

Pathology and biomechanics of the human achilles tendon

Abstract

Biomechanical engineering has achieved much progress in an attempt to improve and recover impaired functions of tissues and organs. Although many studies have been done, progress for biomechanical-engineered Achill tendon has been slow due to their complex structures and mechanical properties. In this review, the Achill tendon anatomical structure, mechanical properties, and risk factors of rupture have been discussed. This is a considerably huge amount work that needs to be carried out; as such, future direction in tendon biomechanical engineering is proposed in hope that this review will give information on future tendon biomechanical engineering.

Keywords: Achilles tendon, Mechanical properties, Risk factors

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Introduction

The tendinous portions of the gastrocnemius and soleus muscles merge to form the Achilles tendon.¹ Achilles tendinopathy, including tendon rupture, occur at a rate of about 250,000 per year in the US alone.^{2,3} The incidences of Achilles tendon ruptures have significantly increased over the last 20 years,^{2,4} achieving, within the tendon disease, an incidence between 6 and 18%.⁵⁻⁷ The Achilles tendon rupture etiology remains poorly known^{8,9} and it is essentially based on two main theories: the degenerative theory and the mechanical theory.

In humans, the Achilles tendon is the thickest and strongest tendon that sustains some of the largest tensile loads in the body.¹⁰ Dysfunction and injuries are commonly seen in the Achilles tendon. The fibrous matrix of tendons mainly consists of collagen and a small amount of elastin, which are produced and maintained by tenoblasts and tenocytes.¹¹ Tendon consists primarily of collagen (70-80% of the tissue's dry weight) and less than 5% tenocytes and tendoblasts.¹² These insoluble elements are embedded within a hydrated environment containing ground substance of proteoglycans, glycosaminoglycan (GAG) and some other small molecules.¹³

The mechanism of tendinopathy and rupture is complex and thought to be influenced by tendon geometry, material-strength, sex, disease and genetics. Achilles tendon rupture is typically reported to occur at 2-6 cm above the insertion of the calcaneus bone, in a region that is hypovascular.¹⁴ It is not understood why this region receives poor blood supply and is prone to rupture.

Research on Achilles tendon has been going on for some time, with the hope of overcoming the present problems. Usually, mechanical and structural information about Achilles tendon are necessary to facilitate studies in biomechanical, tissue engineering, surgical and rehabilitation fields.

Methods

In this review, we try to find mechanical properties in vivo and in vitro because of calculating the human Achill tendon's properties passively and actively. In addition, identifying of structure and risk factors of Achill tendon can provide appropriate information to scientists.

Results

Mechanical properties

The functional and mechanical behavior of human skeletal muscle are in many ways unknown during natural and artificial locomotion. To gain more insight into these questions a method was developed to record directly in vivo and in vitro forces from the human Achilles tendon. The Table 1 shows the mechanical properties of the Achill tendon.

Structure of fibrous matrix

The Table 2 shows the biomechanical constituents of the Achill tendon. The recent study¹⁵ showed that while the majority of the Achilles tendon is supplied by the posterior tibial artery from its medial edge, the peroneal artery provides supply to the middle section of the tendon laterally. The midsection of the Achilles tendon was found to be hypovascular in all cases of the study.

Risk factors

The Achilles tendon is the most frequently ruptured tendon. The Table 3 shows the risk factors of the Achilles tendon rupture. The ruptured Achilles tendons show various forms of degenerative tendinopathy. It is not known why there are differences in types and amounts of degeneration between individual tendons, although there is evidence suggesting that decreased arterial blood flow, resulting local hypoxia and impaired nutrition and metabolic activity are the key factors. A sedentary lifestyle has been proposed as the main reason for poor circulation in the tendon.

Discussion

This research investigated the properties of human Achilles tendon materially, mechanically, anatomically, and pathologically. The human Achilles tendon is the thickest and strongest tendon among all of human's tendons.¹⁰ The incidence of total Achilles tendon rupture has increased during the past decade. The rise is more prominent among men and in the context of sports-related injuries. Majority of ruptures occurs in recreational involved in sports requiring bursts of jumping, pivoting and running (Table 3). Lack of a universal, consistent protocol

for passive and active evaluation of Achilles tendon has prevented any direct comparison of results. This paper makes it possible to analyze and compare the results and seek prognostic factors related to the results.

