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Effect of resistance training on patella tendon mechanical properties and performance in endurance trained women

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Abstract

Purpose: The purpose of this study was to investigate the effects of 12 weeks of concomitant resistance training and endurance on patella tendon (PT) mechanical properties in endurance trained women. We also wanted to investigate if any potential findings would affect running performance and economy.

Methods: 17 female endurance recreational athletes were randomly assigned into two groups. Resistance + endurance training group (RT+END)(n=9) and endurance group (END)(n=8). The RT+END group performed 2 sessions of resistance training per week in addition to their regular endurance training regimen. The END group maintained their regular endurance training regimen. vastus lateralis muscle thickness and patella tendon force, elongation length and cross-sectional area (CSA) was assessed by the use of ultrasound. Isometric knee extension peak torque and squat 1 RM as well as VO_{2max} and distance covered in 40 and 5 minutes of running was tested. The above variables were used to calculate PT stiffness, strain, Young's modulus and running economy. All the subjects were tested at baseline and <7 days after the end of the intervention.

Results: The present study revealed an increase in PT CSA (+4,8 ± 2,3% p=<0,01) and squat 1 RM (45% ± 23% p=<0,01) as a result of 12 weeks of concomitant resistance and endurance training. No changes in Isometric knee extension peak torque, vastus lateralis muscle thickness, PT mechanical properties, running performance or economy was found.

Conclusion: In conclusion, PT stiffness did not change as a result of concomitant resistance and endurance training in endurance trained women. Furthermore, resistance training does not seem to be sufficient stimuli to improve running performance and economy via adaptations in PT mechanical properties.

KEY WORDS: STRENGTH TRAINING, ENDURANCE TRAINING, PATELLA TENDON, STIFFNESS, CROSS-SECTIONAL AREA, RUNNING, PERFORMANCE, ECONOMY

Innhold

Thanks

Well here we are, the end of the road. At least the road that is The Norwegian School of Sport Sciences. This marks the end of an amazing journey towards a master thesis, that will hopefully lay the foundation for which new roads can be built upon. It is with mixed feelings I'm writing this letter. I feel happy and proud to have finished my master thesis, but also a little sad to be leaving this amazing school, with all its amazing people. Anyways, thanks should be given were thanks is due! First of all I would like to thank my two supervisors: Olivier Seynnes, your knowledge in the field of tendon mechanics and sports science in general seems limitless. And you have always been available when I have been in need of guidance and help with my thesis. And In the unlikely event that you should come up short on a question, Jens Bojsen-Møller would be there to answer. Thanks for organizing our Tuesday meetings, Jens. They have been very helpful, especially during the last few months of writing. So, to the both of you, thanks for your guidance and patience along the way, I really appreciate it! I would also like to thank my family for being there with support and kind words. And of course a shout-out has to be directed in the direction of the office and the people sitting there. Eirik Myhr Nossum, Even Granerud and Melina Meyer Magulas: Thanks for dragging me to school early in the morning and making the long days and nights livable. Olav Vikmoen and his supervisor Truls Raastad also deserves a thank you, without Olav's PhD, this master thesis would never had happened. Last but not least, a huge thank you goes to all the test subjects!

Kristoffer Bergstrøm

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1. Theory

1.1 Introduction

Long distance runners have traditionally refrained from heavy resistance training, because it has been believed that it will affect endurance performance in a negative manner. More recently, scientists have revealed that heavy resistance training may have positive impacts on long distance running performance. A ~4% reduction in oxygen consumption and energy cost at two different running velocities (3,0 & 3,5 ms-1) was reported in recreational long distance runners, after 14 weeks of isometric ankle plantar flexion training, 4 times a week (Albracht & Arampatzis 2013). Increases in running economy has also been reported after more traditional resistance training on the lower extremities (Guglielmo, et al 2009; Støren, et al 2008)Studies like this may explain why endurance athletes have become more open to implement heavy resistance training in their training regimen.

It is well known that the role of the human tendon is primarily to transfer, store and absorb both internal and external forces, as well as contribute to stability across joints in the human body. The human patellar tendon (PT) will fulfill one or more of these tasks depending on what's required of it during different kinds of movements. It is well known that the PT have to cope with forces many times bodyweight during movements as running or heavy squatting. It is clear that muscles are able to adapt too many different types of external stimuli such as endurance and resistance training. However, up until recently, it has been unclear whether the tendons accompanying the muscles are able to adapt in a similar way. More recent research suggests that tendons are indeed capable of adaptation to different stimuli. Tendons are in fact, just like muscles, highly specialized structures, which will adapt to different kinds of loading. Changes in PT mechanical and material properties have been reported after both habitual and relatively short term changes in the loading pattern. Couppe et al. (2008) reported an increase in stiffness and a greater region specific CSA in the PT of the leading leg of elite fencers and badminton players. In a more short-term perspective, Seynnes et al. (2009) observed an increase in stiffness and modulus, 24% and 20% respectively, as well as a region specific increase in PT CSA of 5-6% after 9 weeks of heavy knee extension resistance training. When it comes to adaptations to running, more precise long distance running, the literature is not cohesive, in terms of cause and effect.

For a given tensile modulus, a tendon with a greater CSA will elongate less than a thinner tendon when a given amount of force is exerted on it. An increase in stiffness can also be achieved with changes in material properties, such as those reported in some training studies. (Heinemeier & Kjaer 2011). Regardless of which mechanism is responsible for the changes in tendon mechanics after heavy resistance training, it makes sense that the tendon, or rather the muscle-tendon unit, adapts to the increased load by getting stiffer. A stiffer muscle-tendon unit favors the ability to produce the mechanical power as well as the length and position control, which is required during heavy lifting (Biewener & Roberts 2000). On the other hand, Biewener & Roberts (2000) suggests that a more compliant muscle-tendon unit will be more suited for economical force development and elastic energy savings. Accordingly, a more compliant PT seems to be favorable for a long distance runner, as the most economical runners and runners with the lowest personal best time in a 5000 meter race seems to have more compliant PT's compared to less economical and slower runners (Kubo et., al 2010; Arampatzis et., al 2006).

Yet, a stiffer muscle tendon unit may have positive effects on long distance running performance as well. A stronger muscle, as a result of resistance training, will be able to exert greater amounts of force on the stiffer tendon, thereby increasing the amount of elastic energy storage and amplifying the power output from the muscle-tendon unit. This in turn may lead to an increase in long distance running performance, as long as the increased energetic cost of a larger muscle mass does not exceed the metabolic capacity of the runner over the covered distance. This aspect is determining in long distance running due to the need of a relatively low muscle mass to keep the energy cost of running at a minimum. It seems that there has to be a compromise between gains in elastic energy storage and active muscle mass when running, to optimize running economy and performance

Hence, a more economical runner will consume less energy than a less economical runner over a given distance when running at the same submaximal speeds. Given that every other variable is the same.

Running economy is affected by numerous factors, one of which is the muscle tendon unit's ability to store and release elastic energy. The amount of elastic energy savings or tendon strain during the stance phase of a running stride is primarily affected by body mass and running speed, which in turn affects the amount of stress created by muscle contractions. As a result of concomitant endurance training and resistance training, we do not expect a significant increase in body mass. Which means that even if the muscle mass increases, this will not affect the force production by the muscle while running at a given submaximal speed This in combination with a stiffer PT as a result of the resistance training, leaves us to believe that the amount of elastic energy storage, and thereby running economy will decrease. On the other hand, such changes may have positive effects on running performance. The increased muscle mass combined with a stiffer PT will increase the mechanical power output from the muscle-tendon unit. In theory, this would mean that the subjects should be able to run faster over a given distance, however, at a higher energy cost.

1.1.1Purpose

Although we have a pretty clear picture of what is demanded of the human tendon to solve different tasks and how it adapts to meet these demands, to our knowledge, the effects of concomitant resistance training and endurance training on PT mechanical properties are obscure. The purpose of this study was therefore to investigate the effects of 12 weeks of heavy resistance training on PT mechanical properties in endurance trained women, while their usual endurance training regimen was being maintained (≥3 hours/week). We also wanted to investigate if any potential findings would affect running performance and/or economy.

1.1.2 Hypothesis

1. PT stiffness will increase in endurance trained women after twelve weeks of resistance training
2. Endurance trained women will have a decrease in running economy at submaximal running speeds after twelve weeks of heavy resistance training
3. Endurance trained women will cover greater distances in a 40 minute running test and a 5 minute all out test after 12 weeks of heavy resistance training

1.2 Tendons

1.2.1 Structure and composition

Tendons are fibrous structures. Their main tasks are to connect muscles to the skeleton, transfer forces from muscle to bone and contribute to stability in the joint it crosses. The main focus of this master thesis will be on the patella tendon. This tendon is an extension of the quadriceps tendon, which has its origin at the distal part of the quadriceps muscle and attaches to the proximal part of the patella. The PT originates from the distal part of the patella and attaches to tuberositas tibia (figure 1). The PT is reported to have a cross sectional area between 90 – 130mm^2 and to be about 5 – 7 cm long (Kongsgaard, et al., 2007; Basso, Johnson, & Amis, 2001; Reeves, et al., 2003; O'Brien, Reeves, Baltzopoulos, Jones, & Maganaris, 2010). This is however in male subjects, and it is reasonable to believe that female tendons may be shorter and thinner as O'Brien, Reeves, Baltzopoulos, Jones, & Maganaris, (2010) reported an average PT length of 47,6 ± 5.6 mm in female subjects. Tendons are a viscoelastic substance, this means that when a tendon is stretched, elastic energy is stored in the tendon which can be released as kinetic energy when the stretching of the tendon ceases. This ability can, in a very simplified way, be compared to releasing a stretched out rubber band. The tendons viscoelastic properties come from its unique composition and structure.

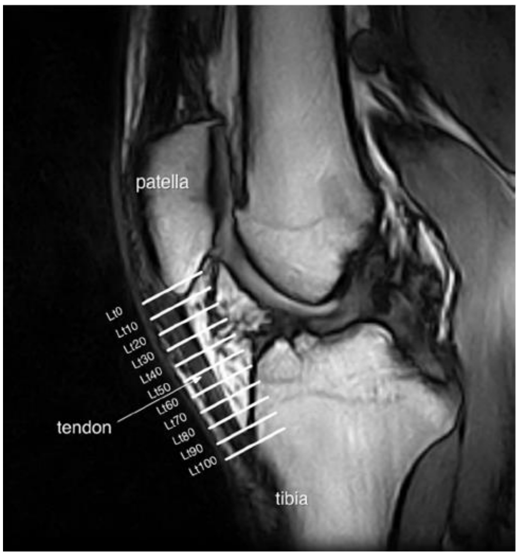

Figure 1: Sagital magnetic resonance (MRI) scan of the human knee, with the femur, patella, tibia and patella tendon. Lt0 marks the origin of the patellar tendon and Lt100 marks the insertion at tuberositas tibia (Seynnes, et al 2009).

Tendon tissue is mainly composed of extra cellular matrix (ECM), water and cells. 55 - 70% of the tendon is water, and a substantial part of this is associated with proteoglycans in the ECM. The ECM consists of collagen equivalent to 60-85% of the tendons dry weight, where about 60% of the collagen is type I. Apart from collagen type I, the presence of collagen type III (0-10%), IV (~2%), V, and VI has also been reported. In addition to collagen the ECM consists of a small portion of elastin fibers (~2% of dry weight). The rest of the ECM consists of ground substance and a small amount of inorganic substance. Accounting for ~4,5% and <0,2%, respectively (Kjaer, 2004).

The purpose of the elastin fibers is not well documented. However, after studying three different kinds of connective tissues with different amounts of elastin fibers, Minns, Soden & Jackson (1973), purposed that elastin fibres contributes to reset collagen fibers to their wave-like resting state after muscle contractions. Surrounding the collagen molecules, we find the ground substance. This substance is composed of proteoglycans, plasmaproteins and glycoproteins. The proteoglycans in the ground substance are involved in giving the ECM its unique function, as they contribute in the binding of water to the ECM (Chakravarti, 2002; Fu, Chan, & Rolf, 2007).

The most prevalent cell type in tendon tissue is fibroblast-like cells called tenocytes. Their main purpose is to repair damaged tissue and maintain the structure and composition of the tendon after different external stimuli, by producing ECM components like collagen and proteoglycans. The tenocytes are located between collagen fibers in the longitudinal direction of the tendon (Wang, Guo, et al., 2012).

The different cells and substances found in tendon tissue are structured in a hierarchical way to form a strong and functional tendon. At the lowest level we find collagen fibrils that are composed of three rod- like collagen molecules. Collagen fibrils bound by endotenon form collagen fibers, which is the next level of the tendon hierarchy. Bundles of fibers enclosed in endotenon forms subfascicles, which joins together to form fascilcles enclosed in endotenon. At the next level, bundles of fascicles, again enclosed in endotenon, forms tertiary fiber bundles. Tertiary fiber bundles enclosed in epitenon and paratenon forms the tendon unit. The epitenon and paratenon makes up the peritendon, which reduces friction with the adjacent tissue. (figure

2)(Jòzsa & Kannus, 1997; Wang, 2006). The collagen fibrils are primarily organized i such a way, that they run in the longitudinal plane relative to the muscle force acting upon it, but they may also run in the transversal and/or horizontal plane (Kannus, 2000). This means that the tendon is able to withstand great forces in the horizontal plane, but it is also able to withstand rotational, horisontal and transversal forces to some degree (Jòzsa & Kannus, 1997).

