Bachelor's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Medicine and Health Sciences
Department of Neuromedicine and Movement Science

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# Muscle Fatigues Contribution to Muscle Hypertrophy in Trained Young Men

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Supervisor: Yngvild Gagnat
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**Abstract**

**Background:** There are several different types of resistance training (RT), and each type serves a different purpose. For people who are looking to gain muscle mass, hypertrophic training would be the obvious choice. Muscle fatigue is a term often associated with hypertrophic training. This study will investigate muscle fatigue's contribution to muscle hypertrophy in trained young men, due to the increased popularity of RT and the lack of specific research on the subject. **Methods:** Studies were found by using Pubmed and Google Scholar as search bases. Inclusion criterias consisted of the subjects being in the age range of 18-35 and preferably recreational trained. Some of the found articles studied muscle fatigue, and muscle hypertrophy, but were excluded because they did not look into the correlation between the two. **Results:** Five studies were included in this literature study. The five articles studied the different increases in hypertrophic gain and one-repetition maximum (1RM), when utilizing different training variations. **Conclusion:** Results from this literature study were not deemed sufficient enough to produce a reliable conclusion on muscle fatigues contribution to muscle hypertrophy in trained young men.

**Abstrakt**

**Bakgrunn:** Det er flere forskjellige typer styrketrening, og hver type har forskjellig hensikt. For folk som vil øke muskelmasse, vil hypertrofisk trening være det selvsagte valget. Muskel tretthet er et begrep som ofte er assosiert med hypertrofisk trening. Dette studiet skal etterforske muskeltretthets bidrag til muskelhypertrofi blant trente unge menn, grunnet den økte populariteten til styrketrening, og den manglende spesifikke forskningen på temaet. **Metoder:** Studiene ble funnet ved å bruke Pubmed og Google Scholar som søkebaser. Inkluderingskriterier bestod av at subjektene var i alderskategorien 18-35 og at de skulle helst være aktive før starten av studien. Enkelte av studiene som ble funnet studerte muskeltretthet, og muskelhypertrofi, men ble ekskludert fordi de ikke så på korrelasjonen mellom de to. **Resultat:** Fem studier ble inkludert i dette litteraturstudiet. De fem artiklene studerte de forskjellige økningene i hypertrofisk økning og en-repetisjon maks (1RM), når forskjellige treningsvariasjoner ble utnyttet. **Konklusjon:** Resultatene fra denne litteraturstudien ble ikke sett på som tilstrekkelig nok til å konkludere med muskeltretthets bidrag til muskelhypertrofi blant trente unge menn.

**Keywords:** Hypertrophy - Muscle fatigue - Resistance training

## 1. Introduction

Resistance training (RT) is a form of training which has had a steady incline in popularity throughout the years, especially in the later years, much thanks to social media, where more and more people are sharing their experiences and advice. This is a positive consequence, considering it is proven that RT has a positive effect on the health of individuals of all ages (1). However there are a variety of different ways to perform RT, where some are broadly researched and documented, while others might not be. A broadly researched RT variable could be preferable when looking to stimulate the muscles in a certain way.

There are three different types of muscle which can be found in the human body; Skeletal, smooth and cardiac muscles. However, in this literature study, the main focus will revolve around the skeletal muscles. The human body consists of around 600 skeletal muscles, which are mostly attached by tendons, to the bones of the skeleton (2). The skeletal muscles comprises approximately 40% of the total body mass (3) and is the muscles that makes it possible to create movement. When performing RT, it is the skeletal muscles that get affected.

Each muscle consists of muscle cells, also called muscle fibers, which are made up of myofibrils. Myofibrils are thin and cylindrical, and consist of myofilaments. Inside the myofilaments, there are two types of protein molecules; actin filaments and myosin filaments. The actin and myosin are organized in over 1000 sarcomeres inside of each myofibril (2). A muscle contraction happens because of the actin and myosin: The myosin is constructed with a head that attaches itself on to the actin, and creates a force (powerstroke) that swings itself towards the M-line, which is the most central point of the sarcomeres. For muscle fibers to work and contract, the muscle is dependent on a neurotic signal from the motor neurons that are attached to the muscle fibers (4).

