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CARACTERÍSTICAS SONOANATÓMICAS DEL COMPLEJO AQUILEO-CALCÁNEO-PLANTAR

SONOANATOMICAL FEATURES OF THE ACHILLES-CALCANEUS-PLANTAR COMPLEX

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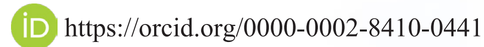
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“La recompensa de nuestro trabajo no es lo que obtenemos,
sino en lo que nos convertimos”.

Paulo Coelho

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LISTADO DE SIGLAS Y ABREVIATURAS

SACP: Sistema Aquileo Calcáneo Plantar

TA: Tendón de Aquiles.

GM: Gastrocnemio Medial

GL: Gastrocnemio Lateral

MS: Músculo Sóleo

CSA: Cross sectional area / Área del tendón.

UMT: Unión Miotendinosa

UOT: Unión Osteotendinosa.

PG: Proteoglicanos.

FP: Fascia Plantar.

US: Ultrasonidos.

RMN: Resonancia Magnética Nuclear.

UTC: Caracterización tisular por ultrasonidos.

PST: Teoría de Estrés de Tejidos.

UDA: Unidad Docente Asistencial.

OEPM: Oficina Española de Patentes y Marcas.

FPI: *Foot Posture Index.*

LMF: *Left Medial Fascicle Plantar Fascia.*

LCF: *Left Central Fascicle Plantar Fascia.*

LLF: *Left Lateral Fascicle Plantar Fascia.*

RMF: *Right Medial Fascicle Plantar Fascia.*

RCF: Right Central Fascicle;

RLF: *Right Lateral Fascicle Plantar Fascia.*

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SEM: *standard error of measurement.*

MDC: *Minimal Different Changes.*

CI: *Confidence Interval.*

FPI : *Foot Posture Index.*

CEUMA: Comité de Experimentación de la Universidad de Málaga.

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CAPITULO I

MARCO CONCEPTUAL

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1. INTRODUCCIÓN.

1.1. Función del Tendón y Estructura.

El tendón es un tejido conectivo en forma de cuerda que conecta un hueso con un músculo(1,2), transfiriendo las fuerzas musculares al sistema musculoesquelético(3).

El tendón en su conjunto tiene la capacidad de realizar las actividades locomotoras (caminar, correr, saltar), es decir, son tejidos que experimentan tensión, elongación y compresión(4,5). El tendón actúa como una palanca/brazo para ayudar a controlar la velocidad del cuerpo y que este pueda moverse protegiendo a los músculos por estiramiento excesivo(5).

Cada vez existe un creciente interés en clasificar la heterogenia y la forma del tendón con respecto a la función que realizan. Principalmente se clasifican en dos(6):

- **Tendón de posición**: son aquellos tendones que inician el movimiento mientras transmiten una fuerza ejercida por el músculo al hueso.
- **Tendón de carga**: son los que almacenan y liberan energía bajo las cargas aplicadas.

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Aunque ambos tipos de tendones poseen propiedades viscoelásticas, los tendones posicionales, al funcionar como un resorte, poseen menos propiedades de este tipo y mayor extensibilidad(7).

El tejido del tendón viene derivado del tejido mesenquimatoso(8), existen varias formas y tamaños en función a los músculos que están asociados. Por tanto, la estructura de un tendón va a depender de su ubicación y de la función que ejerza en el cuerpo. Se puede definir un tendón entre el punto donde se origina un músculo, la unión miotendinosa (UMT), hasta donde se inserta en un hueso, en la unión osteotendinosa (UOT)(9,10).

El tendón es un tejido altamente fibroso(11), compuesto principalmente por fibras de colágeno tipo I (30%) y elastina (2%), entre los que se disponen los tenocitos (células conjuntivas especializadas) y agua (68%); alineadas formando fibrillas en una misma dirección(12).

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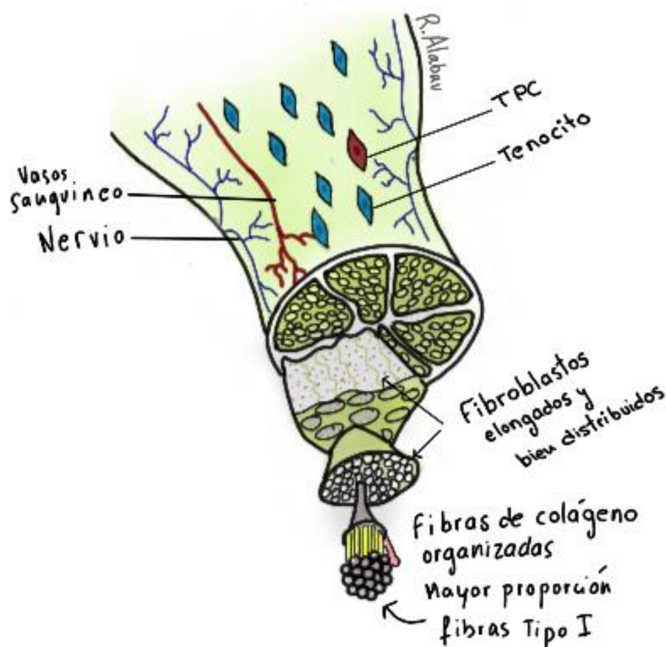

Figura 1. Esquema de la arquitectura jerárquica del tendón de Aquiles. Elaboración propia adaptada de Eriksen(13). [TPC: Células madre tendinosas (tenoblasto)]

El tendón está recubierto por una fina capa de tejido conectivo llamado *paratenon*, que contiene los vasos sanguíneos, las fibras elásticas y las células sinoviales que proporcionan la lubricación y el movimiento en su interfaz con los otros tejidos subyacentes(13). Debajo del *paratenon* hay otra membrana llamada *epitenon*, que se continua con el *endotenon* (también conocida como la matriz interfascicular), que corre entre el haz de colágeno a lo largo del tendón y contiene ramificaciones neurales, vasculares y linfáticas(1).

La vascularización del tendón es pobre e independiente, su superficie vascular representa el 1-2% del total de la matriz extracelular tendinosa(14). La inervación es sensitiva y abundante. Los

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mecano-receptores de tipo III de Golgi son los encargados en la regulación de la contracción muscular(13).

1.2. Organización y composición del tendón.

A nivel ecográfico puede resultar complejo diferenciar un tendón de un ligamento, ambos están compuestos fundamentalmente por colágeno y su porcentaje en agua es similar(15,16) (Tabla 1). Además de comprender su organización y composición la principal característica para saber en qué estructura anatómica nos encontramos es conocer la anatomía y saber que el tendón une complejo muscular con hueso y el ligamento une hueso con hueso(4,17).

El colágeno en el tendón sano normal forma una estructura jerárquica multinivel (Figura 1), en el que el colágeno corre principalmente paralelo al eje longitudinal del tendón(15).

Las células del tendón son los tenocitos y representan el 10% de la masa seca del tendón. Se encargan de remodelar y mantener la matriz tisular, además, están implicados en el inicio y la progresión de la enfermedad del tendón, pero no se conoce el papel exacto que generan(18,19).