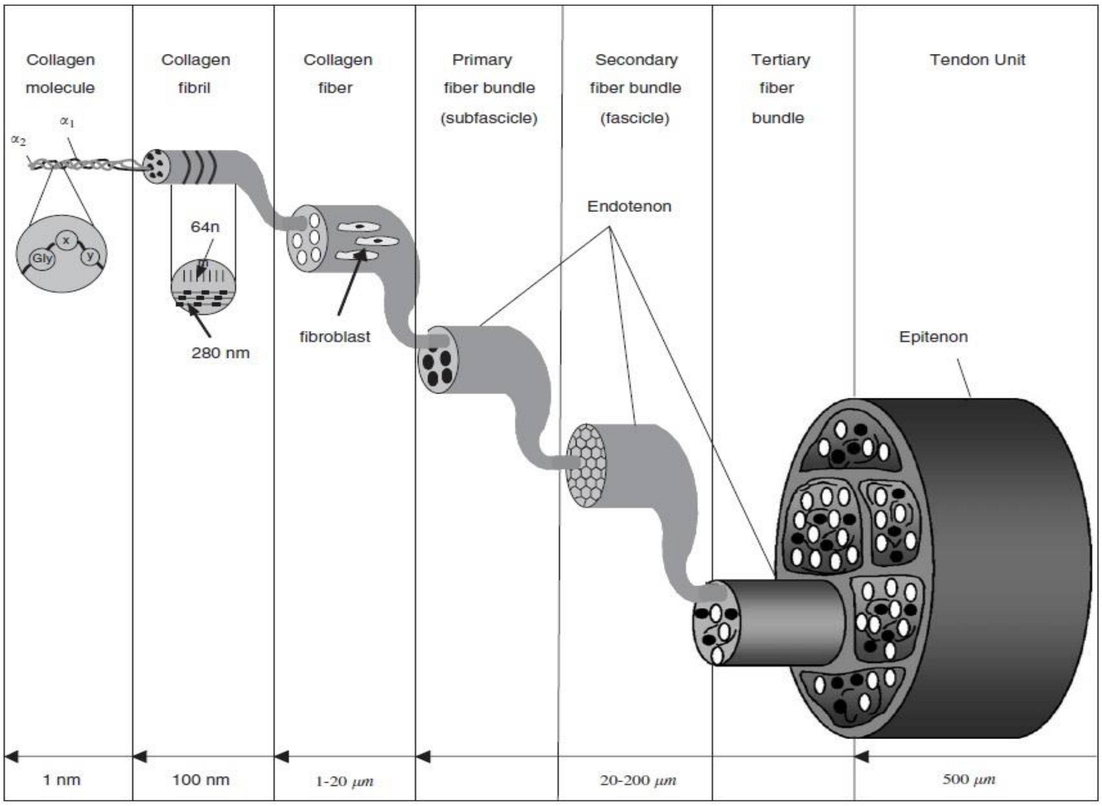

Figure 2: Graphic description of the hierarchic structure of the human tendon from collagen molecules to whole tendon structure (Wang, 2006)

1.2.2 Tendon material and mechanical properties

In contradiction to earlier believes, when it was believed that tendons were rigid structures, we now know that tendon tissue possesses viscoelastic properties. This means that the tendon is capable of being stretched, within certain limits, and still be able to return to its original length. Tendon tissues ability to return to its original length is limited due to its viscous properties. A viscous material is not able to return to its original shape after being stretched. An elastic material on the other hand is capable of doing so. This ability makes it possible for the tendon to store and release elastic energy during movement. Elastic properties fall under Hook's law. In a simplified way, this means that tendon stress and tendon strain are directly proportional, as long as the tendon don't permanently changes shape (Butler, Crowell, & Davies, 2003).Investigation of the tendon mechanical and material properties may be important in a performance perspective, and differences in these properties may contribute to the understanding of why some athletes performs on a higher level than others in different sports.

Over the past 20 years or so, a number studies both *in vivo and in vitro,* human and animal studies designed to investigate tendon mechanical and material properties, have been published. When investigating tendon properties, parameters such as tendon length, elongation, force, CSA, stress, strain, stiffness and Young's modulus are frequently reported.

Tendon length, elongation and CSA are parameters that are measured in cm, cm and cm^2, respectively and are typically recorded with the use of ultra sound *in vivo*. Theoretically, a longer and thinner tendon will have higher stiffness values than a shorter and thicker tendon, providing that the material properties are the same. If two tendons where identical in every way except for the CSA, and if one where to stretch these tendons to the exact same length, a greater amount of mechanical work would be required to stretch the thicker tendon. In general this means that a thicker tendon is capable of storing and releasing more elastic energy than a thinner tendon. The thicker tendon will also be subjected to less stress. Stress (Megapascal, MPa) is the force running through the tendon divided by the tendon CSA.

Stress = Force/CSA

Strain is the total elongation of the tendon (l_1) normalized to its initial length (l_0) Strain is always stated in percentage of initial length.

Strain=l_1/l_0

Stress and strain can be plotted in an X-Y plot to form a stress-strain curve. This curve reflects the tendon material properties and consists of four different regions: Toe region, linear region, microscopic failure region and macroscopic failure region. During regular movement, the tendon operates within the toe region and the linear region. At rest, tendon fibers are organized in a wave-like manner. When force is applied to the tendon, the wave-like fibers straightens out. This mechanism is illustrated by the toe region where a relatively small amount of force causes a relatively large amount of elongation (up to 2% of tendon total strain). The linear region is where the actual lengthening of the tendon fibers occurs. 2-4% of the tendon strain occurs in this region. When the strain values exceed 4% the stress-strain curve is crossing over into the microscopic failure region. At strain values of 8-10% macroscopic failures may occur. The result of strain values exceeding 8-10% may be total tendon rupture. The aforementioned values are results from testing on collagen fibers *in vitro* (Butler et. al 1978). However, when investigating tendon tissue in *vivo*, greater variations are revealed. The mean tendon strain of the PT have been reported to be 5-6% (Couppe, et al., 2008; Kongsgaard, et al., 2009; Kongsgaard, et al., 2010), 9-10% (Reeves, et al., 2003; Seynnes, et al., 2009) and even up to values as high as 14% in males (O'Brien, et al., 2010). The seemingly higher strain rates in human tendon tissue when measured *in vivo* compared to *in vitro was recently addressed by Svensson and co-workers (2012).* They reported a maximal strain rate in the PT of 6,1% and 3,6% when measured *in vivo* and *in vitro*, respectively.

Tendon stiffness depends on numerous factors, such as tendon length, CSA and material properties. Tendon stiffness is measured in the linear region of the force-elongation curve (figure 3) by dividing changes in force (ΔF) with changes in length (ΔL). Stiffness can be defined as an objects resistance to stretch.

Stiffness= $\Delta F / \Delta L$

Young's modulus is a formula used to describe the material properties of the tendon. This is done by normalizing tendon stiffness to the CSA and length of the tendon, thus it describes the relationship between the tendon stress and tendon strain. Young's modulus makes it possible to compare tendons with different length and CSA. A tendon with relatively compliant materials will score a low Young's modulus value (MPa) compared to a tendon composed of stiffer materials, which in turn, will score a higher Young's modulus value.

Young's modulus=Stress/Strain

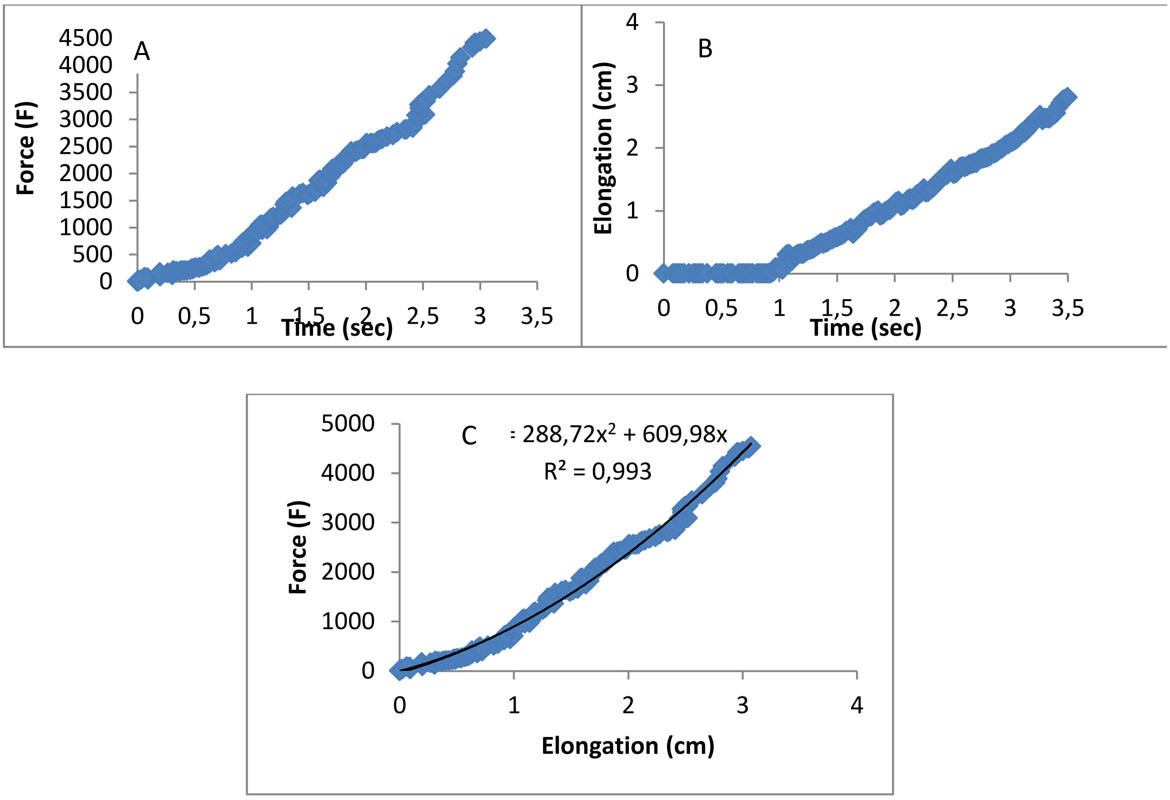

Figure 3: Force (A), Elongation (B) and Force- elongation curves (C) of a test subject with a peak tendon force of 4500N and tendon elongation of 30mm. A 2nd degree polynomial is fitted to the force-elongation curve.

1.2.3 Measuring tendon properties

To calculate tendon stress, strain, stiffness and Young's modulus, measurements of tendon length, elongation, CSA and the force running through the tendon during muscle contraction are necessary.

A number of different methods have been utilized to obtain the aforementioned variables. Historically, the most common method is *in vitro* measurements of tendon biopsies. The biopsies are suspended in stretching devices. Force is applied to the tendon tissue while the tendon elongation is being monitored. This type of measurements are usually conducted by measuring tendon fascicles with the help of stereoscopic microscopy (Haraldsson et al., 2005), or by measuring collagen fibrils with atomic force microscopy (Svensson, et al., 2012; Svensson, et al., 2010; Yang, et al., 2012). This method makes it possible to examine biopsies from different parts of the tendon. This has proven to be an advantage as the tendon properties may differ along the different parts of the tendon. When comparing to the posterior tendon fascilcles, greater stress and Young's modulus values has been reported in the anterior tendon fascicles of the human PT before total tendon rupture (Haraldsson, et al., 2005). Despite the possibility of accurate region specific measurements, one can assume that these types of measurements do not accurately reflect the stresses the tendon tissue is submitted to during human movement. In addition, tendon biopsies has to be treated and stored in numerous ways, this may influence the properties of the tendon biopsies. Based on the technical difficulties associated with *in vitro* measurements of tendon properties, this may be an inconvenient method to describe the properties of the human tendon *in vivo.*

In recent years, scientists have devoted their attention to finding methods that can measure tendon properties *in vivo*, both in the patellar and Achilles tendon. Typically, these measurements are conducted by the use of an isometric knee-extension or ankle plantar flexion apparatus (figure 4). Isometric knee-extension or plantar-flexion torque are measured and synchronized with real-time ultrasound recordings of tendon elongation(figure 5) (Arya & Kulig, 2010; Kongsgaard, et al., 2010; Kongsgaard, et al., 2007; Reeves, et al., 2003; Seynnes, et al., 2011; Svensson, et al., 2012).

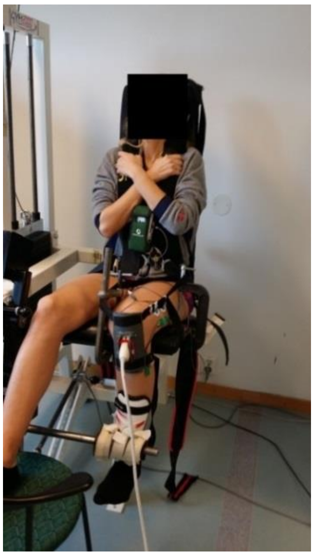

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Figure 4: Shows the setup during measurement of patella tendon elongation and torque in an isometric knee-extension apparatus. The ultrasound probe is firmly fitted to the knee for a full view of the patella tendon.