RT is repeatedly short lasting power manifestations close to the muscles maximum performance, which are necessary to create hypertrophy (2). For people who are looking to induce muscle growth, hypertrophy specific training would be the most obvious choice. During hypertrophy, there is a higher synthesis of actin and myosin, which results in a higher amount of myofilaments, wider diameter of the muscle and a stronger contraction force (2). Mechanical tension, which is the muscular tension that builds up during RT when the muscle is exposed to external stress, is also considered important for muscle hypertrophy (5).

Muscle fatigue is a state which is obtained from long lasting usage of the muscles, which results in a reduced contraction force of the muscle. This means that the muscle cannot contract with the same power nor the same speed, when reaching complete training induced muscle fatigue (6). This gives a feeling of tiredness or lack of energy, which is usually short-lasting and requires rest to be reversed (7). There are a plethora of variables that contribute to muscle fatigue. One of the main factors is the increase in inorganic phosphate, which are coupled to the powerstroke, during exercise. The increase results in a reverse effect on its release step, causing a decrease in force production capability (8).

During heavy exercise, the production of ATP occurs from glucose, which leads to the production of lactic acids (2). Lactic acids make it harder for the muscle to contract properly, and with continuous overloading, the muscle will reach a state called muscle failure. In RT, this is recognized as when the trainee no longer is capable of performing a successful repetition in the appropriate range of motion (9). Muscle failure occurs when the exercise continues through the state of fatigue, with less power and speed, until the muscle is no longer capable of contraction.

During RT we can use different loads of weight to trigger different muscular responses. High load (HL), generally defined as training with >60% of one repetition maximum (1RM), and low load (LL), generally defined as training with <60% of 1RM, are loads which are commonly used in RT (10). Jozo Grgic writes in his meta-analysis from 2020 that some authors regard HL RT to generally stimulate type II muscle fibers. In the same meta analysis Grgic stated that some authors regard LL to trigger more type I muscle fibers hypertrophy. Grgic also stated that these findings between studies remain highly inconsistent (10).

Hypertrophic gain can be measured in several different ways, but the most common method is either using cross-sectional area (CSA) or by measuring the thickness of the muscle. CSA is the transverse section of the muscle and is commonly used to measure changes in muscle volume (11). CSA can be measured by either Magnetic resonance imaging (MRI) or by ultrasounding images, where "the MRI technique exploits the spin density information in the sample to image" (12). Ultrasounding imaging sends ultrasonic waves through the muscle and processes the reflected ultrasonic waves to project an image (12).

Where there is hypertrophy induced RT, there will also occur an increase of strength. 1RM is used as a test to determine a person's strength, where 1RM is the max weight an individual can lift with one repetition, with the optimal technique (13). By measuring a participant's 1RM at the start of a RT program and at the end of a RT program, it is possible to determine the increase in strength during the program. 1RM is a test that can be performed in any gym and at any RT exercise, and does not require any expensive laboratory equipment (13).

The information provided above is essential information when assessing muscle fatigues' contribution to muscle hypertrophy in trained young men, and will also be utilized throughout the literature study. In addition to this, different articles are going to be analyzed and compared. This information will again be used to assess the different amount of hypertrophy that is triggered by those who train to failure vs. those who train to non-failure, and how the hypertrophic gain is affecting the muscle strength (1RM).

## 2. Methods

A literature search was carried out through Pubmed and Google scholar. Search words such as "muscle fatigue", "muscle hypertrophy", "muscle failure" and "muscle exhaustion" combined with "and/vs/or" were used. A total of five articles were included in this study.

*2.1 Inclusion and exclusions criterias*

For studies to be included they had to be written in English, the participants had to be between 18 and 35 years old, and were preferably recreational trained **before** the start of the study. Some of the studies found were also looking at muscle hypertrophy and muscle fatigue, but were not included because they did not look into the correlation between the two.

*2.2 Practical implications*

Studies were divided into multiple training loads based on what was implied in the articles. Where training load was not implied in the articles, repetitions>10 and <60% of 1RM were defined as LL, and repetitions≤10 and >60% of 1RM as HL (10).

The three different levels of failure are non-failure, failure and volitional failure. Non-failure consists of performing a prescribed number of repetitions or giving up before reaching muscular failure (9). Failure is determined by the participants inability to perform the exercise correctly due to exhaustion, while volitional failure is determined by the subjects inability to follow a prescribed rhythm (14).