Las células madre tendinosas (TPC) o tenoblastos mantienen y reparan los tendones en virtud de su capacidad para autorenovarse y diferenciarse en tenocitos y dependen de la carga recibida. Por esta razón, los TPC también pueden ser responsables de la lesión tendinosa

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crónica, o tendinopatía, en respuesta a una carga mecánica excesiva(20).

El colágeno es de tipo I, está compuesto por dos cadenas D1 y una D2, combinadas para formar una triple hélice de colágeno. Estas moléculas de colágeno se unen formando fibrillas, fibras y fascículos dando lugar a la unidad tendinosa(21).

Tabla 1. Diferencias entre la estructura del tendón y ligamento(22)**.**

ESTRUCTURA	TENDÓN	LIGAMENTO
TIPO DE CÉLULA	Tenoblasto y tenocito	Ligamentocito
% COLÁGENO	95%	70-80%
COLÁGENO TIPO I	95%-99%	90%
COLÁGENO TIPO III	1-5%	10%
ELASTINA	Escaso (<2%)	Hasta 2x de colágeno
AGUA	60-80%	60-80%
ORGANIZACIÓN	Organizado	Más aleatorio
ORIENTACIÓN	Orientación del eje largo	Entrecruzado según patrón del tejido

En su composición, el peso húmedo del tendón es aproximadamente un 70% de agua(23). El peso seco, entre el 70-80% es colágeno tipo I y entre el 20-30% restante está compuesto por sustancia fundamental y otros tipos de colágeno(24), como el tipo III. La sustancia fundamental es el término genérico que describe la matriz

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del *endotenon* principalmente no colágena que rodea al colágeno en cada nivel jerárquico. Esta sustancia contiene proteoglicanos (PG), glucosaminoglicanos, glicoproteínas estructurales y otras moléculas pequeñas(25).

Los PG actúan directamente en la formación y fibrilogénesis del colágeno, formando los tendones, aunque las funciones de los PG van a variar dependiendo de la ubicación en el tendón(19). Los tipos más comunes son la fibromodulina, hialuronato, lubricina y lumican; y el más abundante en el tendón es decorin (18)

1.3 Mecánica del tendón.

El tejido tendinoso se caracteriza por su flexibilidad, elasticidad y resistencia mecánica gracias a las características de las fibras de colágeno. La fuerza y la resistencia viene dado por el número y el tipo de enlaces formados intermolecular entre las fibras de colágeno(22).

Las estructuras tendinosas poseen una alta capacidad resistiva a la tracción y elasticidad cuando se les aplica una carga, pero también están sujetas a la deformación cuando aplicamos una tensión/carga extrema(26).

La resistencia a la tracción del tendón/ligamento depende en gran medida del entrecruzamiento de las fibras de colágeno(27). Las investigaciones(28) *in vitro* de la mecánica del tendón aislado sujetan

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los extremos proximal y distal del tendón para someterlo a un estiramiento/carga continuada y observar cómo se comporta.

La curva(28,29) de tensión-deformación recoge todas estas características y nos resulta muy útil para comprender las propiedades genéricas del tendón. (Figura 1).

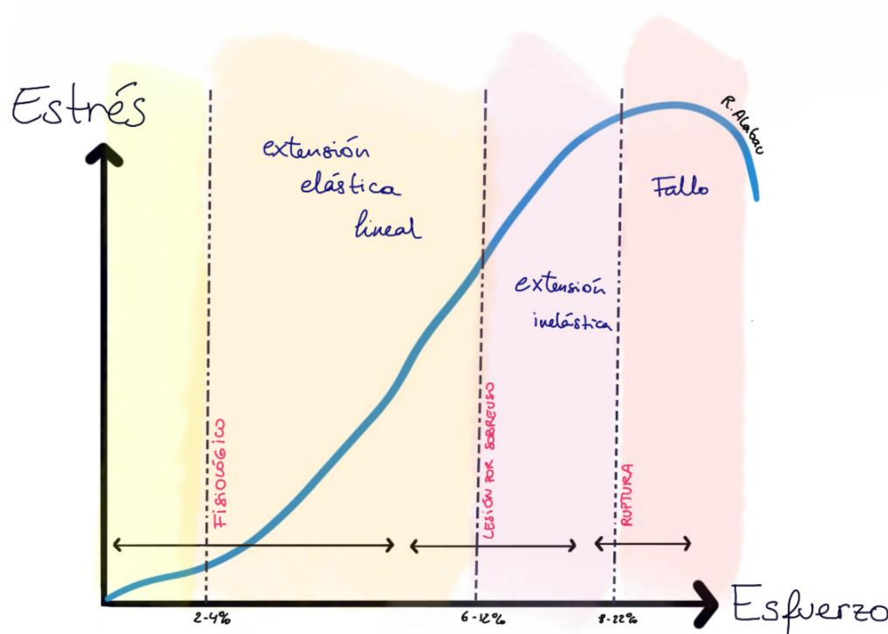

Figura 2. Ilustración esquemática de la curva de tensión deformación del tendón, que muestra cuatro características distintas en cuatro regiones principales(28)

Elaboración propia adaptada de Maganaris y Narici. Mechanical Properties of Tendons. Jan 1, 2005. Nº de Licencia 5700930883403.

En la curva de tensión-deformación del tendón muestra cuatro características distintas en cuatro regiones principales.

a. La primera región (I) llamada región del dedo del pie (Figura 2. color amarillo) es una línea inicial cóncava, por debajo de 4% de tensión, aquí los enlaces de las fibras de colágeno son estables se deforman y se enderezan de forma reversible(30).

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b. La región lineal (II) representa la región elástica del tendón hasta tensiones de 6-12%(31). En esta región se puede obtener el módulo de Young, que es un método de calcular las propiedades viscoelásticas de los materiales sabiendo sus dimensiones.
c. Las regiones (III y IV) es a partir de los 8% de tensión, aquí algunas fibras comienzan a fallar (región III), si la fuerza o la tensión de deformación sigue aumentando conlleva al fallo o ruptura del tendón (región IV).

La capacidad viscoelástica del tendón se cree que viene dada por la unión del colágeno (elástico) con los proteoglicanos y el agua (de propiedades viscosas)(28). La combinación de los comportamientos viscosos y elásticos demuestran comportamientos dependientes como la histéresis mecánica, la relajación de la fuerza y la fluencia(32). La viscoelasticidad hace que los tendones sean más deformables a velocidades de deformación bajas, pero menos deformables a velocidades de deformación altas. Por lo tanto, los tendones a bajas velocidades de deformación tienden a absorber más energía mecánica, pero son menos efectivos para transportar cargas mecánicas. Por otro lado, a altas tensiones, los tendones se vuelven más rígidos y más efectivos para transmitir grandes cargas musculares al hueso(31).

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1.4. Tendinopatía y Envejecimiento del tendón.