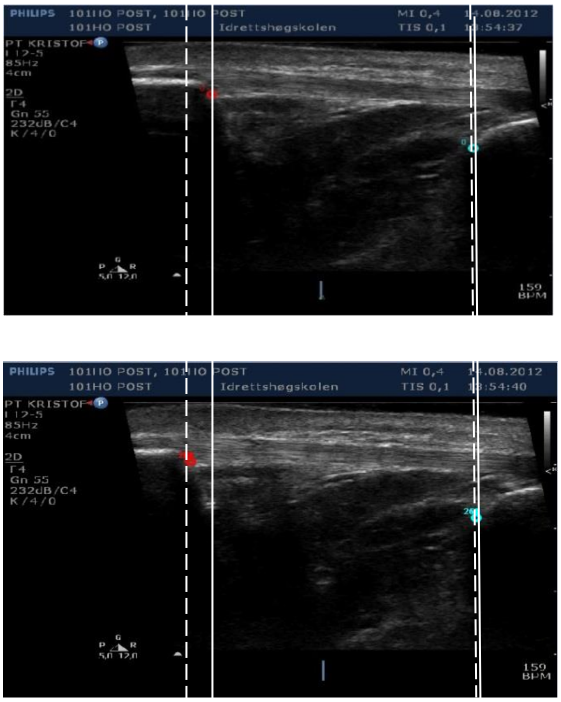

Figure 5: Ultrasound picture of the patella tendon at rest (A) and at maximal tendon force (5200N) during contraction (B) The position of the patella and tibia at rest and maximal tendon force are represented by the solid and dotted lines, respectively. Maximal tendon elongation=2,76mm

Although this has proven to be a reproducible method (Hansen, et al 2006), it has limitations. Due to the relatively small measurable PT elongation values (5-10mm), multiple recordings are desirable to secure a reliable result (Schulze, et al 2012). The strain rate at which the data are collected may complicate the comparing of results from different studies. It appears that tendon stiffness depends on the strain rate at which it is measured, and tendon stiffness increases with increasing strain rates (Pearson, et al 2007; Theis, et al 2012). Even though it seems that different strain rates affects tendon stiffness values, it is worth mentioning that Pearson and co-workers (2007) used a 3,8 cm ultrasound probe in their measurements. This may lead to problems with keeping track of the PT during the isometric contraction as the PT often measures up to and above 5 cm. As a result of this, it is possible that the actual tendon elongation was not recorded.

In summary, tendons are fibrous structures with viscoelastic properties that facilitate movement by transferring forces from muscle to bone. Tendon tissue also has the ability to store and release elastic energy during movement. In the pursuit of a better understanding of tendon material, mechanical and structural properties, scientists have devoted their attention to the development of different methods of measurement. Tendon stiffness, Young's modulus, stress, strain, CSA and length are typical outcome measurements, and can be measured both *in vitro* and *in vivo*. The *in vitro* measurements involves the analyzes of tendon tissue biopsies, while the *in vivo* methods involves the synchronization of real-time ultrasound recordings of the patella tendon and calculations of the force transmitted through the tendon during an isometric contraction.

1.3 Differences and adaptations in tendon properties

1.3.1 Differences between athletes

Muscle size, function and properties have been proven to vary between athletes specialized in different sports. With this in mind, it would be natural to assume similar differences in the tendon tissue between athletes in different sports. A possible reason for this might be that there is probably an optimal range of tendon properties suited for performance in different types of activity. It would be natural to assume that the muscle-tendon units of a long distance runner possess different properties than those of a power lifter. Even though numerous studies conducted in recent years has provided increased insight on how tendons adapt to different types of training, the field of knowledge remains unambiguous compared to how muscles adapts to similar stimuli.

In a study investigating athletes taking part in sports with demands of unilateral usage of the under extremities, a greater CSA and tendon stiffness was revealed in the PT of the leading leg when compared to the contra lateral leg. Three badminton players and four fencers with a side to side strength difference in isometric knee extension of

≥15%, was tested with the use of ultrasound. When compared to the non-leading leg, greater PT CSA was measured at both the proximal and distal part of the tendon of the leading leg. Mean PT stiffness was measured to be 6011 $N \cdot mm^{-1}$ and 4436 $N \cdot mm^{-1}$ for the leading and non-leading leg, respectively (Couppe, et al., 2008). These observations indicate that tendon properties changes over time as a result of long term specific training.

A greater CSA (relative to body mass) of the Achilles tendon has been reported in both volleyball players and runners, when comparing to kayakers and patients that has suffered from an Achilles tendon rupture (Kongsgaard, et al., 2005). It seems that the relative CSA of the Achilles tendon in athletes subjecting their Achilles tendons to repetitive loads, such as runners or more sporadic loads like volleyball players is greater than that of athletes which subject their Achilles tendons to smaller loads. This is another indication of changes in tendon properties as a result of long term training. However, this is cross sectional data and the effect of natural selection cannot be neglected.

Magnusson & Kjaer (2003) reported a significant difference in CSA along the Achilles tendon for both runners and non-runners. Furthermore, the CSA of the most distal part of the Achilles tendon was reported to be 36% greater in runners compared to non-runners. Rosager & co-workers (2002) also reported a significant greater CSA of the Achilles tendon in runners, when comparing to non-runners. Finally, greater CSA of the Achilles tendon has also been shown in elite long distance runners, when compared to controls (Kongsgaard, et al 2005). Achilles tendon stiffness was however only measured by Rosager & co-workers (2002), and no significant differences between the groups were reported. On the other hand, when investigating the influence of the muscle tendon units mechanical properties on running economy, Arampatzis & co-workers (2006) reported that the triceps surae muscle-tendon units of the most economical runners was stiffer and had higher contractile strength from 45-100% of peak torque, when compared to runners with moderate to low running economy. The same study concluded that the most economical long distance runners had more compliant quadriceps femoris tendons at low force levels (<45% of peak torque). This is backed by Kubo & co-workers (2010), which reported that the most economical runners and runners with the lowest personal best time in a 5000 meter race had more compliant

PT's. Arampatzis & co-workers (2006) suggested that a more compliant quadriceps tendon and aponeurosis would be able to store and release more elastic energy which would increase the force potential of the muscle during submaximal running and therefore decrease the volume of active muscle at a given force generation.

Similar observations have been made in male sprinters, where the tendon components of the vastus lateralis muscle where shown to be more compliant than that of untrained persons. However, there was no report of differences in the mechanical properties of the gastrocnemius tendon complex (Kubo, Kanehisa, Kawakami, & Fukunaga, 2000). Stafilidis & Arampatzis (2007) came to a similar conclusion when studying fast and slow sprinters. In addition to finding greater maximal elongation of the vastus lateralis tendon and aponeurosis in fast sprinters, maximal elongation of the vastus lateralis tendon and aponeurosis showed a significant negative correlation (r=0,567) with 100 meter sprint time. With these studies in mind, high values of stiffness in the plantar flexor muscle-tendon units and more compliant knee extensor muscle tendon units may be favorable for optimal sprint and long distance running performance.

In addition to differences between trained athletes and controls, O'Brien & co-workers (2010) reported higher values of PT stiffness in untrained male (28.2 ± 3.6 years) and female (27,4 ± 4,2 years) subjects compared to young boys (8,9 ± 0,7 years) and girls (9,3 ± 08 years). A significant increase in Young's modulus was also reported. These observations may suggest that changes in tendon mechanical and material properties also occur as a result of growth. It seems that these differences lapses after adulthood, as Couppè & co-workers (2009) did not observe any significant differences in dimensions or mechanical properties of the PT between Young (27 ± 2 years) and old (67 ± 3 years) men. However, they did observe a decrease in the collagen concentration of the PT in old men compared to young men. Similar results were reported in a study investigating the effects of aging on PT properties. They observed no differences in PT stiffness when comparing young men and women (27 years) with older men and women (65 years). They did, on the other hand, report a decrease in maximal tendon force, elongation, stress and strain in the older individuals (Carrol, et al 2008). This may indicate that the differences observed in tendon properties between younger and older adults, comes as a result of the accumulated loads the tendons are subjected to and not the age effect itself. The differences between children and adults on the other hand, may be associated with growth.

1.3.2 Changes in tendon properties after training

In light of the demonstrated differences in tendon mechanics between athletes in various kinds of sports, it would be natural to assume that tendons adapt in different ways to different types of training. However, it can be difficult to draw conclusions based on cross-sectional data, as it may be biased by natural selection or the training history of the subjects. The fact that cross-sectional data cannot tell us anything in terms of cause and effect is another limitation. In light of these limitations, numerous studies conducted in recent years, have investigated whether tendon adaptations occurs as a result of external stimuli.

1.3.2.1 Resistance Training

An increase in Achilles tendon-aponeurosis stiffness and a region specific increase in Achilles tendon CSA and was reported after high-strain plantar-flexion exercise, in a study investigating the adaptational responses of the Achilles tendon to high and low-strain exercise. The study concluded that the strain magnitude applied to the Achilles tendon should exceed a given threshold to trigger adaptations in Achilles tendon mechanical and morphological properties (Arampatzis, et al., 2007).

After performing a progressive isotonic resistance training program three times per week for 14 weeks, an increase in PT stiffness and Young’s modulus was reported in elderly individuals, when comparing to a control group. PT CSA was measured at 25%, 50% and 75% of tendon length, but no significant changes were reported (Reeves, et al 2003). Kubo & co-workers (2006) reported an increase in stiffness in the vastus lateralis tendon and aponeurosis after heavy resistance training (80% of 1RM). On the other hand, no changes in stiffness was reported as a result of low-load resistance training with vascular occlusion, spite an increase in both muscle force and muscle CSA as a result of high metabolic stress. No changes in PT CSA were reported in this study. These findings indicate that a sufficient amount of mechanical stress is necessary to change the tendon mechanics. Studies that have investigated changes in PT CSA as a result of resistance training, reports that the majority of changes is located at the most distal and proximal part of the tendon (Kongsgaard, et al 2007). This means that there is a possibility that the measurements from earlier studies (Kubo, et al., 2006; Reeves, et al., 2003) are not optimal. As the majority of changes in tendon CSA may occur between 0%-25% and 75%-100% of tendon length, and not at 25% and 75% of tendon length. It should also be pointed out that two different methods were used during data collection in the aforementioned studies. Kongsgaard & co-workers (2007) measured tendon elongation by tracking the displacement of the patella and tibia plateau, while Reeves & co-workers (2003) and Kubo & co-workers (2006) collected their data by tracking the patella and an external marker taped to the skin above the patella tendon. This may be the reason why Reeves and co-workers (2003) reported far greater maximal tendon strain (~10%) and increase in tendon stiffness (65%) than Kongsgaard & co-workers (2007) (~6% and ~13% increase, respectively). Measurements conducted with only the patella visible in the ultrasound video, may be less reliable as there is a possibility that the skin and thereby the marker attached to the skin will shift during the elongation of the tendon. This might be part of the reason why Reeves & co-workers (2003) reported such major changes in tendon stiffness.

Kongsgaard & co-workers (2007) wanted to investigate if there were any variations in CSA along the length of the PT. They also wanted to address possible region specific changes in PT CSA as a result of resistance training. Twelve subjects trained 3 times per week for 12 weeks in a leg extension machine. The subjects trained both legs; one leg was assigned to do heavy resistance training (heavy-leg) and the other was assigned to do light resistance training (light-leg). The heavy-leg was trained by doing 10 sets of 8 repetitions with loads corresponding to 70% of 1 RM, with 3 minutes of rest between sets. The light-leg was trained by doing 10 sets of 36 repetitions with loads corresponding to the amount of work performed with the heavy leg, with 30 seconds break between sets. After 12 weeks of resistance training, a significant increase in CSA was measured at the proximal and distal parts of the patella tendon of the heavy-leg, when compared to the light-leg. An increase in PT stiffness was also reported in the heavy-leg, but no changes were measured in the light-leg. In addition, a variation in the PT CSA was reported along the length of the tendon, with the smallest CSA being at the proximal part and increasing towards the distal part, where the CSA was biggest.

Increased PT CSA has also been reported after 9 weeks of resistance training. The subjects trained three times per week, where they performed 4 sets of 10 repetitions at 80% of 1 RM of unilateral leg extension training. After the resistance training intervention, increases in PT CSA, stiffness and Young's modulus were reported, which in turn was proven to be well correlated with the physiological CSA of the quadriceps muscle, but not with maximal force. These results indicate that changes in PT structural and mechanical properties are related to muscle hypertrophy but not to strength gains (Seynnes, et al., 2009). It seems that these studies (Kongsgaard, et al., 2007; Seynnes, et al., 2009) are two of few studies that have reported an increase in PT CSA after resistance training. Unlike the studies that reported no changes in PT CSA (Kubo, et al., 2006; Reeves, et al., 2003), both of these studies used magnetic resonance imageing (MRI) to assess the PT CSA. When using ultrasound to measure PT CSA it is crucial that the ultrasound probe is held perpendicular to the tendon, small deviations may lead to overestimation of the tendon CSA. This is part of the reason why MRI is believed to be a more reliable measurement method, when measuring tendon CSA. A downside of the use of MRI is that it is a very costly method compared to the use of ultrasound.

1.3.2.2 Running

Even though, the presence of Achilles tendons with bigger CSA has been reported in long distance runners, when compared to controls (Kongsgaard, et al., 2005; Magnusson & Kjaer., 2003; Rosager, et al., 2002), and that more economical runners have been reported to have stiffer triceps surae muscle-tendon units than less economical runners (Arampatzis, et al., 2006), the direct influence of habitual running on tendon properties are inconclusive and almost exclusively based on animal models. It has been shown that 40 weeks of running regimen did not affect the load-deformation curve of the Achilles tendon in rabbits (Viidik., 1969). Similarly, Woo, Gomez, Woo & Akeson (1982) showed that 12 months of running did not affect the load-deformation or stress-strain properties of the load-bearing, high-stress flexor tendons in swine. In terms with the findings from animal models, Hansen & co-workers (2003) did not find any significant changes in the mechanical properties of the triceps surae tendon and aponeurosis, or in Achilles tendon CSA, after subjecting 11 untrained subjects to 9 months of endurance training (~43 hoursover 34 weeks.) They did however report an 8,6% increase in VO_{2max}. It may be that the training stimulus, in terms of intensity and duration, was inadequate to produce a measureable change in Achilles tendon CSA. Interestingly, a recent study investigating the effects of concomitant resistance and endurance training on running economy, showed a ~16% increase in Triceps surae tendon and aponeurosis stiffness, combined with a ~7% increase in plantar flexion muscle strength, when resistance training was added to the subjects regular endurance training regimen over 14 weeks. No changes were reported in the control group, which continued their regular endurance training regimen (Albracht & Arampatzis 2013).