## 3. Results

A total of five articles were included, with a total of 110 participants. The five articles studied the different increases in hypertrophic gain and 1RM, when utilizing different training variations. Table 1 provides an executive overview of the studies included in this literature study.

Table 1: Descriptive statistics of the different studies used in this literature study.

| Study | (15) | (16) | (9) | (17) | (14) | Total |
|---|---|---|---|---|---|---|
| Participants | 33 | 9 | 14 | 27 | 27 | 110 |
| Age | 23.4±3.0 | 25.0±3.0 | 23.1±2.2 | 23.0±3.6 | 18-22 | NA |
| muscle | Biceps Brachii | Pectoralis major/ Triceps Brachii | Vastus Lateralis | Vastus Lateralis | Pectoralis major/ Triceps brachii | NA |
| Training period (weeks) | 12 | 6 | 10 | 12 | 8 | NA |
| Experienced? | No | Yes | Yes | No | Yes | NA |

Table 2: Changes in Vastus lateralis, Triceps brachii, Pectoralis major and Biceps brachii CSA after different types of Resistance training, presented as mean $\pm$ SD and percentage changes.

| | Training type (References) | Pre ($cm^2$) | Post ($cm^2$) | $\Delta$% |
|---|---|---|---|---|
| **Vastus lateralis** | HL RT-F (9) | $32.9 \pm 5.3$ | $37.2 \pm 5.6$* | 13.5% |
| | HL RT-NF (9) | $32.0 \pm 5.9$ | $37.5 \pm 6.6$* | 18.1% |
| | HL RT-F (17) | $22.8 \pm 5.1$ | $24.5 \pm 5.0$* | 7.5% |

| | | | | |
|---|---|---|---|---|
| | HL RT-NF (17) | 23.0 ± 6.1 | 24.7 ± 5.9* | 7.4% |
| | LL RT-F (17) | 23.7 ± 6.0 | 25.4 ± 5.6* | 7.2% |
| | LL RT-NF (17) | 24.1 ± 5.5 | 25.6 ± 5.3* | 6.2% |
| **Triceps brachii** | HL RT (16) | 21.7 ± 3.6 | 24.0 ± 3.6* | 10.6% |
| | LL RT-VF (16) | 22.3 ± 3.9 | 24.2 ± 3.6* | 8.5% |
| **Pectoralis major** | HL RT (16) | 29.0 ± 5.4 | 33.9 ± 5.8* | 16.9% |
| | LL RT-VF (16) | 28.3 ± 4.2 | 34.1 ± 4.6* | 20.5% |
| **Biceps brachii** | HL RT-F (15) | 11.5 ± 2.1 | 13.5 ± 2.5* | 17.4% |

*RT: Resistance training, HL: High Load, LL: Low Load, F: Muscle Failure, NF: non-Failure, VF: Volitional failure *: P-value<0.05.*

Table 3: Changes in Triceps brachii and Pectoralis major after LL resistance training to failure and non-failure, and HL resistance training, presented as mean ± SD and percentage changes.

| | Training type (References) | Pre ($mm$) | Post ($mm$) | $\Delta\%$ |
|---|---|---|---|---|
| **Triceps brachii** | LL RT-F (14) | 29.2 ± 5.0 | 34.1 ± 3.5 | 16.8% |
| | LL RT-VF (14) | 29.7 ± 5.7 | 32.1 ± 6.8 | 8.1% |
| | HL RT (14) | 30.3 ± 6.3 | 34.7 ± 5.4 | 14.5% |
| **Pectoralis major** | LL RT-F (14) | 30.0 ± 5.4 | 36.4 ± 2.7 | 21.3% |
| | LL RT-VF (14) | 29.3 ± 2.0 | 33.9 ± 2.6 | 15.7% |
| | HL RT (14) | 30.3 ± 4.4 | 34.6 ± 3.4 | 14.2% |

*RT: Resistance Training, LL: Low Load, HL: High Load, F: Failure, NF: Non-failure, VF: Volitional failure.*

Table 4: Changes in 1RM in bench press, knee extension and unilateral preacher curl, presented as mean ± SD and percentage changes.