Las lesiones del tendón se clasifican en agudas o crónicas según el tiempo de evolución siendo múltiples los factores que las provocan. Los factores intrínsecos incluyen la edad, el sexo, el índice de masa corporal, la inestabilidad de tobillo, disfunción muscular del complejo del tríceps sural, disminución del rango articular del tobillo, mientras que los factores extrínsecos son el efecto del calzado, el entrenamiento y el estado de las superficies, los patrones y las técnicas de entrenamiento(33–35).

Existe controversia en la clasificación del término tendinopatía(36). Por lo general, se considera lesión aguda cuando un tendón es lesionado como resultado de un accidente o por un factor extrínseco. Mientras que, una lesión crónica se relaciona generalmente por un uso excesivo o por cargas repetitivas que pueden estar relacionados o no con los factores intrínsecos(37).

Las lesiones tendinosas y la rotura tendinosa suelen englobarse bajo el término "tendinopatía", un término que puede utilizarse para describir la tendinitis, que es el dolor en el tendón debido a una inflamación, y la tendinosis que es dolor sin inflamación(36).

Las tendinopatías se producen en diferentes partes del cuerpo. Las más frecuentes son las tendinopatías del tendón de Aquiles y del rotuliano(4), y se caracterizan por presentar un dolor muy localizado,

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asociado con altas cargas recibidas por el tendón. Otras regiones comunes donde se producen las tendinopatías son: pubis (aductores), hombros (manguito rotador), codo (complejo extensor) y cadera (glúteos). En términos generales, el dolor se localiza en la inserción del tendón o en las estructuras adyacentes, en la prominencia ósea (tendón rotuliano y glúteo), aunque también puede darse en porciones medias como por ejemplo en el tendón de Aquiles(38).

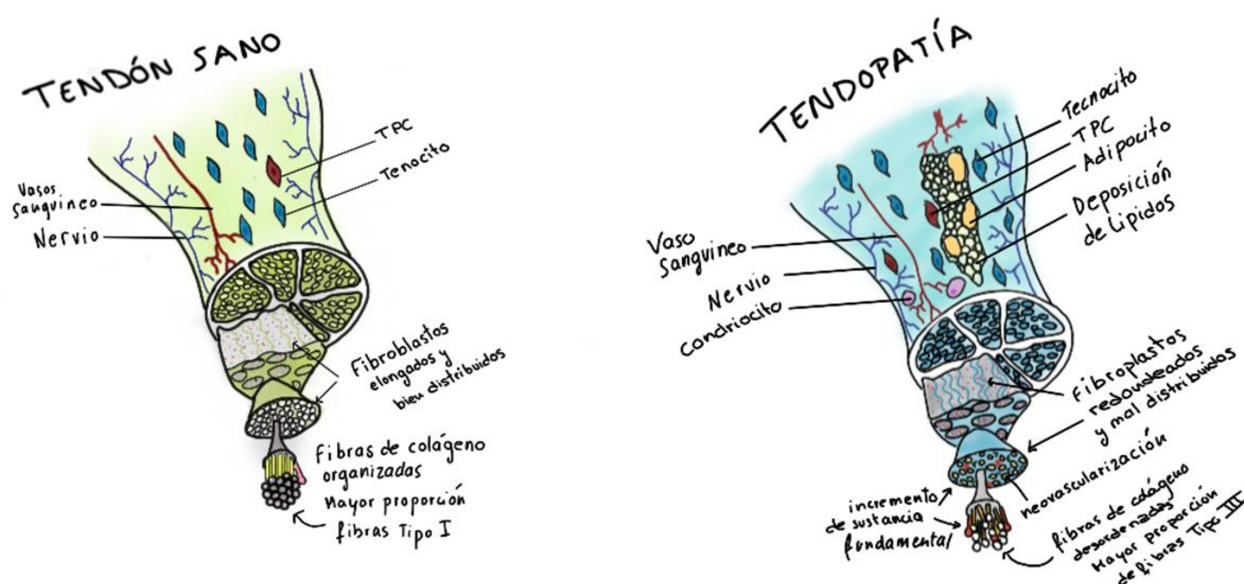

Figura 3. Diferencias en el esquema de la arquitectura jerárquica de un tendón sano y un tendón patológico. (Elaboración propia adaptada de Eriksen(13). [TPC: Células madre tendinosas (tenoblasto)]

Visualmente, un tendón sano tiene un color blanco, pero cuando se desarrolla una tendinopatía tiene un aspecto gris o amarillo (Figura 3). Histológicamente, se observa una desorganización de las fibrillas de colágeno de la matriz extracelular no colágena (proteoglicanos y glicosaminoglicanos), hipercelularidad y neovascularización(39,40).

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Estos cambios fisiológicos (Tabla 2) alteran las propiedades mecánicas del tendón y disminución de la fuerza y el movimiento(41).

El concepto de la tendinopatía ha ido evolucionando a lo largo de los años y se han descrito varios estados patológicos en la patología del tendón. En los años 90, la tendinopatía se describía como un proceso degenerativo con cambios estructurales irreversibles en el tendón(42). Otra teoría define que la tendinopatía aparece en una fase de regeneración, cuando hay presencia de células (tenocitos y tenoblastos) y aumento en la producción de proteínas funcionales(43). Fue complejo crear un modelo experimental único que fuera capaz de relacionar la patología tendinosa con la carga recibida (44).

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Tabla 2. Procesos celulares de degeneración de un tendón.

NIVELES	DEGENERACIÓN	DESCRIPCIÓN
CELULAR	TENOCITO	Pérdida de la forma alargada y orden.
	DESORGANIZACIÓN CELULAR	Alteración del núcleo. Apoptosis aumentada.
	SIGNOS DE HIPOXIA CELULAR	Infiltración vacuolar y grasa; Alargamiento de lisosomas y degranulación del RE.
	NEO VASCULARIZACIÓN	
MATRIZ EXTRA CELULAR	DESORGANIZACIÓN	Fibras colágenas presentan variación en diámetros y dirección de las fibras.
	↓ COLÁGENO TIPO I	Disminución
	↑COLÁGENO TIPO III/IV	Pérdida de capacidad tensil.
	GLICOSAMINOGLICANOS	Disminución global
	PROTEÍNAS FUNCIONALES	Aumento de Biglycan y Fibronectina.
	METALO-PROTEINASAS	Alteración de homeostasis.

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Se han descrito diferentes modelos(43–45) y todos ellos se pueden dividir en tres categorías, basados en los procesos histológicos siguientes:

a) Degradación/rotura del colágeno.

b) Inflamación.

c) Respuestas de la célula tendinosa.

Coombes en 2009 y Littlewood en 2013 hablan de la integración del sistema nervioso central y el dolor con la patología(46,47); sin embargo, ninguno de estos modelos ha considerado la posibilidad de un proceso continuado.