In summary, recent research has shown that tendon tissue are highly adaptable and may change their structural, material and mechanical properties as a result of long and relatively short term training. Although it seems that changes in tendon stiffness and Young's modulus appears after a shorter period of training (8-12 weeks) than changes in tendon CSA (>1 year). In addition, tendon CSA seems to be affect at a greater extent by heavy resistance training, rather than running. Adaptations in tendon tissue seem to be relatively slow, and this may explain why some studies report different results than others. Sex and gender seems to be factors affecting tendon properties. Tendon properties also vary between different types of sports, and it seems to be an optimal range of tendon stiffness for solving different tasks.

1.4 Running economy and factors affecting it

The literature defines running economy as the rate of oxygen consumption per unit body mass when running at a constant pace (Daniels, et al., 1978). Daniels & Daniels (1992) demonstrated significant differences in the rate of oxygen consumption between runners while running at the same velocity. This means that an increase in running economy may have significant impacts on long distance running performance. Many studies have tried to describe the complexity of running economy by the use of kinematic parameters (Williams & Cavanagh, 1987; Martin & Morgan, 1992; & Kyrölainen, et al., 2001), but this has proven to be difficult. (Martin & Morgan (1992) suggested that variables describing muscle force production (i.e. force-length-velocity relationship and activation) are suitable for explaining running economy. Mechanically speaking, there are two main factors that may affect the force-length-velocity relationship and the muscle activation while running. The mechanical advantages of the muscles (ratio of an agonist muscle group moment arm to that of the ground reaction force acting about a joint) may affect the force production in relation to the active muscle-volume. The second factor that can influence the force-length-velocity relationship is the viscoelastic properties of the tendon and aponeurosis. A more compliant tendon and aponeurosis will allow the muscle fibers to contract at lower shortening velocities than the whole muscle-tendon unit. As a result, their force-generating potential will be higher, due to the force-velocity relationship. Due to the viscoelastic properties of tendon tissue, it is able to store strain energy when the muscle-tendon unit is elongated. This energy is independent of metabolic processes and may cause an enhancement of the mechanical energy produced by the whole muscle-tendon unit (Arampatzis, et al., 2006).

2.Methods

2.1 Recruitment

All the participants in this study, was recruited via the ongoing PhD study of Olav Vikmoen, which looks at the influence of heavy strength training as a supplement to endurance training (Running, cycling & cross country skiing). 25 female recreational endurance athletes were recruited for this study.

2.2 Inclusion

Inclusion criteria were that the participants had to do endurance training minimum 3 times/week and had to have done so for at least the past 12 months. Also, the participants could not have participated in any form of organized strength training for the past 6 months. The 25 participants were randomly assigned into two groups: One which continued with their regular endurance training (END) and one group which trained heavy resistance training on the lower extremities two times pr. week in addition to maintaining their regular endurance training regimen (END+RT). Of the 25 participants we started with, 5 had to withdraw from the project due to different reasons, one due to pregnancy, one due to back pains associated with strength training, one due to tibiaperiostitt and two due to problems with the project taking up too much time. In addition, 3 more had to be excluded due to problems with the measurements and illness during the intervention period. After the removal of the withdrawn and excluded participants, the groups are as following: END (N=8) and END+RT (N=9).

2.3 Ethics

All the participants handed in written consents which stated that they were free to withdraw from the study without a reason, together with information about possible discomforts that they could experience. The project plan (from the original project) was handed in to the regional ethics committee, but was found to fall outside of their remit, meaning that the project could be conducted without their official consent. The study was performed in accordance with the Helsinki declaration.

2.4 Intervention

The participants in this study underwent the same intervention which was used in Rønnestad et. al (2011), were male cyclists were tested. The intervention consists of a 12 week heavy resistance training program for the under extremities. The subjects trained two times/week and the loads were gradually increased over time. The training program consisted of four different exercises: Squat to 90° in the knee joint in a smith rack, one-legged leg press to 90° in the knee joint in an almost supine position, Hip flexion in the cable cross apparatus and plantar flexion on a box in the smith rack. The training program had an inter week variation, in terms of volume and intensity. The program was also divided in to three different periods, where the intensity was increased in each new period. The 1st period lasted for three weeks and consisted of one session of 10 RM x 3 sets and one session of 8 RM x 3 sets per week. The 2nd three week period consisted of one session of 8 RM x 3 sets and one session of 5 RM x 3 sets per week. The last period lasted for six weeks and the participants underwent one session of 6 RM x 3 sets and one session of 4 RM x 3 sets per week (Table 1). The subjects performed at least one session per week under supervision of one of the researchers. The researcher was there to guide and give feedback as well as record the subjects training. When the researcher was not there the subjects were responsible for recording their own training in handed training logs. They were also encouraged to do the training in pairs when the researcher was absent.

Table 1: Shows the progression of the twelve week training program, where the loads are displayed as sets x repetition maximum (RM)

Week	**Session 1**	**Session 2**
1	**3 x 10 RM**	**3 x 6 RM**
2	**3 x 10 RM**	**3 x 6 RM**
3	**3 x 10 RM**	**3 x 6 RM**
4	**3 x 8 RM**	**3 x 5 RM**
5	**3 x 8 RM**	**3 x 5 RM**
6	**3 x 8 RM**	**3 x 5 RM**
7	**3 x 6 RM**	**3 x 4 RM**
8	**3 x 6 RM**	**3 x 4 RM**
9	**3 x 6 RM**	**3 x 4 RM**
10	**3 x 6 RM**	**3 x 4 RM**
11	**3 x 6 RM**	**3 x 4 RM**
12	**3 x 6 RM**	**3 x 4 RM**

2.5 Equipment

Ultrasound: Dynamic videos of the patella tendon elongation during a ramp contraction (Isometric knee extension with gradually increasing force) were gathered by using an M-mode ultrasound apparatus (HD11XE, Phillips, Bothell, WA, USA). The ultrasound apparatus utilized a broad banded transducer (L12-5) with a length of 50mm and a 12 – 5 MHz expanded frequency range. The videos were recorded with a 40mm depth and a frequency of 52 fps and stored on the ultrasound apparatus' hard drive. The stored ultrasound videos were later converted to AVI files and exported to a portable storage device trough the machines built in USB port. The ultrasound was also used for recording patella tendon length, cross sectional area (CSA) as well as femur length, Vastus lateralis CSA, muscle fiber length and penation angle.

Force recording: To measure isometric knee extension force during a ramp contraction and a fast contraction, an isometric knee extension apparatus were used (Knee extension, Gym 2000, Geithus, Norway). While sitting in the apparatus, the subjects had a fixed hip and knee angle of 90°. The force exerted on the apparatus was measured with a force cell (U2A, Hottinger Baldwin Messtechnik GmbH, Darmstadt, Germany). The force data were recorded on a sampling frequency of 1500 Hz.

Electromyography (EMG): EMG data from biceps femoris were collected by a wireless transmitter (TeleMyo 2400 G2 Telemetry System, Noraxon Inc., Scottsdale, AZ, USA), trough surface electrodes mounted to the subjects skin (Ambu, Blue Sensor M, Ballerup, Denmark). The isometric force data and the EMG data were synchronized by a wireless receiver (Mini-Receiver for TeleMyo G2, Noraxon Inc, Scottsdale, AZ, USA). The force data were transferred to the receiver by an analog connection, while the EMG data had a wireless connection from the transmitter to the receiver. Isometric force data and EMG data were manually synchronized with the dynamic ultrasound videos by a specially designed trigger mechanism (Bojsen-Möller, Hansen, Aagaard, Kjaer & Magnusson, 2003). The trigger mechanism left a visible mark on the ultrasound video, isometric force data and the EMG data which allowed us to synchronize the data manually.

EMG and isometric force data were stored in a Noraxon software (MyoReasearch XP Master Edition Version 1.08.17, Noraxon Inc, Scottsdale, AZ, USA) on a computer.

Isometric and isokinetic force: Isometric peak torque at 60° and 90° in the knee joint and isokinetic force at two different angular velocities (60, and 240°/sec) were measured with a dynamometer (REV9000, Technogym, Gambettola, Italy).

2.6 Procedure

All the subjects conducted familiarization testing in all the relevant exercises minimum 24h before test start. On the test day, the data were collected in the same order.

Vastus lateralis and anthropometric measurements: Femur lengths were measured by ultrasound. A steel wire which was visible on the ultrasound image was attached to the ultrasound probe. This allowed us to use a pen to mark the greater trochanter and the lateral epicondyle of the knee on the skin. The distance between the two points were measured and used as the femur length. These measurements were conducted with the subjects in a supine position.

With the subjects still in a supine position, the measurements of vastus lateralis CSA, fiber length and penation angle were performed. The ultrasound images were captured at 50% of femur length and there was captured three acceptable images in the sagittal plane.(figure 6) The location of the images was marked on the skin and transferred to a transparent sheet together with anatomical landmarks such as the patella, scars and moles. The sheet was used as a template during the post test, and allowed us to do the scans in the same location in both tests.

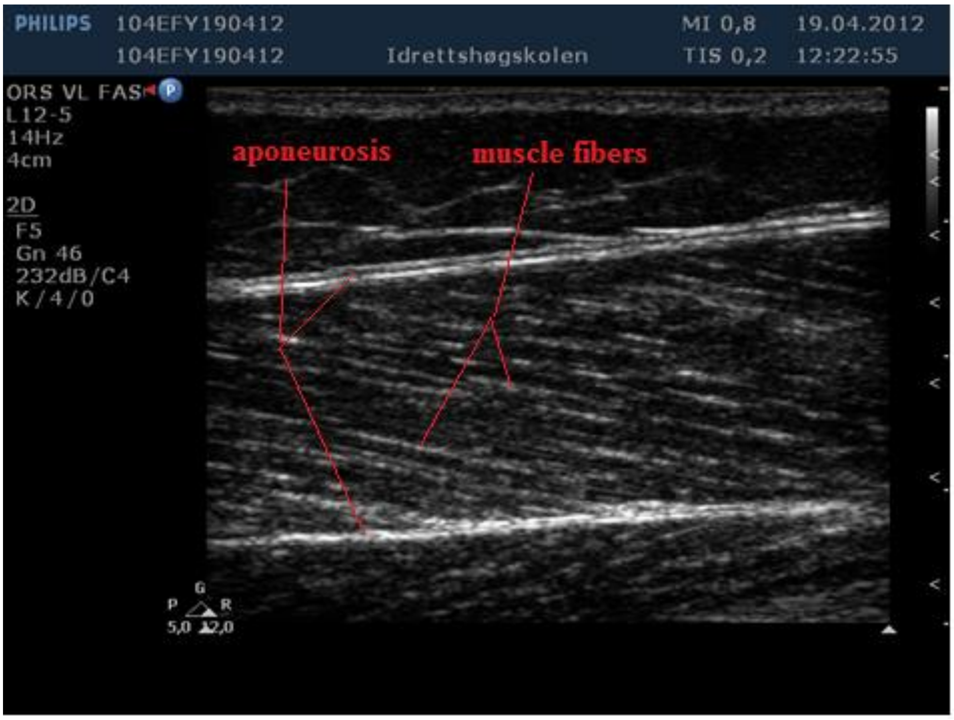

Figure 6: US Picture of the vastus lateralis muscle in the sagittal plane with its aponeurosis and muscle fibers.

Tendon anthropometry: Before the subjects were seated in the isometric knee extension apparatus, EMG electrodes were attached to the biceps femoris muscle on the left thigh. All the tests were conducted on the left leg. Before the electrodes were attached, the skin was prepared by sanding with very fine sanding paper and scrubbed with alcohol to reduce impedance in the skin. The electrodes were attached to the belly of biceps femoris with a distance of 2 cm and a reference electrode were attached to a bony area on the knee. After the electrodes were attached, the subjects conducted a 5 minute warm up on a stationary bike (Ergomedic 828 E, Monark, Varburg, Sweden).

Followed by the warm up, the subjects were seated in the knee extension apparatus. Measurements of the PT CSA were conducted with the subjects seated in the apparatus with a 90° angle in the hip and knee joint. Three video clips of the tendon was captured, one proximally, one medially and one distally on the PT. All the videos were captured in the transversal plane. Furthermore, the PT length was measured by using the same “wire technique” that was used to determine the femur length. The patella apex and the osteotendinous junction on tibia were marked on the skin, and the distance between these points was measured with a tape measure and referred to as the PT length. The medial CSA measurement was conducted at 50% of PT length

Tendon force & elongation: Followed by the warm up and tendon anthropometry measurements, the subjects were secured to the knee extension apparatus with a 4-point seat belt, and the distal part of the left leg shank was fixed to the apparatus’ lever arm, by using a specially designed leg cuff. When the subjects were secured safely to the apparatus, the ultrasound probe was attached to their left knee with a specially designed holding device (see figure 4 for more details about the setup). The probe was secured to the knee in a way that allowed us to see the entire PT, and at the same time prevent the probe from shifting during the contractions. With the ultrasound probe in place the subjects conducted ramp contractions were they were instructed to gradually produce force and trace a drawn line on a monitor that corresponded to 100 Newton per second. They were also instructed to do fast contractions were they produced the force in their own rate. This was done in an attempt to investigate possible differences in tendon behavior and mechanical properties at different rates of force development. The testing continued until three approved measurements of each type of contraction was available. The order of which the ramp contractions and fast contractions were measured was randomized. Three seconds prior to the testing, three submaximal familiarization contractions were conducted. This was done to reduce the influence of the tendons wavelike resting structure (Seynnes, et al. 2009). Shortly after the knee extension trails, peak torque in an isometric knee flexion were measured. The force and EMG data from this measurement was used to correct for hamstring co-activation during the data analysis (Bojsen-Möller, et al. 2003).