| | Training type (1RM) (References) | Pre (kg) | Post (kg) | Δ% |
|---|---|---|---|---|
| **Bench press** | HL RT (14) | 58.8 ± 9.4 | 73.8 ± 10.9 | 25.5% |
| | LL RT-F (14) | 58.9 ± 6.5 | 65.0 ± 6.0 | 10.4% |
| | LL RT-VF (14) | 59.7 ± 9.3 | 70.9 ± 13.4 | 18.8% |
| | HL RT (16) | 51.2 ± 11.4 | 62.1 ± 11.4* | 21.3% |
| | LL RT-VF (16) | 60.8 ± 11.4 | 67.0 ± 11.2* | 10.2% |
| **Knee extension** | HL RT-F (9) | 55.6 ± 8.6 | 73.3 ± 9.8* | 33.3% |
| | HL RT-NF (9) | 56.4 ± 9.6 | 73.9 ± 8.4* | 33.7% |
| | HL RT-F (17) | 50.5 ± 17.0 | 64.2 ± 18.5* | 27.1% |
| | HL RT-NF (17) | 49.3 ± 11.9 | 65.4 ± 16.4* | 32.7% |
| | LL RT-F (17) | 51.9 ± 14.9 | 64.8 ± 19.9* | 24.9% |
| | LL RT-NF (17) | 51.3 ± 14.6 | 64.5 ± 16.4* | 25.7% |
| **Unilateral preacher curl** | HL RT-F (15) | 12.8 ± 3.2 | 17.7 ± 3.7* | 38.3% |

*1RM: one repetition maximum, RT: Resistance Training, HL: High Load, LL: Low Load, F: Failure, NF: Non-Failure, VF: Volitional failure, *: P-value<0.05.*

In the study conducted by **Ogasawara and colleagues** (16), 9 participants performed 6 weeks of HL RT, followed by 12 months of detraining and then the same participants performed 6 weeks of LL RT to volitional failure. The testing of CSA and 1RM took place prior to both RT programs, and 3-4 days after the end of both RT programs. All of the participants completed 2 - 3 familiarization sessions and received instructions on proper technique and to practice 1RM. The Measurement procedures consisted of MRI for the muscle size measures, and a strength measurement that took place the same day. The strength was measured with a 1RM test in the free weight bench press. For the muscle size measurements, Multi-slice MRI images were obtained by using an MRI scanner (General Electric Yokogawa Signa 0.2-T, Milwaukee, WI, USA).

In the study conducted by **Santanielo and colleagues** (9), the participants' vastus lateralis muscle CSA were assessed in a laboratory using ultrasound. Following this, the participants familiarized themselves with the 1RM and training protocols. 72 hours post of the familiarization, the subjects performed a new 1RM test. If the results differed by more than 5% from the previous test, a new test was conducted 72 hours later. The subjects, on average, completed three 1RM tests. 72 hours after the last training session, muscle CSA and 1RM were re-assessed.

**Nóbrega and colleagues** (17) studied the effect of resistance training to muscle failure vs. volitional interruption at high- and low intensities, and what effect this had when assessing muscle strength and CSA. The participants started with a familiarization session with the 1RM test and the training protocol. A new 1RM test was performed 72 hours after the familiarization, and if the results varied more than 5% from the familiarization test, a new test was performed 72 hours later. On average, the subjects performed three 1RM tests. After at least 72 hours, VL muscle CSA was assessed using ultrasound. Each of the subjects legs were allocated and randomized to one of four training protocols according to the 1RM test and CSA values, to reduce inter-subjects variability. There were a total of 16 legs in each of the training protocols. When the training period started, the participants performed their respective training protocols for 12 weeks, with a reassessment of the 1RM and muscle CSA (with a 72 hour interval between). An adjustment of the load was done following the reassessment after the sixth week. The training continued for 6 weeks with the increased load. After the twelfth week, a new 1RM test and a measurement of muscle CSA was performed, using the same protocol as earlier.