Cook y Purdam propusieron en 2009 el modelo Continuum(44), con el objetivo de comprender mejor la patología tendinosa. El Continuum se basa en las características de tres estados tisulares: tendinopatía reactiva, tendón desestructurado y tendinopatía degenerativa (Figura 3). A diferencia de otras propuestas(46,47), el modelo Continuum describe cambios continuos en la estructura del tendón. Cada estado de la estructura del tendón representa una presentación clínica particular y requiere un tipo particular de manejo (tratamiento). El estudio del modelo *Continiuum* se respalda con evidencia observada en estudios histopatológicos, estudios de imagen y estudios clínicos, y siendo el más actual es el que se utiliza para el análisis de patologías de los tendones Figura 4. (48–52).

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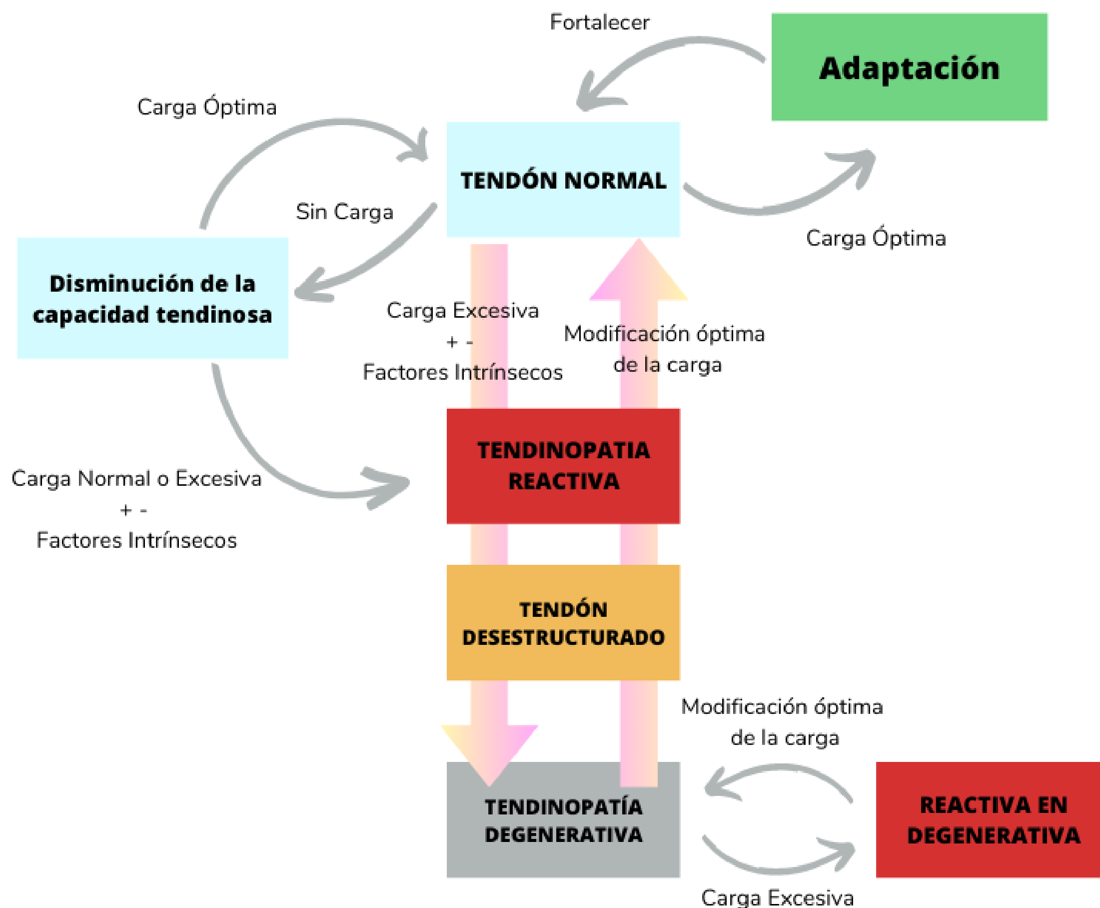

Figura 4. Esquema de la transición de la tendinopatía normal a la degenerativa. Adaptado de J. Cook(44)**. (Elaboración propia).**

(44)La primera etapa se denomina tendón reactivo y se inicia cuando aparece una sobrecarga que implica respuesta inflamatoria y proliferación celular. Se estimulan las proteínas de la matriz extracelular, especialmente los proteoglicanos y el colágeno que aumentan el CSA del tendón. En esta fase, el tendón puede recuperarse completamente. Sin embargo, si la sobrecarga se mantiene, el recambio de la matriz continúa y empieza a alterar el colágeno(44)provocando la desestructuración del tendón (44).

Al evaluar una tendinopatía clínicamente, las imágenes por resonancia magnética y ecografía pueden permitir al clínico a

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diagnosticar estos estadios de la tendinopatía. Cuando se alcanza un estado degenerativo irreversible con mucha actividad celular y graves alteraciones de las fibras de colágeno en la matriz se puede visualizar ecográficamente (53).

La lesión tendinosa provoca una interacción entre estructura, dolor y función, y a esto se le denomina cuadro clínico de la tendinopatía(44,51). El modelo más actualizado por Cook et al en 2016 revisa y evalúa el contexto de las nuevas pruebas. 1) Se resumen las nuevas evidencias en la investigación de la tendinopatía, 2) se analiza el dolor tendinoso y la relevancia de un modelo basado en la estructura y 3) se describe los elementos clínicos relevantes (dolor, función y estructura) para empezar a construir una mejor comprensión de la afección. Esta actualización del modelo orienta al clínico a utilizar tratamientos más específicos y a mejorar los resultados de los pacientes (51).

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1.4.1. Salud y envejecimiento de los tendones.

La lesión del tendón es común en los atletas, con una mayor incidencia en hombres que en mujeres(54). Aunque, cada vez existe una mayor prevalencia de lesión tendinosa en la población sedentaria(33). Wang et al., 2022 halló que la prevalencia global de tendinopatía de Aquiles era de 0,06 (IC 95%, 0,04-0,07).

El envejecimiento de la población aumenta con el avance de la tecnología en medicina(55). La población cada vez está más envejecida por todo el mundo y en particular en los países desarrollados debido a la mejora de la calidad de vida y de los servicios sanitarios(55,56).

Según el Departamento de Salud del Reino Unido y Age UK, el 58% de las personas de 60 años o más informan tener una afección crónica, y el 25% de las personas mayores de 60 años tienen dos o más problemas de salud(56). De estas afecciones, las enfermedades musculoesqueléticas se consideran una de las mayores cargas globales para las personas, aunque (58)aún no se conocen bien los procesos de envejecimiento(35) que se producen en las personas mayores en los tejidos tendinosos.

Entender las alteraciones del comportamiento mecánico del tendón con el envejecimiento es importante para desarrollar protocolos de entrenamiento y rehabilitación en los tendones lesionados. Los primeros estudios sobre la tendinopatía relacionada con la edad se realizaron generalmente *in vitro*, centrándose en la estructura y

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composición del tejido. Estos estudios han demostrado que se observa un descenso significativo de la densidad celular en el tendón lesionado con el envejecimiento(57), una reducción del diámetro de las fibrillas y del ángulo de ondulación, y un aumento de la reticulación del colágeno a nivel celular(23).

