Achilles Tendon Characteristics According to Body Fat and Body Mass Index

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Abstract

Aim: The Achilles tendon is a biggest and strongest tendon in the body although it is very likely to be injured due to the amount of compression and tension on it. The study aimed to analyze the effect of BMI and body fat on the Achilles tendon.

Methods: The study recruited 25 individuals who were divided equally into three groups (very lean, normal and obese) and focused on three factors to measure (length, thickness and strain ratio).

Results: Strain ratio was found to be an indicator of the stiffness of the tendon. The strain ratio was varying between the ranges from 0.09 to 1.13. People with high BMI were noticed to have less strain ratios, in the opposite side lean people were having the highest strain ratios and normal people were having normal strain ratios.

Keywords: Achilles tendon, tendon forces, muscle mechanics, BM, strain ratio

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INTRODUCTION

The word Achilles is derived from Greek mythology referring to the strongest warrior and hero in the Greek army during the Trojan War. Achilles tendon is considered as the most important tendon in the human body and multifunctional, which is considered as a strongest and largest tendon in the human body. It connects soleus muscles (calf muscles) and gastrocnemius by a strong band of fibrous tissue. Achilles tendon is found in the back from the lower leg, above the calcaneus. It helps humans to go up onto tiptoes. It does almost all activities like jumping, swimming, walking and running. The Achilles tendon could carry about 9 KN that equivalent to 12.5 times the human body when running in higher speed, where minimum forces range from 1 to 4 KN are applied to Achilles tendon in most mechanical work by ankle joints such as jumping or cycling. Achilles tendon in most mechanical work by ankle joints such as jumping or cycling.

Problem Statement

Achilles tendon disease is popular during daily physical activity. The parameters that may affect the tendon’s chance to risk of rupture and mechanical stress are muscles' flexibility, strength and imbalance. Achilles tendon is also influenced by obesity, age, gender, recreational sports, steroid injections and certain antibiotics [3].

Aims and Objective

The purpose of this study was to investigate if the different weights and BMI affects the Achilles tendon’s strength and extent of impact on injury to reduce Achilles tendon overuse injuries.

LITERATURE REVIEW

Anatomy of the Foot

The foot is a flexible structure of bones, joints, muscles, and soft tissues. The foot is divided into three main sections as shown in the figure 1. The hindfoot contains the ankle and heel. The talus bone function to support the tibia and fibula (leg bones), forming the ankle. The heel bone (calcaneus) is considered to be the largest bone in the foot. The midfoot is made up of several bones that together form the arches of the feet. These include the three cuneiform bones, the cuboid bone, and the navicular bone. The forefoot contains the five toes (phalanges) and the five longer bones (metatarsals) as shown in the figure 2.

Figure 1: Anatomy of the foot.

Source: Henry Gray (1918)
The gastrocnemius and soleus muscles are united in one band of tissue which forms the Achilles tendon. Muscle fibers come from soleus to its lower end. Achilles Tendon surrounded vascular. Blood derive from musculo-tendinous junction, the osteotendinous junction and from the extrinsic segmental vascular system through the paratenon surrounding the tendon [5]. The material of Achilles tendon consists of collagen which formed approximately 70% and elastin maybe 1% to 2% in the dry mass of the tendon [5]. Achilles tendon includes many receptors relating pain and other neurotransmitter effect [6]. These nerves behind the vascular channels within the tendon, combine with each other through indirectly and transversely oriented fibers finally end in sensory nerve habitation [5]. The Achilles tendon end is the part which it inserted into the calf muscle. Bursa is a small sac of fluid and it is located between the bone and the tissue. Normal body has 160 bursae (2). During flexing in the calf muscles the Achilles tendon pulls on the heel, this mechanism let us able to stand, walk, jump and run. Achilles tendon average length is about 15cm which ranges from 11 to 26cm. Average width of Achilles tendon is about 6.8 cm (4.5– 8.6 cm) when its origin, then become thinner at mid- section 1.8 cm (1.2-2.6cm) [7][8].
Physiology of Achilles Tendon

Achilles Tendon provides complex movements needed for motion, balance and difficult moves. The Achilles tendon connects the heel to the calf muscle and it is essential for walking, running, jumping, climbing and standing on the toes [4].