Isometric and isokinetic knee extension: peak torque in isometric and isokinetic knee extension was measured on a separate day. The measurements were conducted with the subjects strapped in the machine, by a 4-point seat belt in, a seated position with a 90º hip joint angle and the right leg strapped to a lever arm just above the ankle joint. The measurements were initiated by three recordings of isometric knee extension force at 90º knee joint angle, with 1 minute rest in between contractions. After 2 minutes of rest, the same procedure was repeated with 60º knee joint angle. Another 2 minute break preceded the isokinetic tests, where three consecutive contractions at an angular velocity of 60°/sec was performed two times, with a 1 minute break in between each set of three contractions. Finally, the same procedure was conducted at an angular velocity of 240°/sec.

VO_{2max} test: All the tests involving running was conducted on three separate days with a minumum of two days in between each test day. Lactate profile and VO_{2max} the first day, 40 minute running test the 2nd day and 90 minute submaximal running and 5 minute all out test the 3rd day.

After performing the lactate profile test, which is not a part of this thesis, and a 15 minute cool down, VO_{2max} was measured with the subjects running on a treadmill (PPS 55 Sport, Woodway Inc, USA) at gradually increasing speeds. All the subjects started the test at 8 km/h and the speed was increased by 1 km/h every minute, until exhaustion. The treadmill inclination was set to 5,3%. The oxygen consumption was continuously recorded by indirect spirometry (OxyconPro, Erich Jaeger, Hoechberg, Germany) during the test. The oxygen consumption at 9 km/h was later used to calculate running economy.

40 minutes running test: The 40 minute running test was performed on a treadmill (PPS 55 Sport, Woodway Inc, USA) with an inclination of 5,3% The subjects started with a pace equivalent to lactate values of 2,5 mmol/l. VO_2 measurements was taken by indirect spirometry (OxyconPro, Erich Jaeger, Hoechberg, Germany) every last minute of every 5 minute interval. The subjects were blinded to every parameter of the treadmill except speed. After the first 5 minute interval, the subjects were allowed to adjust the speed at will and were instructed to run as far as possible in 40 minutes.

5 minutes all out test: After 90 minutes of submaximal running on a treadmill (PPS 55 Sport, Woodway Inc, USA) with 5,3% inclination at 60% of mean speed during the last two minutes of the VO_{2max} test, the subjects performed a 5 minute all out test with the treadmill in the same inclined position. The researchers controlled the speed and provided oral encouragement while the subjects ran as far as possible during a 5 minute interval.

2.7 Data analyses

Vastus lateralis CSA, penation angle & fiber length, was analyzed by using a picture analyzing computer program (ImageJ 1.45s, National Institute of Health, Austin, TE,USA).The anatomical CSA was measured by drawing three lines across the belly of the muscle. One line at 50%, one at 30% and one at 70% of the image size. The mean length of these three lines was used to calculate the CSA.

The penation angle was measured by manually drawing up the angle between the aponeurosis and the fiber by using an angle tool.

The fiber length was measured by manually tracing a fiber across the muscle. In most cases the fiber was longer than the image size, which was 5 cm, and the end of the fiber had to be projected from the visible part of the fiber.

All of the above measurements were possible because the depth of the US image was known. This was used to calibrate the correct relationship between pixels in the picture and actual length. CSA, penation angle and fiber length was measured on three pictures for every subject. To increase the reliability of the measurements, the results were reported as the combined mean values of all the pictures.

Tendon CSA: The tendon CSA was also analyzed in ImageJ. A still image from the video with the most visible tendon edges was chosen to be analyzed. The edges of the PT was manually traced and marked by using an area tool. As the depth of the image was known, the program was able to calculate the area inside the edges. This was referred to as the tendon CSA. The same procedure was conducted on the proximal part, the medial part and the distal part.

Tendon elongation: Tendon elongation was analyzed from dynamic ultrasound videos stored as AVI files in the ultrasound apparatus. The video files were exported from the ultrasound apparatus and stored on a computer were they were analyzed by using a video analyzing computer program (Tracker Video Analysis and Modeling Tool, Open Source Physics, Douglas Brown, 2012). The patella apex and the tibia plateau were marked inside a coordinate system. The computer program automatically tracks the coordinates of the two points during the contraction (Hansen et. Al. 2006). Because the depth of the image was known, this could be used as a reference to the displacement of the two points. The actual elongation of the tendon was calculated by subtracting the tibia plateau coordinates from the patella apex coordinates

Tendon Force: Tendon force was calculated from the force measured in the force cell corrected for hamstring co-activation, internal and external moment arm in the knee joint. Both the force data and EMG data was stored in the Noraxon program. All the EMG signals were smoothed by calculating the root mean square over a 50 msec time frame. To correct for hamstring co-activation, a linear relationship between EMG amplitude and force was assumed. We assumed that the EMG amplitude in the knee flexion peak torque and the force corresponding to that value equaled 100%. The percentage of EMG amplitude during the ramp and fast contractions was calculated and the force corresponding to that percentage was later added to the force curves of the ramp and fast contractions. The internal moment arm was calculated from the femur length (Visser, Hoogkamer, Bobbert, & Huijing, 1990). The external moment arm was measured from the center of the knee joint to the lever arm on the knee extension apparatus.

The tendon force was calculated by adding the above factors to the following formula:

$F_1=((F_q+F_h)M_e))/M_i$

Where F_q is force measured by the force cell, F_h is estimated hamstrings co-activation force, M_i and M_e corresponds to internal and external moment arm respectively.

Tendon material and mechanical properties: Before the tendon elongation data could be plotted against the tendon force data, the data had to be synchronized by down sampling the tendon force data, which was sampled at 1500Hz, to fit the tendon elongation data, which was sampled at 50Hz. To implement this in the data set we used an Excel add-on (Microsoft Office Excel 2010 Inc., Microsoft) which simply removed every 30th sample from the tendon force data. After the down sampling proses, both the tendon elongation data and tendon force data had a sample rate of 50Hz. With the two data sets synchronized, we plotted them against each other in a 2nd degree polynomial. To increase the validity of the measurements, mean values from all the recordings with useable data was used to plot the force – elongation curve, which both absolute and relative stiffness was calculated from. All the recordings used in the results had a fit of R^2= 0,92 or better. Absolute stiffness was calculated in the top 10 percent of the force – elongation curve for each subject. The highest common force level's (4000N) top 10 percent (3600N – 4000N), was used to calculate the relative stiffness in all the subjects except three: Subject 112's tendon force was set to 3500N and subject 104 and 17's tendon force was set to 3000N. This had to be done due to problems with the tracking of the tibia plateau and patella apex in the higher force levels of these subjects. By using the absolute and relative stiffness data, both absolute and relative Young's modulus was calculated. This was done by multiplying the stiffness values with the ratio between the PT resting length (l_0) and the mean CSA of the PT (mCSA).

Young's modulus = Stiffness(l_0/mCSA).

PT l_o and maximal length (l_1) was used to calculate the PT strain.

Strain = $((l_1-l_0)100)/l_0$

2.8 Statistics

The interactions between the control group and the intervention group was analyzed by the use of a 2 way ANOVA test , where p < 0,05 was considered to be significant. Within group changes was analyzed with a paired ttest, p< 0,05 was considered to be significant. The results are presented as mean ± standard deviations. The statistical analyzes was solved in Excel (Microsoft Office Excel 2010 Inc, Microsoft) and Graphpad prism (Graphpad prism. 6,04, GraphPad Software, San Diego, CA, USA).

3. Results

Mechanical and material properties: No significant changes in absolute stiffness, strain or Young's modulus where found between the END group and RT+END group. Scatter plots of all the individual stiffness, strain and Young's modulus values are displayed in figure 7.

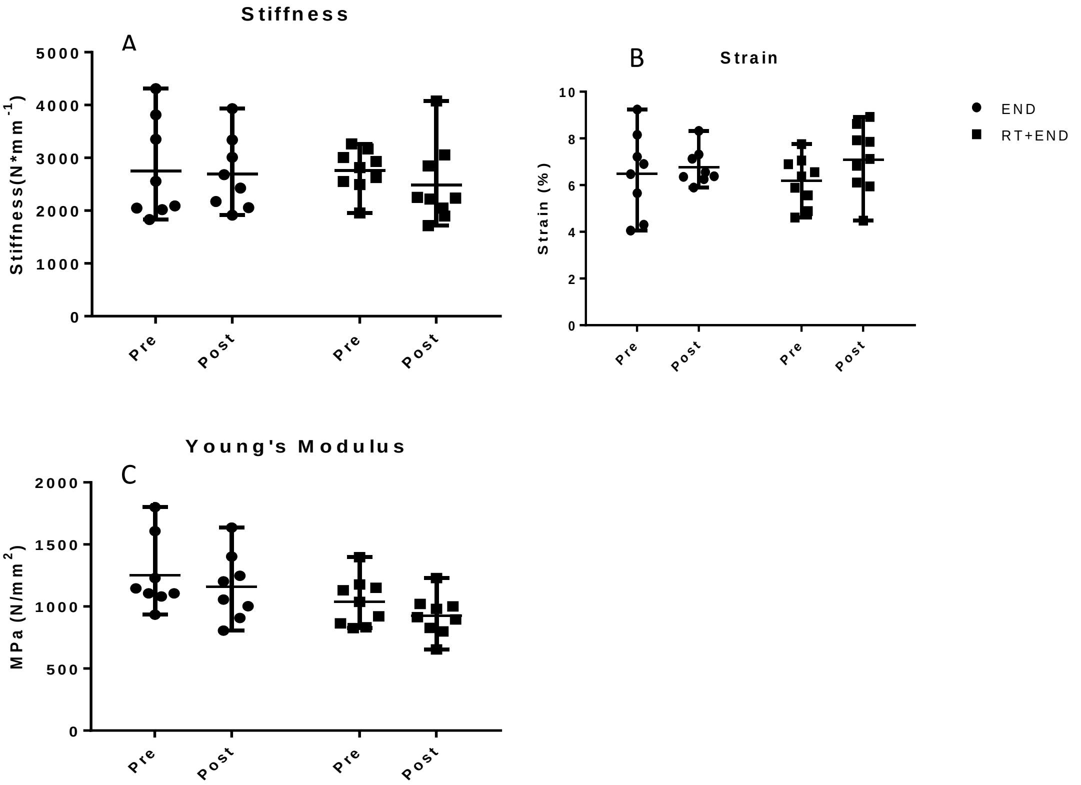

Figure 7: Stiffness (A), strain (B) and Young's modulus (C) values for the RT+END group (n=9) and END group (n=8). The vertical lines represent the group range and the group mean are marked by the horizontal lines.

When calculating relative stiffness, strain and Young's modulus, two subjects had to be discarded due to low force levels, compared to the rest of the subjects. The analysis of the rest of remaining subjects revealed no significant interactions between the groups.

A significant interaction between the groups was observed in mean tendon CSA (P=0,0088) (figure 8).However, when looking at the three different sites of measurement (proximal, middle and distal), the middle part of the PT was the only site where a significant interaction between the groups was observed (P=0,028). Changes in PT stiffness, strain, modulus, and tendon CSA for both the groups are displayed in table 2.

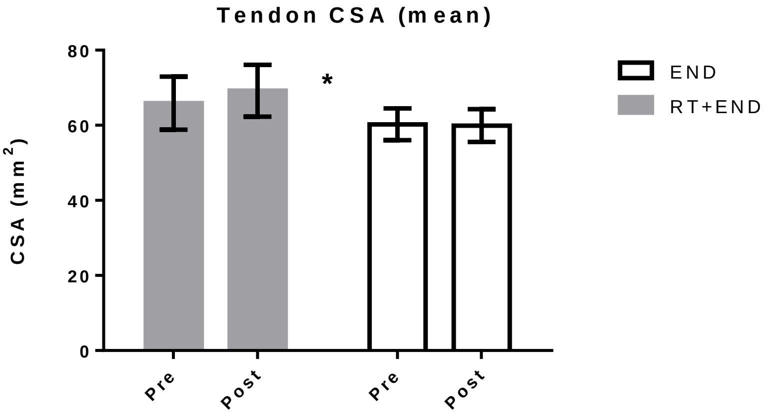

Figure 8: Mean tendon cross-sectional area for the RT+END group (n=9) and the END group (n=8). Values are displayed as Mean±SD *: Significant interaction between groups.

Table 2: Changes in material and mechanical properties of the patella tendon. Values are displayed as changes from baseline ±SD (% change from baseline)

	RT+END (n=9)	END (n=8)	P-value
Stiffness (N*mm^{-1})	-275 ± 702 (-11%)	-60,5 ± 714,1 (-2,2%)	0,542
Strain (%)	0,92 ± 0,95 (12,9%)	0,28 ± 1,9 (4%)	0,382
Young’s modulus (Mpa)	-113 ± 235 (12,2%)	-93,6 ± 292,5 (-8%)	0,880
Tendon CSA proximal (mm^{2})	3,3 ± 4,4 (5%)	1,9 ± 2,9 (3,3%)	0,474
Tendon CSA middle (mm^{2})	4,3 ± 4,7 (5,6%)	-2,7 ± 7,1 (-4,2%)	0,028
Tendon CSA distal (mm^{2})	2,4 ± 4,5 (3,6%)	-0,2 ± 5,5 (-0,4%)	0,299
Tendon CSA mean (mm^{2})	3,3 ± 2,3 (4,8%)	-0,3 ± 2,7 (-0,6%)	0,008

Strength tests: There was no significant interaction between the groups regarding peak torque in one legged knee extension, at 90º knee angle. There was however, a significant increase in 1 repetition maximum (1RM) in the squat to 90º knee joint angle (P=<0,0001). Bar graphs of the results from the knee extension, and squat tests are displayed in figure 9. Changes from baseline in both knee extension peak torque and squat 1 RM for the RT+END and END group are shown in table 3.