Existen estudios que se han centrado en los cambios en el tendón producidos por la edad gracias al desarrollo de métodos para explorar la mecánica de los tendones in vivo. Sin embargo, todavía hay discrepancias en los estudios; se informa de un aumento del tendón(58), también de una disminución(59), o que no existen cambios (60)en las propiedades mecánicas. El consenso general de todos ellos es que aparece una rigidez "*stiffness*" con la edad.

Este hallazgo concuerda con los estudios in vitro(61) de la estructura del tendón, que han demostrado que, a medida que la glucosa se acumula en un tejido entre las moléculas de colágeno, hacen que el tendón sea más rígido de lo normal(62).

No obstante, las correlaciones directas entre estudios in vivo e in vitro son difíciles, ya que los estudios in vivo a menudo investigan las propiedades biomecánicas del tendón en su conjunto(61). Pero en muchas ocasiones, la alteración de las propiedades puede no deberse simplemente a cambios en la estructura del tendón, sino que también puede deberse a cambios en la estructura del complejo músculo-tendón, a cambios musculares(63).

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1.5. Tipos de inserciones musculo-tendinosas.

El aparato locomotor posee un componente fascial y uno musculo-tendinoso(64). El componente fascial está formado por tejido conectivo (epimisio, perimisio y endomisio) y el componente musculo-tendinoso es funcional y dinámico, y lo forman los tendones y las aponeurosis como transmisores de fuerza, así como la fibra muscular que actúa de elemento contráctil (64,65).

En la patología del sistema musculo esquelético es importante distinguir la presencia de la fascia superficial y profunda.

a. La fascia superficial es la capa que envuelve al musculo inmediatamente por debajo de la piel, es la capa grasa subcutánea formada por la propia grasa y por el tejido conectivo denso y laxo(66).

b. La fascia profunda es la capa de tejido conectivo denso más externa y que modela a modo de una envoltura los tejidos subyacentes, separando grupos musculares según su función(64).

Es posible clasificar las lesiones en función de la zona muscular afectada, la lesión se puede situar en el componente fascial o en el musculo-tendinoso Figura 5. Si es componente músculo-tendinoso tendrá lugar en la unión tendón perióstica o en la unión miotendinosa (músculo-tendón)(64,67).

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La lesión muscular afecta siempre la unión musculo-tendinosa (UMT), este tipo de lesión puede afectar a una expansión aponeurótica o tendinosa, o puede afectar a una aponeurosis o tendón intramuscular, si la lesión en la UMT está más cercana al componente fascial dará lugar a una lesión miofascial(8,64).

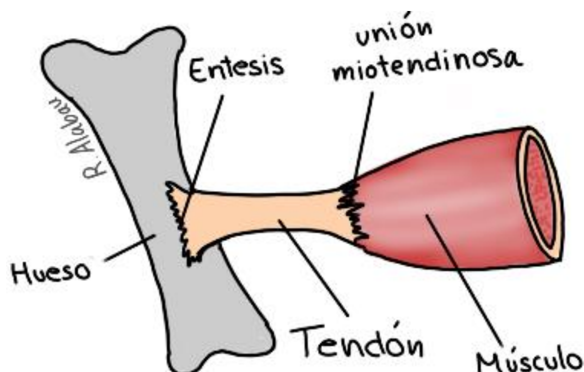

Figura 5.Tendón; desde su origen muscular hasta su unión con el hueso. Elaboración propia.

La lesión de la UMT que se sitúa a nivel de una aponeurosis central "lesión del tendón central o tendón intramuscular", es típica en la extremidad inferior en el tendón central del recto femoral, aductor mediano, recto interno del muslo y del musculo sóleo(64,68).

En la lesión miotendinosa existe un despegamiento entre la fascia y epimisio o entre dos fascias, debido a que la ruptura está muy cercana a éstas y es característica del gastrocnemio respecto al sóleo(64,69).

En la definición del concepto de arquitectura o estructura muscular son varios los autores que nos aportan que **"***la disposición de las fibras musculares dentro de un músculo es relativa al eje de generación de*

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fuerza" la que nos hace referencia al eje mecánico del músculo y la medición de longitudes y ángulos(65,70).

La fibra muscular está formada por sarcómeros en serie de una longitud constante, que son considerados la unidad funcional del músculo(65,71)**.**

Tener mayor número de sarcómeros en serie, que poseen los fascículos más largos proporciona mayor acortamiento por unidad de tiempo y por lo tanto una mayor velocidad de acortamiento del músculo(8,69). Según la arquitectura nos encontramos con:

- **Músculos rectos**, con fibras paralelas al eje mecánico de musculo.
- **Músculos de fibras en dirección oblicua**, con fibras orientadas en un ángulo relativo al eje mecánico.

La morfología tendinosa y la variedad de inserción de las fibras musculares permiten clasificar las uniones musculo tendinosas en diversos tipos(8,72):

- Inserción de extremo a extremo lineal o curviplana, como los músculos anchos del abdomen (Figura 6A)
- Inserción bilateral: las fibras musculares se implantan de forma oblicua en el tendón, como las barbas de una pluma en su tallo

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común; al músculo se le llama peniforme (de *penna,* pluma): por ejemplo, los músculos interóseos palmares. (Figura 6B)

- Inserción unilateral: los haces musculares se insertan de un solo lado, como el músculo semimembranoso o el flexor profundo de los dedos.

- Inserción en un cono tendinoso: los músculos que tienen esta característica se denominan por lo general peniformes con cono tendinoso. (Figura 6D).

- Inserción fascicular en fibras tendinosas que se introducen en el cuerpo muscular como, por ejemplo, el músculo subescapular. (Figura 6E)

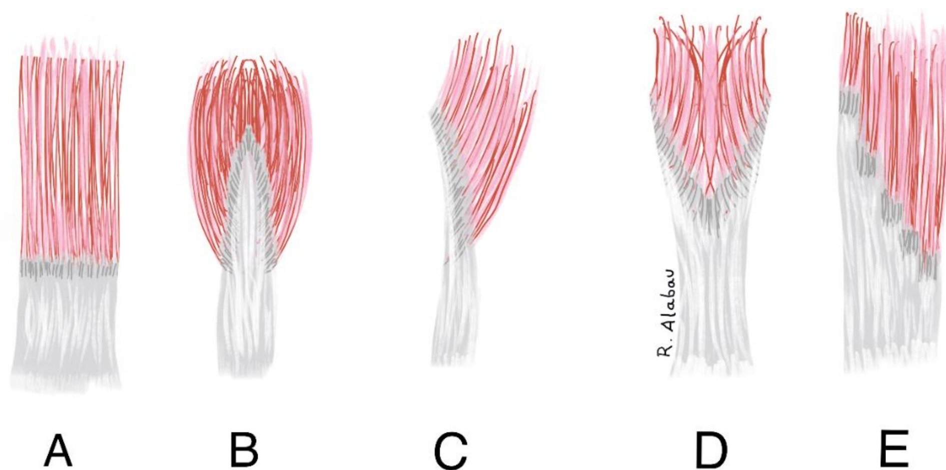

Figura 6. Esquemas de los distintos tipos de unión tendino-muscular. a. Inserción de extremo a extremo lineal o curviplana; b. inserción bilateral; c. inserción unilateral; d. inserción en un cono tendinoso; e. inserción fasciculada. (Elaboración propia).