Tendon Contraction/Expansion Types

Achilles tendon is responsible for different movements that require a flexion (tension) or contraction (compression) like in normal walk there will be contraction on the tendon during to the vertical load on it. When landing from a jump, a higher contraction occurs in the tendon. On the opposite side when the leg is in a flexion position, like standing up or standing on toes, the tendon will be in tension and performs expansion to help the leg performing its movement.

Injury of Achilles Tendon

Often ruptures are cause by surprised increase of stress on Achilles Tendon. For example, falling from a height, jumping, stepping into a Hole or increasing the intensity of sports participation. Achilles tendinitis is a common injury among athletes that put a lot of stress in the Achilles tendon like runners, basketball players and dancers etc. Achilles tendon can also get tear or rapture where the fibers separated during to extremely suddenly high stress on it. Achilles tendinopathy is divided into two diseases; mid-portion of the tendon (55–65% of injuries) and the insertion of the tendon (20–25%) [10]. Usually, rupture is reported from healthy, active people with a reported average age of patients from 37 to 43.5 years old [11]. The most popular ruptures are of the mid substance Achilles, usually occurring in a vascular watershed region 3–6 cm near to the insertion site on the calcaneus. Chronic Achilles tendinopathies often found in athletes and it is painful conditions, especially in middle age male runners. Achilles tendinopathy divided into insertion of the tendon (20–25%) and disease of the mid portion of the tendon (55–65% of injuries) [12].

Symptoms, Diagnosis and Treatment of Achilles Tendon Disease

The main symptom is a pain above the heal specially when making an action that depends mostly on Achilles tendon like standing up, jumping and standing in toes. The area may also feel swollen, tender and stiff. The injured Achilles tendon may also cause a difficulty in walking with a pain in each step on the foot that has injured Achilles tendon. Achilles tendon can be diagnosed by the ultrasound or magnetic resonance imaging. Minor to moderate Achilles injuries usually heal in their own. To speed up the healing the patient, must rest his foot as much as possible. Icing it and elevating it also can increase healing time. In severe cases like tear or rapture, there might be a need for casting the leg and allow the tendon to recover without any load on it. In some cases, a surgery must be done to repair the tendon or remove an extra tissue.
Figure 4: Percutaneous and minimally invasive suture techniques.

Source: Michael R Carmont (2011)

METHODOLOGY

The study recruited 25 healthy volunteers who were then divided into three groups six individuals from category A, seven individuals from category B and twelve individuals from category C according to their BMI. Category A: under normal BMI (very lean), category B: normal BMI, category C: over weights (obese). The experiment was made on only the right leg. BMI and height were measured in the nutrition lap as the first step to get important readings, the length taken separately by (Stadiometer HOLTAIN LIMITED) and other reading taken by (InBody720 body composition analyzer) before doing the experiment. (BMI) Body mass index of each volunteer was measured by using this formula; BMI = Mass in kilogram / height in meters ^2

The equipment used in this study were the Ultrasound Elastography device is (sonix touch SXTCHPL241611A1101) and linear probe (L14-5W/60 Linear) with frequency range (14 - 5 MHz), focal range (2 - 9 cm) and image field 14mm. All experiments were performed in the lab of Applied Medical Science College at KSU. The volunteers took prone position because it is the best position for the Achilles tendon to be examined easily. To determine the start of Achilles tendon, the probe was put on longitudinal direction which the trigger is indicating up. Also, the center of right leg was selected and imaging was started from the calcaneus bone and continued upward until the start of Achilles tendon which has a special curve in the starting. The start of Achilles tendon was marked and kept moving slowly upward until the end of Achilles tendon was marked on the patient leg. Determining the end of Achilles was by noticing the shiny silver color start merging with the path of the tendon (Figure 6). This shiny silver represents either the fat or the muscles of calve.
The length was then measured by a metric tape as shown in (Figure 8). Achilles tendon lengths were taken three times and the average was taken as a central region. The Achilles tendon was divided into three sections for regular evaluation: distal third (insertion at the calcaneus), middle third (above insertion at the calcaneus), and proximal third (musculotendinous junction). In this study, the middle third was taken as a region of interest (ROI), according to previous studies. It is placed on two steps where the highest point is determined from the width of the image taken for the Achilles tendon, then take other point down to the end of Achilles Tendon in a straight line.
The probe was then put in perpendicular form to the Achilles tendon (Figure 9), with convenient pressure to avoid moving or changing of the elastogram that indicated to the strain indicator. ROI selected are that included a whole thickness of the Achilles tendon with the calcaneus bone surface and rubber. Images were saved in the memory of the Ultrasound Elastography device. These readings were repeated eight times to choose three nearest values and calculate the average in millimeters. The authors used this method to avoid any errors from the specialist or volunteer. These errors occur usually when patient or volunteer move, shake or change position.