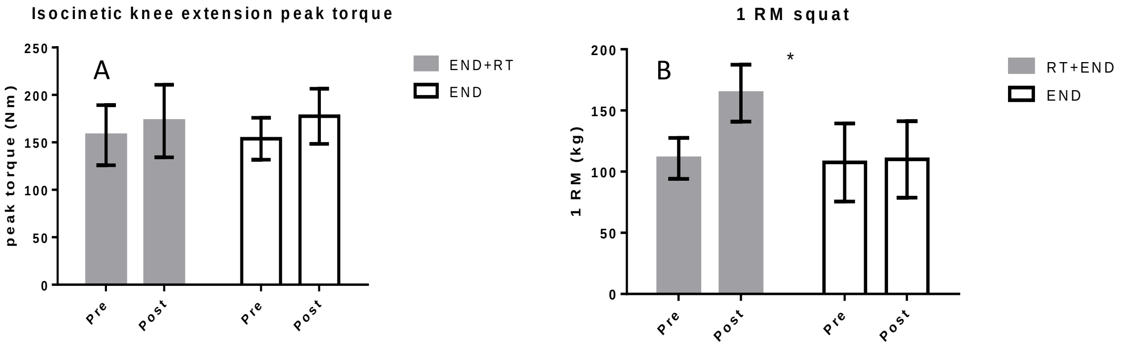

Figure 9: Pre and post measurements of knee extension peak torque at 90º of knee flexion (A) and 1 repetition maximum in squat to 90º knee angle (B), for both RT+END (n=9) and END (n=8). Values are displayed as Mean±SD *: Significant interaction between groups.

Table 3: Changes in knee extension peak torque and 1 RM squat. Values are displayed as changes from baseline ±SD (% change from baseline).

	RT+END (n=9)	END (n=8)	P-value
knee extension peak torque (Nm)	17,2 ± 13,7 (11,2%)	23,7 ± 16,6 (15,4)	0,255
1 RM squat (Kg)	48,2 ± 21,8 (45%)	2,5 ± 10,7 (3%)	0,0001

As seen in figure 10, the ultra sound scans of the Vastus lateralis (VL) muscle revealed no significant changes in the muscle thickness.

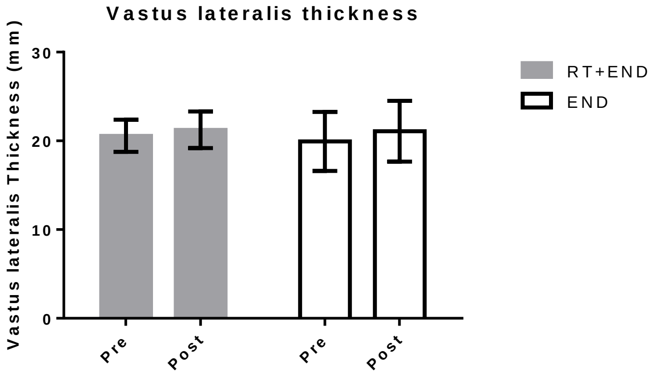

Figure 10: Shows the vastus lateralis muscle thickness at pre and post tests for END+RT (n=9) and END (n=8) group. Values are displayed as Mean±SD

Running tests: The running tests revealed no significant changes in VO_{2max} or running economy. Distance traveled in the 40 minutes running test and in the 5 min all out test after 90 minutes submaximal running also remained unchanged (figure 11).

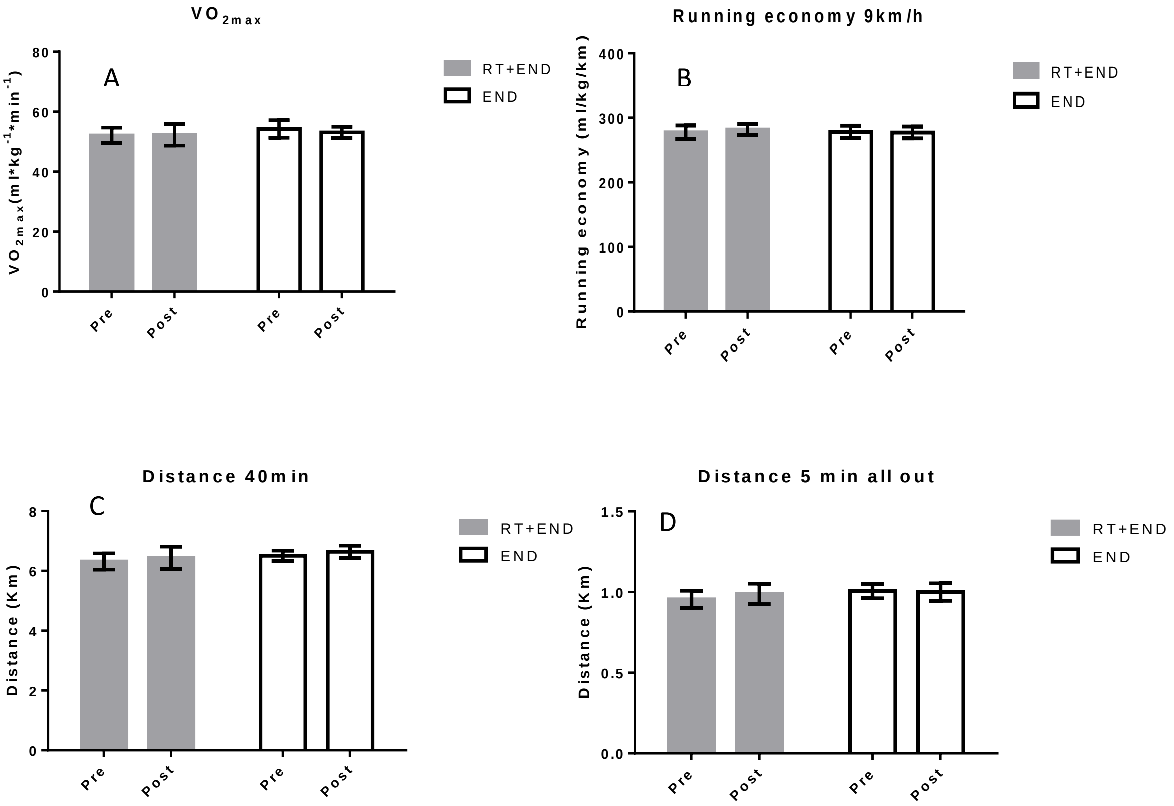

Figure 11: Shows pre and post measurements of VO_{2max} (A), running economy (B), distance traveled in the 40 minutes test (C) and distance traveled in the 5 minutes all out test (D) for END+RT (n=9) and END group (n=8). Values are displayed as Mean±SD.

Correlations: A significant negative correlation between changes in distance traveled in the 40 minutes running test and PT stiffness was found in the RT+END group (P=0,017). Furthermore, a significant positive correlation between changes in distance traveled in the 5 min all out test and changes in force developed in isometric knee extension at 90° of knee joint angle (P=0,04), was also revealed in the END+RT group (figure 12).

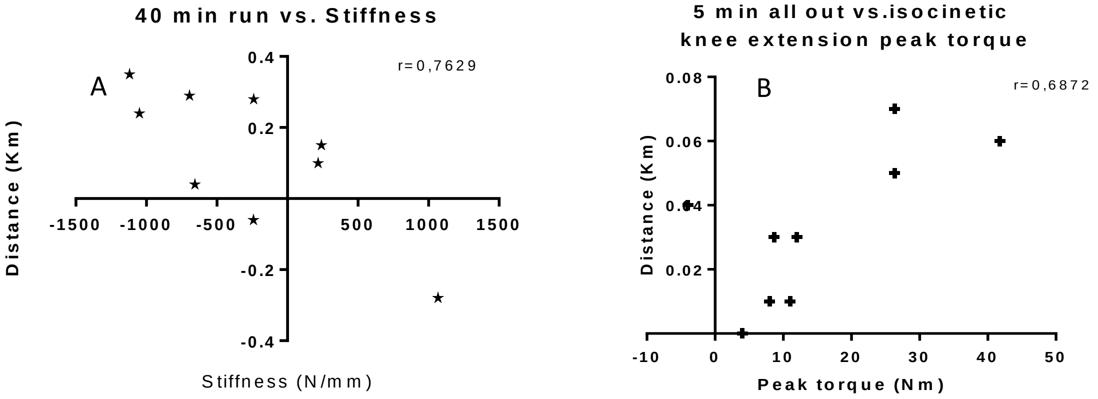

Figure 12: Displays the correlation between changes from pre to post in distance traveled in the 40 min running test and PT stiffness (A). As well as correlation between changes from pre to post in distance traveled in the 5 min all out test and peak torque in isometric knee extension with a 90° knee joint angle. Both graphs represents the RT+END group (n=9)

4.Discusion

In the present study we examined the effects of 12 weeks of concomitant endurance and heavy resistance training on PT mechanical properties and running performance in endurance trained women. The study was conducted by studying two groups of endurance athletes, one group who maintained their regular endurance training regimen (END) (n=8), and one group which was subjected to heavy resistance training of the lower extremities two times per week in addition to their regular endurance training regimen (RT+END) (n=9). A significant increase in mean PT CSA was revealed in the END+RT group. PT stiffness, strain and Young’s modulus on the other hand, did not change. Furthermore, no changes in vastus lateralis muscle thickness or peak torque in isometric knee extension at 90° of knee joint angle was discovered. However, we did find a significant increase in 1 RM squat to 90° of knee joint angle in a smith machine in the RT+END group. Regarding running performance, distance covered in 40 minutes and 5 minutes remained unchanged. As a result, it may not be surprising that both VO_{2max} and running economy was unchanged in both groups. However, we did discover a significant negative correlation between changes in distance covered in 40 minutes of running and changes in PT stiffness. Lastly, we can also report a significant correlation between changes in isometric knee extension peak torque and changes in distance covered in a 5 minutes all out running test.

As a result of these findings, our hypothesis had to be discarded. PT stiffness did not increase, nor did running economy or running performance after 12 weeks of concomitant endurance and heavy resistance training in endurance trained women.

An increase in 1 RM in the squat to 90˚ of knee joint angle after twelve weeks of resistance training is to be expected. Our results revealed a 45%±23% (p=<0,01) increase in 1 RM. As our subjects may be considered untrained in terms of resistance training, these numbers are in line with previous findings, which report an increase in 1 RM in the applied exercises of ~40%, over periods of 4 weeks to 2 years. It has also been reported that the majority of these changes occur relatively quick after onset of training (4-8 weeks) (Kraemer, et al., 2002). We know that there is a correlation between muscle mass and muscle strength, and as a result it may seem strange that the increase in squat 1 RM is not followed by an increase in vastus lateralis thickness. The absence of vastus lateralis hypertrophy does however support the lack of increase in isometrick knee extension peak torque. On the other hand, significant within group increases was revealed in both the RT+END (+11,9 ± 10,4% p=0,001) and END group (+15,5 ± 11,6% p=0,005), but no significant interaction between the groups was discovered. Although, highly speculative, the increase in isometric knee extension peak torque in the END group might be related to familiarization to the testing procedures. The within group increases in isometric knee extension peak torque is nevertheless dwarfed, when compared to the increase in squat 1 RM. The literature is incohesive, in terms of the effects of concomitant resistance and endurance training on muscle strength and mass. However, our findings are supported by Bell & coworkers (2000), who reported reduced changes in knee extension strength and a lack of skeletal muscle hypertrophy as a result of concomitant resistance and endurance training, compared to resistance training alone. The lack of increase in vastus lateralis muscle thickness may indicate that neurological adaptations are responsible for the increase in squat 1 RM.

The squat is a complex multi joint movement, which requires great amounts of balance and control in terms of agonist and antagonist activation during the lift. Although our subjects performed the squat in a smith rack, it is still a technically challenging exercise compared to the isometric knee extension. Because of its technicality level, there is much room for improvements in controlling the movement and firing of the appropriate muscle groups at the appropriate time. Because the squat is such a technical exercise, it can be argued that a significant amount of the increase in 1 RM can be related to improvements in technique and neural adaptations. According to the literature, the nervous system plays a significant role in the strength increases observed in the early stages of adaptation to resistance training. On the other hand, muscle hypertrophy usually becomes evident 6-7 weeks after onset of training (Kraemer, et al., 2002). This should mean that our study should reveal increases in vastus lateralis muscle thickness. However, it may be that the concomitant endurance training inhibits the muscle hypertrophy, like in the study by Bell & coworkers (2000).This might be an attempt to maintain running performance, as increased muscle mass would mean an increase in mechanical work required during locomotion, and thereby a possible reduction in running performance.