El diseño arquitectónico de un músculo influye en su capacidad para transmitir, más o menos eficientemente, la fuerza producida por las

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fibras musculares al tendón. Se ha demostrado que entre dos músculos de igual volumen y cuyas fibras actúan con la misma tensión (fuerza/superficie), el peniforme con un ángulo relativamente pequeño, puede ejercer más fuerza que el de las fibras paralelas debido a su mayor eje. Así, se concluye que los músculos de las fibras paralelas son músculos más rápidos, mientras que aquellos de fibras oblicuas son músculos más fuertes(72).

Los músculos de fibras oblicuas permiten almacenar una mayor cantidad de material contráctil en el mismo espacio, por lo que pueden ejercer más fuerza. La contracción muscular provocará grandes modificaciones en la arquitectura muscular(73).

Dentro de la arquitectura del músculo hay diferentes variables que son necesarias de conocer para poder analizar y estudiar las modificaciones que sufre al realizar fuerza.

Las principales variables de la arquitectura muscular son:

- **Angulo de peneación**: hace referencia al ángulo de los fascículos con la aponeurosis del músculo y nos va a influir en la transmisión de fuerza en los músculos con fibras oblicuas respecto al eje mecánico dado que, al aumentar, disminuye la eficacia(73).

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- **La longitud de los fascículos musculares**: los fascículos son fibras musculares agrupadas y envueltas por el perimisio, que son la unidad funcional del músculo(74).
- **Grosor muscular**: es la distancia perpendicular entre la aponeurosis superficial y profunda de un músculo(75), es una medida lineal (para el cálculo de volúmenes musculares), se obtiene normalmente de un corte mediante ecografía(76).
- El **área de sección anatómica transversal** (**CSA**) y **fisiológica** (**PCSA**): la fuerza que un músculo puede producir es proporcional a su **CSA**(77). Es la superficie resultante de un corte perpendicular al eje mecánico de un músculo, es un buen indicador del tamaño real del músculo (78). El **PCSA** es el área resultante de un corte perpendicular a la dirección de todas las fibras en paralelo que forman un músculo. El **PCSA** es igual al **CSA** en los músculos rectos, pero no es así en los músculos de fibras oblicuas.

1.5.1. Ángulo de Peneación.

La peneación permite a las fibras funcionar en la zona óptima de sus curvas tensión /deformación (79,80), pues en los músculos de fibras en dirección oblicua se acortan menos para un determinado recorrido del tendón, debido a que, al acortarse, rotan al mismo tiempo, lo que permitiría a los sarcómeros trabajar más cerca de su longitud óptima durante la contracción. Presentan la desventaja

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mecánica que supone el ángulo de peneación, pues sólo una parte de esta fuerza revierte en el eje del músculo (Figura 7).

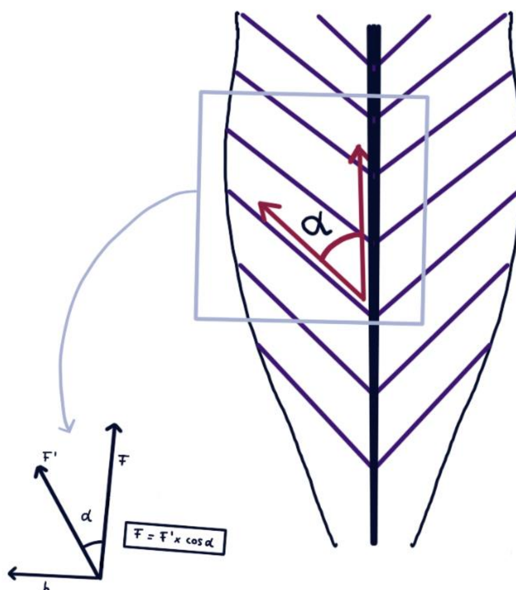

Figura 7. Influencia del ángulo de peneación en la transmisión efectiva de la fuerza al eje mecánico del músculo. F: Fuerza transmitida al eje mecánico. F': Fuerza desarrollada por las fibras musculares. α: ángulo de peneación. h: grosor muscular. (Elaboración propia).

El ángulo de peneación y el grosor muscular aumentan desde el nacimiento hasta el final de la adolescencia, donde alcanzan un valor estable(81). Los pequeños ángulos de peneación que aparecen en las primeras etapas cumplirían la función de proteger los tendones y las inserciones en las aponeurosis de una excesiva tensión(82) .

Los deportistas de carreras de velocidad tienden a poseer menores ángulos de peneación y mayores longitudes de fascículos(83) .

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La hipertrofia muscular lleva a un aumento del grosor muscular, del ángulo de peneación, del CSA y PCSA(78,84,85) Los músculos hipertrofiados presentan mayores ángulos de peneación(86) .

La relación entre el aumento de tamaño del músculo y los cambios en el ángulo de peneación se vuelve a confirmar en el estudio realizado por Aagaard y cols. (85)

En los músculos con mayor hipertrofia, al aumentar el ángulo de peneación disminuye la cantidad de fuerza producida por área de sección transversal (CSA). Esto se explica dado que la hipertrofia del musculo está asociado con daño muscular agudo, caracterizado por dolor muscular, deterioro de la función muscular y daño estructural a las membranas de las células musculares y sus componentes. Estas consecuencias pueden ser perjudiciales para el rendimiento del ejercicio futuro, según Person en su ensayo aleatorizado de diferencias de sexo en el impacto de la carga del ejercicio de resistencia sobre el daño muscular(86–88).

El ángulo de peneación aumenta con la intensidad y el tipo de la contracción, mientras que la longitud de los fascículos disminuye(73,75,89–91).

La atrofia muscular provoca una disminución de los ángulos de peneación y de la longitud de los fascículos(92). Sin embargo, en el estudio realizado por Bleakney y Maffulli(71) se observó la disminución

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de los ángulos de peneación, pero no de la longitud de los fascículos como se había mostrado con anterioridad.

1.6. Complejo Aquileo-Calcáneo plantar.

El sistema Aquileo-calcáneo-plantar (SACP) tiene una función muy importante en la marcha humana y la distribución de la carga (93). Este sistema está compuesto por el complejo del tríceps sural (Figura 8, A y B), el Tendón de Aquiles (TA); cuyas fibras tendinosas se forman a partir de la unión del músculo gastrocnemio medial (GM), músculo gastrocnemio lateral (GL) y el músculo sóleo (MS); y la fascia plantar (FP) (94,95).

A nivel fisio-anatómico existen diferencias en las mediciones del área de sección transversal de cada músculo del tríceps sural, siendo el MS, el músculo que tiene el mayor volumen y el GL el que tiene el menor volumen(94,96).