**Terada and colleagues** (14) investigated how RT to failure at low-load affected the acute responses and chronic muscle adaptations compared with low load RT to velocity fatigue at equal work volume. The participants started with two familiarization sessions for the bench press exercise. three to five days after the familiarization, measurements of muscle thickness and muscle strength were conducted. B-mode ultrasound (SSD-3500; Aloka, Tokyo, Japan) was used for muscle thickness, and 1RM bench press for muscle strength. The training protocol consisted of two training sessions each week, for eight weeks, where the participants were split into three groups; LL-F, LL-NF and HL. Muscle strength was reassessed after the eighth training session and the load was adjusted accordingly.

The 33 participants of the **Erskine and colleagues** (15) study, completed 3 weeks of elbow flexor RT, followed by 6 weeks of no training. After this, a 12 week period of experimental elbow flexor RT was performed. While data was not reported during the initial 3 weeks of RT, it provided the participants with extensive familiarization to the exercises and neuromuscular tests, prior to the 12 week training period. The training protocol consisted of three training sessions per week, for 12 weeks. During these training sessions, the participants performed two different exercises; Unilateral seated elbow flexion 'preacher curls' with dumbbells, where they alternated between their dominant and non-dominant arms, and then bilateral preacher curls on a RT machine (Body Solid, Forest Park, USA). Both exercises were performed with a 2 minute break between the sets. The repetition range for both exercises was  8-10 RM, and the load was increased if the participants could perform more than ten repetitions during their last set of the exercise. Week 1-2 consisted of two sets for both exercises, and increased to three sets (unilateral) and two sets (bilateral) during week 3-4, and three sets on both exercises for the rest of the training period (week 5-12). Three to four days before and after the 12-week training program, muscle strength (1RM) and CSA of the elbow flexor muscles were measured in the dominant arm. **Magnetom Symphony 1.5-T MRI scanner (Siemens AG, Erlangen, Germany)**

## 4. Discussion

The different studies used in this literature study investigated how different RT variables affect muscle strength and hypertrophy, and the muscles measured in these studies were

Pectoralis major, Triceps brachii, Vastus lateralis and Biceps brachii. Since all of the studies have been categorized as either HL or LL, and either to failure, non-failure or volitional failure, it is easy to compare the results with each other. These results provide a view of how much hypertrophy is triggered by the different RT variables, and how the hypertrophic gain is affecting the muscle strength (1RM).

### *4.1 Measurements*

In this literature study there are used two different measurements to determine hypertrophic gain; CSA ($cm^2$) and muscle thickness (mm). Both of these measurements are included due to a strong positive correlation between the two (18), and therefore makes it possible to compare the results from the study done by Terada and colleagues (14). with the other studies used in this literature article.

### *4.2 Strength measurements*

The two studies which measured muscle strength on Vastus lateralis, showed a greater increase in 1RM when training with HL, rather than LL RT, which is consistent with our beliefs that HL RT results in a greater increase in 1RM than LL RT. In the first study, there was no significant difference between RT to failure (33.3%) and RT to non-failure (33.7%) when it came to changes in 1RM (table 4), however both groups trained using HL (9). Whereas the study conducted by Nóbrega et al. used both HL and LL, and trained to failure and non-failure. This study showed similar results in the HL to non-failure (32.7%) as the first study, but for the other training variables there is reported a lower gain in 1RM than in the first study (17). In general, RT with HL seems to result in a higher increase in 1RM of the knee extension than RT with LL. Also, both studies report a higher increase in 1RM for those groups who did not train to failure (table 4). Compared to the hypertrophic gain, it seems that for the Vastus lateralis, training with a HL to non-failure results in a higher hypertrophic gain as well as increased muscle strength. However, it is interesting to see that participants who were reported as trained had a higher increase in both hypertrophic gain and in muscle strength than those who were reported as untrained.

Consistent with the general belief, RT with a higher load resulted in a greater increase in 1RM than RT with a lower load. The last study, reported by Erskine and his colleagues (15), only had one group of participants, all performing the biceps unilateral preacher curl with a

HL to failure; it is necessary to compare it to the other studies. Erskine and his colleagues (15) reported a very high percentage change in the 1RM test (38.3%) after the 12 week RT intervention. This is higher than all of the other studies (table 4), however the results that are closest are the other groups who also performed with a HL.