Next, elastographic mode was selected to measure the strain ratios of Achilles tendon. To determine strain ratios, two regions within ROI were compared using ultrasound system with built-in software. In this study, strain between Achilles tendon and rubber taken as a reference material were compared. Difference in hardness was shown in the screen, in the descending order of blue, green, yellow and red, where red color refer to harder region and the blue refer to softer. Four squares of stress were applied that induced deformation for all readings. Two squares were taken
after the probe was placed on the ROI one from the middle of the tendon and other one as a reference, subcutaneous fat eight readings were taken as a reference, then select nearest three to calculate the average. Also, all steps were repeated using the rubber. The two squares must be equal in size in order to have an accurate result.

RESULTS & DISCUSSION

Results

Strain ratio was higher in people with low BMI (very lean), followed by people with normal BMI (average), and finally people with high BMI (obese), when BMI increase strain ratio decreases.

![Category A](image1)

**Figure 11: Strain ratio vs BMI for category A**

*Source: Authors (2023)*

![Category B](image2)

**Figure 12: Strain ratio vs BMI for category B**

*Source: Authors (2023)*

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Figure 13: Strain ratio vs BMI for category C
Source: Authors (2023)

Figure 14: Comparison of strain ratio vs BMI from category A, category B and category C
Source: Authors (2023)

Figure 15: Strain ratio vs whole body fat for category A
Source: Authors (2023)
**Figure 16: Strain ratio vs whole body fat for category B**

*Source: Authors (2023)*

**Figure 17: Strain ratio vs whole body fat for category C**

*Source: Authors (2023)*
When leg body fat increases the strain ratio decrease as shown in figures 18, 19, and 20.

Source: Authors (2023)

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**Figure 18:** Comparison of strain ratio vs whole body fat from category A, category B and category C

**Figure 19:** Strain ratio vs leg body fat for category A

Source: Authors (2023)
When comparing leg fat to the thickness of Achilles tendon it was found out that the more leg fat is the more thickness of the tendon as shown in figures 21, 22, and 23.

Source: Authors (2023)
DISCUSSION

It was observed that BMI and body fat clearly have an impact to the Achilles tendon structure. Achilles tendon position is very critical because a lot of weight and compression is on it. It was noticed that the more load on the tendon, the less strain ratio it will be. Low strain ratio indicates high elasticity (stiffness) in the tendon according to hook’s law. This means people with high BMI have stiff Achilles tendon that can tolerate high stress without having high deformation (strain).

Load on the Achilles tendon is represented by BMI or Fat and both of them has an inverse relationship with strain ratio. These findings are contrary to previous studies where they came out with a result that strain ratio increase when BMI increase (32). Strain ratio was obviously higher in people with low BMI which means their tendon is softer and more flexible than other groups (Hooke’s law). While the strain ratio in normal and obese groups were less, it means that the more BMI the stiffer is the tendon. When taking the leg body fat alone and comparing it, it was found
that the more leg body fat, the less strain ratio. Also, it was found that the thickness of Achilles tendon has a varying relationship with the leg body fat. To be more precise, persons from the same category with different leg body fat were compared and found that the higher leg body fat, the higher thickness the tendon is (figures 21, 22, 23). The reason why thickness is higher in people with high fat or BMI is because the compression on the tendon is higher and it is well-known in biomechanics that the compression is causing shortening in the length (33). This shortening in the length causes a lengthening in the width (more thickness) (33).

RECOMMENDATIONS

Achilles tendon rupture has been shown to cause significant morbidity and treatment is continued long time after acute Achilles tendon rupture. Therefore, we always refer to adherence to the natural BMI because of its direct effect on the injury of the Achilles tendon.

CONCLUSION

This study concludes that in regards to BMI and body fat, strain ratio will always be high for lean persons. For people with normal BMI gets normal strain ratio range while obese people have less strain ratios. Thickness increase whenever leg body fat increase due to the excess of compression. According to twenty-five volunteers, it was observed that overweight volunteers have higher stiffness compared to others which raise the possibility of having Achilles injury.

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