Los dos músculos gastrocnemios cruzan la articulación de la rodilla, la articulación del tobillo y la articulación subastragalina, por lo que ayudan a la flexión y extensión controladas de la rodilla, flexión plantar y dorsiflexión de la articulación del tobillo, así como la pronación y supinación de la articulación subastragalina (Figura 8). Estos vientres musculares se juntan y se unen en la parte más proximal del tendón de Aquiles en la UMT del gastrocnemio(96).

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El músculo sóleo se origina en el peroné y la tibia (Figura 8B) discurriendo anteriormente en paralelo al músculo gasctrocnemio GL y GM uniéndose distalmente con el tendón del gastrocnemio en la UMT del sóleo. Por el contrario, el sóleo no cruza la articulación de la rodilla, así que sólo ayuda a la flexión plantar y la dorsiflexión del tobillo y a la pronación y supinación de la articulación subastragalina(97).

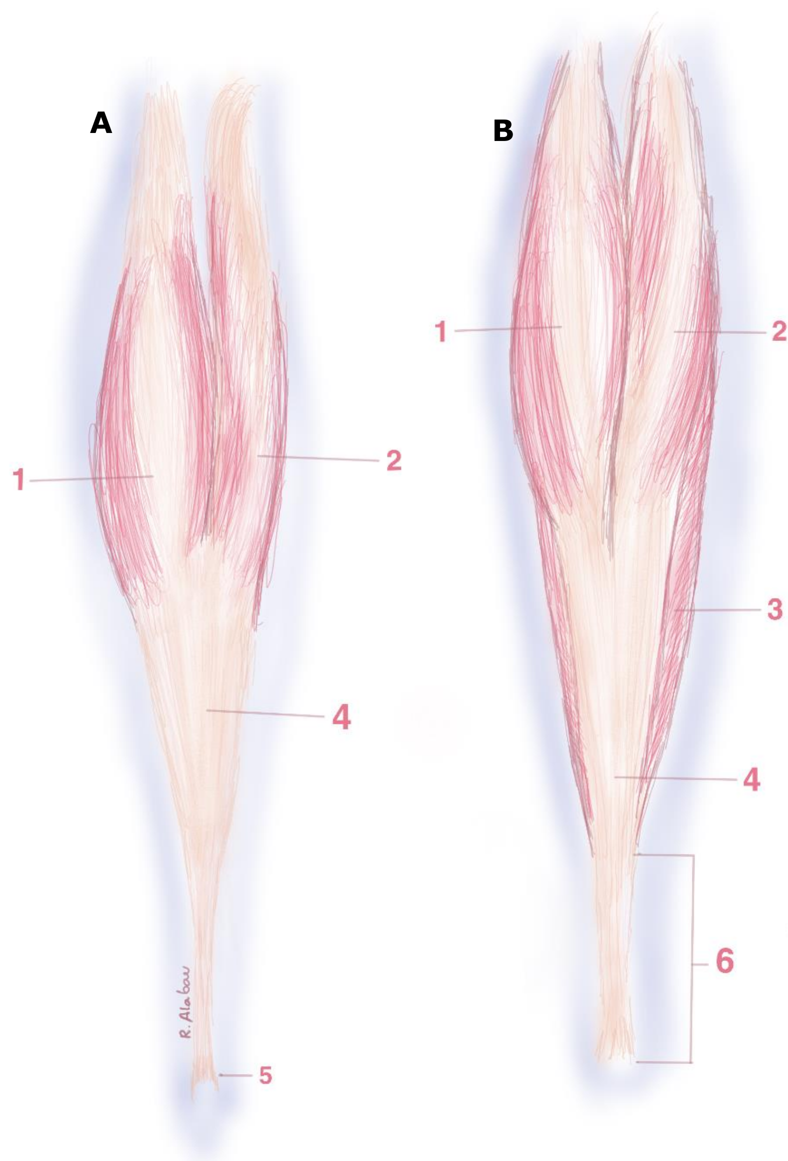

Figura 8. Imagen A y B: Muestran ilustraciones de una vista posterior del grupo músculo-tendón del tríceps sural. GL (1), GM (2), MS (3), TA (4), inserción del TA (5) y Tendón libre del TA (6). Elaboración propia.

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El TA y la Fascia Plantar (FP) juegan un papel vital en la distribución de la carga del pie; tanto el TA como el PF son importantes para absorber el choque mecánico, así como para estabilizar y prevenir el colapso del arco longitudinal durante la propulsión (98). La FP forma una estructura primaria que soporta el arco longitudinal medial del pie, junto con los músculos intrínsecos del pie (99,100). La principal función biomecánica de la FP es reducir los efectos de las fuerzas de reacción del suelo sobre las cabezas de los metatarsianos (101,102). El TA también tiene la capacidad de almacenar y liberar energía potencial elástica durante el movimiento, lo que ayuda a ahorrar energía metabólica (101). Sin embargo, existe debate sobre la relación morfológica y funcional entre el TA y la FP y si estas dos estructuras están conectadas.

Varios estudios (102–105)han encontrado un vínculo biomecánico entre el TA y la FP al medir las propiedades de carga-deformación. Este vínculo biomecánico proporciona fundamentos para la hipótesis de que existe una continuidad entre el TA y la FP (106). De hecho, algunos autores han descrito una continuidad de por vida entre las dos estructuras(107), mientras que otros solo coinciden en que la continuidad se da en una población fetal o neonatal(108,109), y otros concluyen que la conexión cesa en la edad adulta tardía(107).

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1.7. La Fascia Plantar.

1.7.1. Anatomía de la Fascia plantar.

La fascia plantar (FP) es una estructura anatómica formada por tejido conjuntivo que se encuentra situada en la planta del pie. Esta estructura tiene su origen en la cara antero medial del calcáneo y se extiende distalmente en forma de abanico en cinco bandas digitales, insertándose a nivel proximal con la tuberosidad medial del calcáneo y a nivel distal con en las articulaciones metatarsofalángicas de cada dedo. Su estructura mecánica e histológica está constituida por fibras de colágeno, guardando una estrecha relación con la estructura fisiológica de un tendón.(110,111)

Se compone de 3 partes diferenciadas: banda medial, central y lateral. La banda central es la más gruesa, coincidiendo con la tuberosidad del calcáneo en su inserción. Las fibras de la fascia plantar también se mezclan con la dermis, los ligamentos transversos de los metatarsianos y las vainas tendinosas de los tendones flexores. Sus fibras más proximales conectan con el tendón de Aquiles a través de las trabéculas y el periostio del hueso calcáneo(110).

La FP tiene un gran papel en la biomecánica del pie, puesto que esta estructura forma el arco longitudinal medial, además, interactúa con los mecanismos de propulsión disipando las fuerzas y energías que implican al pie durante la marcha o en otras condiciones de carga repetitiva como es la carrera continua(99). Recientemente se demostró

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que la FP es capaz de almacenar energía de deformación y convertirla en fuerza de propulsión, comportándose como un tejido cuasi-elástico(112,113).

Sin embargo, se ha prestado poca atención a los aspectos anatómicos-histológicos de la FP. Se la ha considerado como una aponeurosis porque casi todas sus fibras son de colágeno tipo I y están dispuesta en longitudinal(99,110). Todavía no se sabe nada de su contenido en fibras elásticas o las características de su matriz extracelular(99).