Even though multiple studies have observed increases in PT stiffness and Yong's modulus after periods of resistance training (Kongsgaard, et al., 2007; Kubo, et al., 2006; Seynnes, et al., 2009; & Reeves, et al., 2003), the present study showed no significant changes in PT mechanical properties. A study by Albracht & Arampatzis (2013) also revealed an increase in tendon stiffness after 14 weeks of concomitant endurance and resistance training. However, the Achilles tendon was the tendon in focus in this study. The Achilles tendon adapts to resistance training by region specific increase in CSA and increased stiffness (Arampatzis, et al., 2007). According to the literature, runners are reported to have thicker Achilles tendons than controls (Kongsgaard, et al., 2005; Magnusson & Kjaer., 2003), but no differences in mechanical properties has been reported (Rosager, et al., 2002). On the other hand, a stiffer Achilles tendon seems to favor running economy (Arampatzis, et al., 2006). In terms of the PT, the opposite may be the case, as a more compliant PT seems to favor running economy and performance (Arampatzis, et al., 2006; Kubo, et al., 2010). With this in mind, it seems logical that the Achilles tendon adapts to concomitant resistance and endurance training by getting stiffer, as it seems to be a favorable adaptation for both running and resistance training performance. In the PT's case however, it seems that it is faced with two antagonistic adaptations, when subjected to concomitant resistance and endurance training: A stiffer PT to optimize length control and the transferring of forces from muscle to bone and to be able to cope with the new stresses added by the resistance training, or maintain its elastic properties to preserve energy savings and running economy. It can be argued that the lack of increase in PT stiffness in the present study, is a result of these antagonistic adaptations and that the result is a compromise between the preservation of elastic energy savings on one side and length control and effective transferring of forces on the other.

Another possible explanation may be that our expectations are based mainly on studies conducted on male subjects. The results reported in these studies may not necessarily be representable for female subjects. Magnusson & co-workers (2007) tested trained (running approximately 50 km⁄week over the last 5 years) and untrained male and female subjects and reported a lower response to mechanical loading, a lower rate of new connective tissue formation and lower mechanical strength in female connective tissue. They also reported no increase in PT CSA in the trained female subjects as opposed to the trained male subjects. These results however, originate from runners. We on the other hand, revealed a significant increase in mean PT CSA (+4,8 ± 2,3% p=0,003) in the RT+END group. The lack of increased mean PT CSA in the END group, suggests that the increase revealed in the RT+END group originates from the resistance training. The literature is incohesive in terms of increased PT CSA as a result of relatively short term resistance training. However, our results is in line with the results of Seynnes & co-workers (2009) which reported increases in PT CSA of 4,9% – 5,7% at different portions of the tendon, and an increase in mean PT CSA of 3,7 ± 2,2%. The researchers of this study assessed the tendon CSA at every 10% of the tendons length by the use of MRI, which is a more reliable type of measurement compared to ultra sound. This could mean that our results are less accurate. However, the significant increases in PT CSA in the study by Seynnes & co-workers (2009), were reported at 20%, 30%, 60%, 90% and 100% of tendon length. That makes us fairly confident that our measurements at the proximal, middle and distal part of the tendon makes up a valid result. In the same study, the increased PT CSA was followed by an increase in PT stiffness and Young's modulus. The fact that this was not revealed in our study supports the idea that there is a compromise between antagonistic adaptations going on in the tendon tissue as a result of concomitant resistance and endurance training. Although highly speculative, it can be argued that the increase in PT CSA occurs to protect the tendon from the increased stress introduced by the resistance training. *In vitro* tests have revealed tendon stress of 86 – 100 Mpa at tendon failure. It is suggested that mammalian tendon tissue has a safety margin of ~4 or maybe as much as ~8 (Reeves, et al., 2003). It is possible that the increase in PT CSA seen in the present study is part of an effort to maintain that safety margin.

As for the lack of improvement in running economy and performance, that is supported by the lack of changes in the variables that might affect those properties, such as VO_{2max}, and tendon mechanical properties. Interestingly, even though this is just a correlation and cannot tell us anything in terms of cause and effect, we did reveal a significant negative correlation between changes in distance covered in 40 minutes and PT stiffness. On the basis of the lack of increased VO_{2max}, this correlation indicates an improvement in running economy in the subjects with more compliant tendons. This is in line with the aforementioned study by Kubo & co-workers (2010) which revealed that the most economical runners and the runners with the lowest personal best time in a 5000 meter race had the most compliant tendons. And the study by Arampatzis, & co-workers (2006) which suggested that a more compliant quadriceps tendon and aponeurosis would be able to store and release more elastic energy which would increase the force potential of the muscle during submaximal running and therefore decrease the volume of active muscle at a given force generation. This will in turn improve running economy. Another interesting observation is the correlation between changes in distance covered in the 5 minute all out test and isometric knee extension peak torque. The 5 minute all out test was designed to mimic a sprint to the finish at the end of a long distance race, thus it seems that an improvement in isometric knee extension peak torque is beneficial for this type of performance. As we revealed no changes in any of the measured variables that might affect running performance, such as VO_{2max} and tendon mechanical properties, this relationship might be explained by an increased power output by the muscle tendon unit, which in turn might be beneficial for running performance over a restricted time period and distance. Even though long distance runners spend the majority of a race at submaximal intensity, this correlation implies that long distance runners may benefit from an increased power output from their knee extensors, as long distance races are often settled with a sprint towards the end of the race.

Long distance running performance and economy might be affected by numerous, factors including but not limited to VO_{2max}, tendon mechanical properties, running technique, muscle force production and local muscular endurance. The fact that measuring all these variables would have been far too costly and time consuming may be considered a limitation and might affect the overall story of the present study. Furthermore, our pool of subjects might not be optimal to describe the issues at hand, as they have different training backgrounds and the majority of the subjects participated in a mixed selection of endurance sports (running, cycling and cross country skiing) before and during the intervention. It is possible that a subject pool of specialized runners would have yielded different results. Daily variations in running economy could also be a potential limitation, as Morgan & co-workers (1991) reported that the aerobic demand of running in trained subjects, similar to our subjects, would be expected to vary between ±1,32% and ±2,64% in trials controlled for treadmill running experience, time of day, footwear and training.

4.1 Conclusion

In conclusion, PT stiffness did not change as a result of concomitant resistance and endurance training in endurance trained women. Furthermore, resistance training does not seem to be sufficient stimuli to improve running performance and economy via adaptations in PT mechanical properties.

To our knowledge the only similar study to the present one, is the study by Albracht & Arampatzis (2013) were the Achilles tendon was investigated. Further research is needed to fully describe how the human PT adapts to concomitant resistance and endurance training and how it may affect running economy and performance. Future studies should obtain a subject pool of specialized runners and attempt to account for other factors affecting running performance and economy.

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Table overview

Figure overview

Abbreviations

Abbreviation	Meaning
CSA	Cross-sectional area
EMG	Electromyography
END	Endurance
MRI	Magnetic resonance imaging
PT	Patella tendon
RM	Repetition maximum
RT	Resistance training

Appendix

Forespørsel om deltakelse i forskningsprosjektet

”Effekten av styrketrening på prestasjonen i løp og sykling og effekten av samtidig utholdenhetstrening på endringer i styrkeparametere og muskelmasse ved styrketrening”

Bakgrunn og hensikt

Dette er et spørsmål til deg om å delta i en forskningsstudie for å bedre forstå hvordan styrketrening som et supplement til utholdenhetstrening kan påvirke prestasjonen i utholdenhetsidrettene løping og sykling og viktige parametere som bestemmer denne prestasjonen hos kvinnelige utøvere. Maksimal styrketrening har i de siste årene fått større oppmerksomhet blant utøvere i tradisjonelle utholdenhetsidretter og flere og flere utøvere trener tung styrketrening ved siden av sin vanlige utholdenhetstrening med målsetting om at dette vil øke prestasjonsevnen i sin utholdenhetsidrett. Dette har ført til at forskningen innen dette området har økt de siste årene men den er fortsatt mangelfull. Forskningen tyder på at tung styrketrening kan føre til at løpere løper mer effektivt og dermed bedrer prestasjonen i en løpskonkurranse. Når det gjelder sykling er forskningsresultatene mer uklare. Den meste av forskningen innen dette temaet er også utført på menn og det er derfor vanskelig å si om resultatene er overførbare til kvinner. I dette prosjektet vil vi derfor undersøke om tung styrketrening kombinert med den vanlige sykkel og løpetreningen kan påvirke prestasjonen i sykkel og løp hos kvinner som er aktive både innen sykling og løp. På denne måten vil vi også undersøke om det er noen forskjell i hvordan prestasjonen i disse idrettene kan påvirkes av styrketrening. I tillegg ønsker vi å gjøre en del målinger (se mer senere) for å kunne si noe om mekanismer bak styrketreningens eventuelle effekt på prestasjonen. Resultatene fra dette prosjektet kan bli viktige med tanke på å optimalisere styrketreningen og treningen generelt for utøvere innen sykkel og løp. Dette vil kunne hjelpe utøverne til å bedre sin prestasjon og få mest mulig utbytte av treningen. Testingen til prosjektet vil utføres av fagansatte ved idrettsseksjonen på høgskolen i Lillehammer (HiL) og ved Norges

Idrettshøgskole og prosjektet ledes av førsteamanuensis Bent Rønnestad og Stian Ellefsen ved HiL.

Hva innebærer studien?

Det skal rekrutteres 30 kvinner i alderen 18-40 år som er aktive innen både sykling og løping (typiske deltagere i birkebeinertrippelen) som ikke har gjennomført systematisk styrketrening siste 6 måneder (mindre enn 1 gang i uken siste 6 måneder). Det vil bli en treningsgruppe som trenes og testet ved Norges idrettshøgskole (NIH) og en gruppe som trener og testes ved HiL. Dere blir ved loddtrekning fordelt i to grupper der den ene gruppen i tillegg til å fortsette sin utholdenhetstrening som normalt skal trene 2 økter med maksimal styrketrening for beina 2 ganger i uka. Den andre gruppen fortsetter sin utholdenhetstrening som normalt. Gruppene fordeles likt mellom Oslo og Lillehammer.

Selve treningsintervensjonen vil foregå vår-sommer 2012 og det vil bli gjennomført diverse tester før under og etter intervensjonen. I løpet av ukene før treningsintervensjonen vil det bli gjennomført testing av maksimalt oksygenopptak, laktatprofil og prestasjonsevne i både sykling og løp, testing av muskeltverrsnitt av låret med magnetisk resonanstomografi (MR), kroppssammensetning med DXA, maksstyrketester (1RM tester), muskel og sene stivhet i beina og kostholdsregistrering. I tillegg vil det bli tatt en biposi (vevsprøve) fra m. vastus lateralis (muskel på fremsiden av låret). Disse testene vil også bli gjentatt etter treningsperioden.

Mulige fordeler og ulemper

Som deltaker i prosjektet vil du få testet ditt maksimale oksygenopptak og laktatterskel både i sykkel og i løp. Dette er tester som vanligvis er forbeholdt eliteutøvere og som mosjonister vanligvis må betale for. I tillegg vil du lære mye om styrketrening både teoretisk og praktisk. Utøverne i begge grupper vil få tilbud om å få satt opp et styrketreningsprogram videre når prosjektet er over. Deltakerne vil også få gratis tilgang til styrketreningsrommet ved HiL eller NIH. Etter prosjektet vil alle få tilgang til sine egne testresultater.

For ikke-styrketrente personer vil styrketrening kunne oppleves som fysisk og psykisk belastende. Testing av styrke medfører tung fysisk belastning og det er alltid en liten fare for skade under trening og testing. Ved biopsi kan du føle noe ubehag ved selve prøvetakingen og stølhet i muskelen 1-2 dager etterpå. Biopsitaking er assosiert med en viss infeksjonsfare. Risikoen er derimot svært liten ved bruk av prosedyrene som vil bli benyttet i dette prosjektet. Biopsitakingen vil bli gjennomført i sterile omgivelser i en operasjonssal. Inngrepene kan føre til varige og synlige arrdannelser og i ekstreme tilfeller keloiddannelse (abnormt tydelig arrdannelse etter hudskade). Forsøksperioden vil til sammen strekke seg over ca 16 uker, og vil ta mye av din tid og oppmerksomhet. Vi vil under hele perioden være imøtekommende og vil bestrebe oss for å legge treningstidene til rette for deg.

Hva skjer med prøvene og informasjonen om deg?

Prøvene tatt av deg og informasjonen som registreres om deg skal kun brukes slik som beskrevet i hensikten med studien. Alle opplysningene og prøvene vil bli behandlet uten navn og fødselsnummer eller andre direkte gjenkjennende opplysninger. En kode knytter deg til dine opplysninger og prøver gjennom en navneliste.

Det er kun autorisert personell knyttet til prosjektet som har adgang til navnelisten og som kan finne tilbake til deg. All informasjon og prøvene som samles vil slettes innen 15. januar 2020.

Det vil ikke være mulig å identifisere deg i resultatene av studien når disse publiseres.

Frivillig deltakelse

Det er frivillig å delta i studien. Du kan når som helst og uten å oppgi noen grunn trekke ditt samtykke til å delta i studien. Dette vil ikke få konsekvenser for din videre behandling. Dersom du ønsker å delta, undertegner du samtykkeerklæringen på siste side. Om du nå sier ja til å delta, kan du senere trekke tilbake ditt samtykke uten at det påvirker din øvrige behandling. Dersom du senere ønsker å trekke deg eller har spørsmål til studien, kan du kontakte Olav Vikmoen (tlf: 61288315, epost: olav.vikmoen@hil.no), Stian Ellefsen (tlf: 61288103, epost: stian.ellefsen@hil.no) , eller Bent R. Rønnestad (tlf: 61288193, epost: bent.ronnestad@hil.no).

Ytterligere informasjon om studien finnes i kapittel A – utdypende forklaring av hva studien innebærer.

Ytterligere informasjon om biobank, personvern og forsikring finnes i kapittel B – Personvern, biobank, økonomi og forsikring.

Samtykkeerklæring følger etter kapittel B.