Table 1 Summary of structural and mechanical properties of human Achilles tendon

Type of study	Age (y)	Loading rate	Ultimate strength (MPa)	Ultimate strain (%)	Tangent modulus of elasticity (MPa)	Maximal force (N)	Deformation (mm)	Stiffness (N/mm)	Young's modulus (MPa)	Hysteresis (%)	Elongation (mm)	Tensile force (N)	Yield stress (MPa)	Yield strain (%)	Reference
T	36-50	10%/s	73±8	21±4	459±54										21
	52-67	10%/s	73±13	25±3	401±59										
		100%/s	81±14	21±1	545±43										
	79-100	10%/s	48±16	22±8	333±109										
	36-100	10%/s	59±16	22±7	375±102										
V						1924±229	2.2±0.6	2622±534							22
T	35-80	1%/s							816±218				71±17	BT 12.8±1.7 MD 7.5±1.1	23
		10%/s							822±211				86±24	BT 16.1±3.6 MD 9.9±1.9	23
T			~67 >70										100		23, 24, 25
V			W 59 R 111 R 57.4									W 1400- 2600 R 3100- 5330			23 24
			~100 44.4	4-10					1000-2000						26 28
T										10 5-10 <12					26 27
V										S 7 G 24					26 27
			~20-42	~5-8		~200-3800		~17-760	1200 (300- 1400)	18(11-19)	2-24				26
V								193±18a 207±22b		5±2a	13±1.2a 14.3±0.9b				27
T									1160±150	18±3					29
T	36-100		59±18	22±7	375±102			685±262							30

Values are in second: mean ± SD. Abbreviation: R (running), W (walking), V (in vivo), T (in vitro), BT (bone-tendon), MD (midsubstance), S (attach to soleus), G (lateral and medial Gastrocnemius), 10% and 80% of maximum voluntary contraction (MVC) forces at fast (a) and slow (b) loading rates.

Table 2 The biomechanical constituents of Achilles tendon

Contents of fibrous matrix	Value (%)	Explanation	Reference
Collagen I	95%	All of collagens 70% (dry weight)	16,17
Collagen II			17
Collagen III			16-18
Collagen IV			17
Collagen V			17,19
Collagen VI			17
Elastin	1-2% (dry weight)	*Bearing of 200% strain before failure *Produced and maintained by tenoblasts and tenocytes	16-18,20
Blood supply	Values are in percent.	Posterior tibial artery Peroneal artery	15

Table 3 Summary of Achilles tendon rupture (ATR) risk factors

Cause	Explanation	Range	Reference
Middle-aged	Decreasing blood flow rate Increasing stiffness Decreasing the ability to withstand stress	30 - 40 y 40 - 50 y	31,36,41 40
male	Male relative to female	1.7:1 - 12:1 2:1 - 19:1 2:1 - 12:1 5:1	31 32 37,38 41
Serum lipid profile (hyperlipidemia)	Total cholesterol (TC) Triglyceride (TG) LDL-C VLDL-C		31,33

Table Continued...

Cause	Explanation	Range	Reference
O blood group			31,33,34
Inflammatory conditions			31,36,37
Autoimmune disorders			31,36,37
genetic	Collagen abnormalities		31,36,37,42
Infectious diseases			31,36,37
Neurological disorders			31,37
drugs	Injectable steroid (corticosteroid) Antibiotics (fluoroquinolone)		31-33,36,37
Decreased blood flow rate	With increasing age Lowest vascularity area at approximately 2-6 cm from the calcaneal insertion (80% ATR) Male Loading conditions		36,37 32,35,37,38 37 37
Sport activity	Recreational (75% compare with competitive 8-20%) Frequent jumps and landings Great speed variance & rapid footwork	Gymnastics Cheerleading Dance Soccer Football Basketball Tennis Long-distance running	32,37,39
Degeneration (degenerative theory)	Increasing of Collagen III and V		32,33,37
Violent muscular strain	Acute rupture		32
Left side	Right-sided dominance and pushing off with the left		32,41
Repetitive overuse (mechanical theory)	Accumulating of micro-trauma		32,36,37
Dehydration			33
Hyperuricemia			33
Ankle equinus			36
Achilles calcification			36
Abnormal pronation and mechanics	Subtalarhyperpronation		36,37
Hyperthermia	During exercise (after 30 minutes)		33,37
Tendon geometry			38
Material-strength			38

Conclusion

This article tries to help the future studies are about the injuries, rehabilitations, pathology, tissue engineering, and bio-mechanical engineering of Achilles tendon.

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None.

Conflicts of interest

None.

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