consume a meal low in protein, such as a meal with 15 grams of protein they will not move into positive protein balance. Instead they need to shoot for a minimum of 10-15 grams of EAAs per meal, rich in leucine content. This can occur through 30-40 grams of protein.

8. Carbohydrates are important for performance, but should not dominate a fat loss diet. Instead protein levels should be a minimum of 1 gram per pound of bodyweight and perhaps higher. This will stabilize glucose levels, lower insulin levels, increase insulin sensitivity, and drastically increase fat loss.

That concludes this series. I have also been asked questions on the boards in regards to this paper by some extremely intellectual members. You can read these responses here http://www.abcbodybuilding.com/forum/showflat.php/Cat/0/Number/1218375/an/0/page/0#1218375

If you are not a member of the forums you can sign up free here

http://www.abcbodybuilding.com/forum/newuser.php?Cat=0