Kapittel A- utdypende forklaring av hva studien innebærer

Kriterier for deltakelse

Studien vil inkludere 30 friske ikke-styrketrente kvinner som har aktivt drevet med både med sykling og løp siste 12 måneder og deltatt konkurranser sesongen 2011 (minimum 2 sykkeløkter og 2 løpeøkter i uken i intervensjonsperioden) og som planlegger å fortsette denne satsingen gjennom prosjektets varighet. De skal ikke ha drevet systematisk styrketrening det siste året (maksimalt en økt i uken).

Bakgrunnsinformasjon om studien

Bruk av tung styrketrening har i de siste årene fått større oppmerksomhet blant utøvere i tradisjonelle utholdenhetsidretter som sykling og løping og flere og flere løpere og syklister trener tung styrketrening ved siden av sin vanlige utholdenhetstrening med målsetting om at dette vil øke prestasjonsevnen. Dette har ført til at forskningen innen dette området har økt de siste årene men er likevel mangelfull, spesielt blant kvinner. Prestasjonen i utholdenhetsidretter bestemmes hovedsakelig av en utøvers maksimale oksygenopptak, hvor stor andel av dette oksygenopptaket man klarer å jobbe på i tiden konkurransen varer (utnyttingsgrad) og hvor effektiv utøveren er i den aktuelle bevegelsesformen (arbeidsøkonomi). Forskningen tyder på at tung styrketrening kan føre til bedret prestasjon i løping og at dette skyldes at man løper mer effektivt etter en periode med tung styrketrening for beina. Det tyder ikke på at tung styrketrening endrer det maksimale oksygenopptaket eller utnyttingsgraden. Når det gjelder sykling er forskningsresultatene mer uklare. Akutt ser det ikke ut at verken det maksimale oksygenopptaket, arbeidsøkonomien eller utnyttingsgraden endres, men at arbeidsøkonomien muligens kan bedres under langvarig arbeid. Løping og sykling som aktivitetsformer har visse forskjeller som kan tenkes å påvirke responsen til et styrketreningsprogram. Et løpssteg inneholder i motsetning til et sykkeltråkk noe som kalles en strekk forkortningssyklus som gjør at det kan lagres energi i muskler og sener i noen faser i løpssteget som man kan utnytte i fasen som gir fremgang. Muskler og seners elastiske egenskaper kan endres ved styrketrening og disse endringene kan tenkes å være en av mekanismene bak bedret effektivitet ved løping. Vi ønsker i dette studiet å undersøke hvordan tung styrketrening som et supplement til utholdenhetstrening kan påvirke prestasjonen og viktige faktorer som bestemmer denne i sykling og løp og eventuelle gjennom hvilke mekanismer styrketrening kan påvirke prestasjonen. Vi vil også se om det finnes forskjeller i responser mellom sykling og løping. Siden en klar overvekt av forskningen innen dette temaet er utført på menn og det er derfor vanskelig å si om resultatene er overførbare til kvinner ønsker vi å undersøke dette hos kvinnelige utøvere.

Tester og undersøkelser

Det vil bli tatt tverrsnittsbilder av låret ved bruk av magnetresonanstomografi (MR). Formålet ved disse tverrsnittsbildene er å avdekke eventuelle endringer i muskelstørrelse etter treningsperioden. Det vil bli gjennomført kostholdsregistreringer før, under og etter treningsperioden. Dette for å kontrollere næringsinntaket. Kroppssammensetning vil bli målt før og etter treningsperioden ved bruk av dual-energy x-ray absorptiometry (DXA). Det vil bli tatt biopsier (vevsprøve) vastus lateralis (muskel på lårets ytterside) før og etter treningsperioden. Biopsiene vil bli oppbevart i en biobank uten kommersielle interesser (vurdert av Regional Etisk Komité). I tillegg til dette vil følgende styrketester bli gjennomført før, hver tredje uke og etter treningsperioden: isometrisk (statisk) kraftutvikling i kne-ekstensjon, maks styrke i knebøy i Smith-maskin, en-fots beinpress, hoftefleksjon og tåhev. Testing av arbeidsøkonomi på submaksimale belastninger og testing av VO2max skjer ved sykling og løping på testsykkelen og tredemølle på testlaben ved Høgskolen i Lillehammer eller Norges idrettshøgskole. For å måle hvor mye melkesyre det er i blodet stikkes det et lite hull i en fingerspiss og noen dråper tas ut for analyse. Dette vil bli gjort under selve testingen.

Ved kortidsprestasjon (30 sek) på sykkel registreres kraftutviklingen i hvert pedaltråkk. Test av langtidsprestasjon vil gjøres ved en 3- timers submaksimale test, der forsøkspersonene skal sykle i 3 timer på 150 W for deretter å sykle i 5 minutter med maksimal arbeidsbelastning. I løpet av de 3 timene vil hjertefrekvens, laktatverdier, tråkkfrekvens og oksygenopptak bli målt regelmessig. Under 40 minutters prestasjonstest på sykling og løp skal deltakerne sykle eller løpe så "langt" som mulig på 40 minutter og hjertefrekvens og oksygenopptak blir målt regelmessig.

Testene vil gjennomføres på HiL eller NIH og ved sykehuset innlandet.

Trening

Treningen kan om ønskelig foregå i styrketreningsrommet på HiL eller NIH. Hvis trening foregår på egenhånd trengs en Smith-maskin, beinpressmaskin og trekkapparat. Treningen vil bestå av 2 treningsøkter og treningsøvelsene per økt vil være knebøy i Smith-maskin, en-fots beinpress, hoftefleksjon og tåhev. Dere bør trene minst to og to sammen, slik at de kan sikre hverandre under treningen. I tillegg vil du få tett oppfølging av testleder de første ukene (hver styrketreningsøkt) og en gang per uke deretter. I forbindelse med hver økt vil du få tildelt energisjokolade og energidrikk. Dere skal også opprettholde utholdenhetstrening som normalt og skal føre treningsdagbok på dette.

Tidsplan

Testingen til prosjektet vil begynne i uke 15 2012. Dette er rett etter påsken. Treningsperioden vil for halvparten av dere starte i uke 17 og for andre halvparten i uke 19 og være i 12 uker. Posttestingen vil foregå i de 2 første ukene etter styrketreningsintervensjonen.

Mulige fordeler ved å delta

Som deltaker i prosjektet vil du få testet ditt maksimale oksygenopptak og laktatterskel både i sykkel og i løp. Dette er tester som vanligvis er forbeholdt eliteutøvere og som vanligvis er veldig dyrt å få testet som mosjonist. I tillegg vil du lære mye om styrketrening både teoretisk og praksis og de som havner i styrkegruppen vil få innlært gode styrkeøvelser for sykkel og løping. Du vil få tett oppfølging av fagpersonell med stor kunnskap om både styrke og utholdenhetstrening gjennom hele perioden. Utøverne i begge grupper vil få tilbud om å få satt opp et styrketreningsprogram videre når prosjektet er over. Deltakerne vil også få gratis tilgang til styrketreningsrommet ved HiL eller NIH. Etter prosjektet vil alle få tilgang til sine egne testresultater.

Mulige ulemper og bivirkninger

For ikke-styrketrente personer vil styrketrening kunne oppleves som fysisk og psykisk belastende. Testing av styrke medfører tung fysisk belastning og det er alltid en liten fare for skade under trening og testing. Ved biopsi kan du føle noe ubehag ved selve prøvetakingen og stølhet i muskelen 1-2 dager etterpå. Biopsitaking er assosiert med en viss infeksjonsfare. Risikoen er derimot svært liten ved bruk av prosedyrene som vil bli benyttet i dette prosjektet. Biopsitakingen vil bli gjennomført i sterile omgivelser i en operasjonssal. Inngrepene kan føre til varige og synlige arrdannelser og i ekstreme tilfeller keloiddannelse (abnormt tydelig arrdannelse etter hudskade). Forsøksperioden vil til sammen strekke seg over ca 16 uker, og vil ta mye av din tid og oppmerksomhet. Vi vil under hele perioden være imøtekommende og vil bestrebe oss for å legge treningstidene til rette for deg.

Studiedeltakers ansvar

Ved å si ja til å være med på studien har FP ansvar for å stille til avtalt tid og følge de retningslinjene som testene krever. FP har også ansvar for å informere prosjektledelse om hendelser eller andre forhold som kan tenkes å påvirke resultatene.

Studiedeltakers rettigheter

Forsøkspersonene vil bli orientert så raskt som mulig dersom ny informasjon blir tilgjengelig som kan påvirke deres villighet til å delta i studien. FP skal opplyses om mulige beslutninger/situasjoner som gjør at deres deltagelse i studien kan bli avsluttet tidligere enn planlagt.

Kapittel B - Personvern, biobank, økonomi og forsikring

Personvern

Opplysninger som registreres om deg er fødselsår, kjønn, høyde, vekt, data fra styrketestene, data fra løpe og sykkeltestene, MR data, kostholdsregistrering og data fra vevsanalysene.

Høgskolen i Lillehammer ved administrerende direktør Kari Kjenndalen er databehandlingsansvarlig.

Biobank

Muskevevsprøvene som blir tatt og informasjonen utledet av dette materialet vil bli lagret i en forskningsbiobank ved Høgskolen i Lillehammer. Hvis du sier ja til å delta i studien, gir du også samtykke til at det biolo¬giske materialet og analyseresultater inngår i biobanken. Stian Ellefsen er ansvarshavende for forskningsbiobanken. Biobanken planlegges å vare til 2020. Etter dette vil materiale og opplysninger destrueres og slettes ihht interne retnings¬linjer.

Rett til innsyn og sletting av opplysninger om deg og sletting av prøver

Hvis du sier ja til å delta i studien, har du rett til å få innsyn i hvilke opplysninger som er registrert om deg. Du har videre rett til å få korrigert eventuelle feil i de opplysningene vi har registrert. Dersom du trekker deg fra studien, kan du kreve å få slettet innsamlede prøver og opplysninger, med mindre opplysningene allerede er inngått i analyser eller brukt i vitenskapelige publikasjoner.

Økonomi

Studien og biobanken er finansiert gjennom forskningsmidler fra Høgskolen i Lillehammer og Regionalt forskningsfond – Innlandet. Det er ingen interessekonflikt knyttet til finansieringen.

Forsikring

Deltagere i studien er dekket gjennom en særskilt forsikring som heter "Ansvar for skade på person og ting". Denne dekker eventuelle skader på personer som er forsøkspersoner i forsknings- og/eller utviklingsarbeid ved Høgskolen i Lillehammer.

Informasjon om utfallet av studien

Du vil selvsagt få tilgang til dine egne resultater ved å kontakte oss. Utfallet av studien vil bli publisert i offentlig tilgjengelige forskningsartikler.

Samtykke til deltakelse i studien

Jeg er villig til å delta i studien

(Signert av prosjektdeltaker, dato)

Jeg bekrefter å ha gitt informasjon om studien

(Signert, rolle i studien, dato)

Extract from the training log of one of the subjects

Uke 6: Økt1: 8 RM, Økt 2: 5 RM

Økt1	Antall sett	Sett 1	Sett 2	Sett 3
Knebøy	3	107,5	110	110
Beinpress Høyre	3	100	100	100
Beinpress Venstre	3	100	100	100
Hoftefleksjon høyre	3	25	25	25
Hoftefleksjon venstre	3	25	25	25
Tåhev	3	100	95	95
Økt2				
Knebøy	3	117,5	120	120
Beinpress Høyre	3	105	107,5	107,5
Beinpress Venstre	3	105	107,5	107,5
Hoftefleksjon høyre	3	30	32,5	30
Hoftefleksjon venstre	3	30	32,5	30
Tåhev	3	100	110	110

Kommentarer

Diet registration from one of the subjects

Ukedag 27.07. Tid	Vekt i gram	Matvarer	Kalorier
9:45	240	3 egg	250
	50	Tomat	15
	20	Skinke	20
		Kaffe	20
12:30	150	Banan	130
	100	Squash	19
	20	Mandel	122
	50	Tomat	15
14:15	65	Havregrøt	207
17:15		Makrell i tomat liten boks	220
		Rugsprø 2 stk	60
	30	Parmasan	240
21:00	200	Indrefilet storfe	250
	200	Div grønnsaker	250
	20	Saus	150
	250ml	Rødvin	200

Ukedag 26.7. sommerferie Tid	Vekt i gram	Matvarer	Kalorier
9:40	65 25	Havregrøt Kli Kaffe	207 70
12:00		Recovery bar	200
13:30	200 160 50 30 20	Salat Egg Mozzarella ost Skinke dressing	600
16:00	60g tørrvare	Sportsdrikk	215
20:00	200 750 ml 80 10	Salma laks Div tilbehør Hvitvin Ost fet kjeks	400 50 450 300 30

Ukedag TID	Vekt i gram	Matvarer	Kalorier
11:00	65 25 150 1 dl 50	Havregrøt Kli Banan Melk Rostbiff Kaffe	207 70 130 40 58
14:00		Joghurt lett Banan Advocado middels stor	57 130 200
15:00	7,5 dl	sportsdrikk Sportsbar	215 209
18:00	100 20 30	Cottage Cheese Skinke	90 30
20:0	200 200 100 250ml	Indrefilet storfe Div grønnsaker Ost Rødvin	250 250 300 200

Dato…lørdag

Ukedag Tid	Vekt i gram	Matvarer	Kalorier
08:30	65	Havregrøt	207
	25	Kli	70
		Kaffe	
10:30	7,5 dl	sportsdrikk	215
		Sportsbar	209
13:30	180	Pære middels	
	100 ml	Sjokolademelk	49
	184	Kyllingfilet	175
	50	Pasta	175
15:30	180	Pære	
	200	Salat	
	250	Tomat	
	20	Pesto	90
	300	Cottage Cheese	300
	100	skinke	114
20:00	200	Salma laks	400
	200	Div grønnsaker	250
	250ml	Hvitvin	200

Dato…………