*4.3 Hypertrophy measurements*

There were two articles that investigated the hypertrophic gain in the Vastus lateralis muscle, and the notable sight is that they report two different results (table 2). Santanielo and colleagues (9) reported a big difference between RT to non-failure (18.1%) vs RT to failure (13.5%), with both of the groups training with a HL. The study conducted by Nóbrega and colleagues (17) on Vastus lateralis showed almost no difference between three of the four RT variables (HL RT-F: 7.5%, HL RT-NF: 7.4%, LL RT-F: 7.2%), the exception being LL to non-failure being 1% lower than the others. A notable factor is that the study by Santanielo and colleagues (9) was completed by trained individuals while the study by Nóbrega and colleagues (17) used untrained individuals (table 1). This differs from a study conducted by Ahtiainen and his colleagues (19), which states that trained individuals have a harder time to gain muscle mass than untrained individuals (19). Even though the second study had a two week longer RT intervention than the first study, they still report a much higher hypertrophic gain in both groups, whilst the difference between those two groups are also significantly big.

Both studies that investigated the Pectoralis major and Triceps brachii showed similar results in the HL and LL to volitional failure groups. Both studies showed that while Pectoralis major had a greater amount of growth in LL to volitional failure, the opposite is the case for Triceps brachii, which shows a greater growth in HL (table 2 and 3). This might be the case because of the reported wide grip (2x shoulder width) in the bench press (14), which offers greater stimulus to the Pectoralis major while not exhausting the muscles (20). For the RT with HL, where they did not perform to failure but to a predetermined number of repetitions, which may indicate that the Pectoralis major needs to be pushed to failure to have more hypertrophic gain. The reason that the Triceps brachii showed more growth in the HL may be because it is a smaller muscle and may be pushed to failure when using a HL. However, when training with a LL to failure both Pectoralis major and Triceps brachii had a greater growth than in HL and LL to volitional failure (14). This might again indicate that training to failure with LL results in the most amount of hypertrophic gain.

The study that reported one of the highest percentage growth in hypertrophic gain is the study by Erskine and his colleagues (15), with a growth of 17.4% (table 2). This differs from what the other studies reported, where LL is the group with the highest hypertrophic gain. The reasoning for this might be because of the different muscles trained, whereas the larger muscles report a greater hypertrophic gain in the LL, the smaller muscles have a greater gain in HL.

It does not seem like there is a huge correlation between hypertrophic gain and strength. For some studies, the group with the highest percentage hypertrophic gain also has the highest percentage change in 1RM. However for other studies, the results are opposite; the group with highest hypertrophic gain had the lowest percentage change in 1RM. A reason for this might be that some studies only did RT with HL, while some studies used both. However, the general results seems to be that the HL groups had a higher percentage change in 1RM, while the LL had the highest percentage change in hypertrophic gain.

*4.4 Limitations*

Due to a lack of studies conducted on this specific subject, the literature search granted us a smaller selection of studies than previously wished. A solution for this could have been to be less strict on the inclusion and exclusion, however a decision was made to stay strict exactly because of the lack of studies. Though the five included articles provided a good amount of research and results, a larger pool of studies to compare and analyze would be more adequate. This is reflected when looking at the number of participants and the significant difference in participants in each study, which preferably would be higher.

Only two of the included studies had a training protocol that lasted the same amount of weeks. However, these two did not investigate the same muscles. This might be a dependent factor due to the comparison of the results, which most likely would have been more reliable if everyone trained for the same amount of weeks.

Dietary control may be another limitation, due to the fact that none of the studies reported a controlled dietary plan for the participants. There were three studies which involved previously recreationally trained individuals, which might have a better understanding of the dietary involvement in RT.

Lack of motivation when training to fatigue could also be a potential limitation. Repeatedly stopping prematurely of fatigue would impact the results, and is only reliable on the participant as an individual, whereas exercising with a prescribed amount of repetitions and sets is easily controllable.

## 5. Conclusion

Following a completed literature study, the results were not deemed sufficient enough to make a reliable conclusion on muscle fatigue's contribution to muscle hypertrophy in trained young men. This is due to the lack of studies conducted on this specific topic, and the inconsistency of the results in the included studies. However, it may seem that the higher the load, the higher the increase in 1RM. Apart from that, a higher percentage change in hypertrophic gain does not imply a higher percentage change in 1RM. Hypertrophy triggered by those who trained to failure vs non- failure varied in each study, therefore it is challenging to conduct a conclusion.

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