1.7.2. Cambios histológicos asociados a la degeneración de la Fascia Plantar.

Las alteraciones estructurales que ocurren en un tendón afectado desde el punto de vista histológico se han citado a lo largo de este trabajo, pero en la FP es importante tener en cuenta el concepto biomecánico del pie y las implicaciones que esto conlleva(13).

Cuando las tracciones excesivas persisten, el proceso natural de reparación no es capaz de hacer frente a las constantes exigencias mecánicas. El tejido intenta repararse aumentando el colágeno tipo III en detrimento del colágeno tipo I. Se produce una inmadurez en los tejidos con presencia de hipervascularización y fibrosis porque la reparación no es del todo exitosa. La FP se engrosa y pierde su elasticidad. La rigidez mecánica de una FP degenerada es 5 veces

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superior a la de una fascia sana. Por tanto, la estructura es inestable y vulnerable a las tracciones. Todos estos cambios estructurales producen una disminución de las propiedades biomecánicas de la FP y pueden dar origen al dolor, además de ser la causa de la cascada de acontecimientos en el fracaso del proceso de reparación natural. El patrón tisular normal es sustituido por tejido cicatricial indiferenciado y esto puede derivar en convertir a la fasciopatía plantar en una patología recalcificante(42,114–116).

1.7.3. Epidemiología e Etiología de la patología de la Fascia Plantar.

La fascitis plantar tiene un impacto negativo en la funcionabilidad y la calidad de vida de las personas que la padecen(117). Afecta tanto a deportistas como a las personas sedentarias. Sin embargo, en corredores de larga distancia se observa incremento de fascitis plantar si se compara al resto de población, afecta hasta al 17,4% de la población que corre(110,118). La tendinopatía de Aquiles, La fascitis plantar y las fracturas por estrés son las lesiones de pie y tobillo más prevalentes por sobreuso en el mundo del deporte(119). Una revisión sistemática, mostró una prevalencia entre el 5,2-17,5% en un total de 3500 corredores de fascitis plantar y una incidencia, número de lesiones por cada 1000 horas de carrera, del 4,5-10%(120).

La literatura científica no muestra datos concluyentes para asociar fascitis plantar y género. Tauton et al. en su estudio retrospectivo de

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5 años obtuvo que las mujeres con un índice de masa corporal superior a 21 kg/m ^{2} tenían un riesgo significativamente mayor de padecer fascitis plantar. (121,122) (123). Sin embargo, hay estudios que demuestran que la tendinosis aumenta significativamente su incidencia en relación a la edad, sexo masculino y la obesidad(124–127). Frey y Zamora en su estudio obtuvo que el sobrepeso o la obesidad aumentaban significativamente las posibilidades de tener tendinitis en general. Si los sujetos tenían sobrepeso u obesidad, había una mayor probabilidad, aunque no significativa, de sufrir fascitis plantar.

La etiología de la fascitis plantar es multifactorial(110). En los casos agudos se caracteriza por una clínica que cursa dolor, inflamación y disminución en la funcionalidad. Pero, en las fascitis crónicas no aparecen los signos propios de la inflamación, es decir, presencia de macrófagos, linfocitos y células plasmáticas. Histológicamente, presentan degeneración de los tejidos a nivel de la tuberosidad medial del calcáneo, con una reparación insuficiente de las fibras de colágeno cursando con fibrosis e hipervascularización(128).

Una de las hipótesis más aceptadas es que la fascitis plantar se inicia por un sobreuso, un exceso en las fuerzas de tracción sobre la FP, esta discusión biomecánica implica al mecanismo de “Windlass”, que genera un gran estrés a nivel de la inserción de la fascia plantar con la tuberosidad medial del calcáneo (129). Como se ha citado anteriormente, es pertinente comparar la etiología, la fisiopatología y

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el tratamiento de la fascitis plantar a procesos análogos que se producen en algunos tendones, puesto que la FP tiene una histología muy similar a la de un tendón(110,130).

1.8. El Tendón de Aquiles

El tendón de Aquiles (TA) es el tendón más grueso, fuerte y grande del cuerpo humano(131). Se origina en el músculo gastrocnemio y termina en el hueso calcáneo en el talón(132). La longitud del tendón de Aquiles difiere sustancialmente entre individuos (133), pero la longitud en reposo varía entre 159,8 +/- 20,8 mm y 256+/-19 mm(133). Desde el calcáneo hasta el extremo distal de la unión musculotendinosa del sóleo se conoce como tendón de Aquiles libre (134), con una longitud típica de 64,00+/- 15,35 mm(135).

El área y la forma de la sección transversal del tendón de Aquiles también son muy variables, tanto entre individuos como a lo largo de la longitud del tendón(136). El grosor del tendón oscila entre 4,5 - 8,6 cm cerca de la unión músculo-tendinosa, disminuyendo gradualmente hasta 1,2 - 2,6 cm en la porción media del tendón, antes de aumentar de nuevo a 2,0 - 4,8 cm cerca de la inserción calcáneo. El CSA cambia de ovalada a más redondeada aproximadamente 4 cm por encima de la inserción (137). El CSA del TA es mayor en las personas mayores que en las jóvenes, así como mayor en los hombres que en las mujeres(138). En general, el CSA suele duplicarse en individuos con

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tendinopatía en comparación con las personas sanas normales(139,140).

El tendón de Aquiles se compone de los haces tendinosos que nacen de los diferentes grupos musculares que conforman el tríceps sural. La capa superficial está formada por fascículos tendinosos del músculo gastrocnemio medial, mientras que las capas más profundas se originan en los músculos gastrocnemio lateral y sóleo(139,141). A medida que se va formando el TA, los fascículos tendinosos de los diferentes músculos, forman en tendón de Aquiles libre. Estos fascículos rotan lateralmente a medida que descienden hasta su inserción con la tuberosidad del calcáneo. Se cree que gracias a estas rotaciones el TA es capaz de soportar mejor las cargas y dinámicas y la rotura, previniendo lesiones(96).

La torsión se observa en todos los niveles del tendón de Aquiles, pero calcular el grado de torsión puede ser muy difícil y complejo. Por lo que sólo se ha comprobado mediante estudios in vitro de forma aislada, sin tener en cuenta los factores asociados en el contexto in vivo(94).

La estructura en torsión se observó a principios de 1946 en unas disecciones *in vitro*, y principalmente se basaba en la visualización de los músculos sóleo y gastrocnemio(142). Aunque existe un consenso general en el cual se afirma que existe torsión en el tendón de Aquiles,

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el grado de torsión varía significativamente entre individuos(94) (Figura 7).

La torsión se clasifica en tres tipos; el tipo I es el que menos torsión fibrilar presenta, el tipo II tiene una torsión moderada y el tipo III como torsión extrema (Figura 9, 10 y 11). El tipo I es el más común, con una prevalencia del 48% en la población general, el tipo II (46%) y el tipo III (6%)(141).

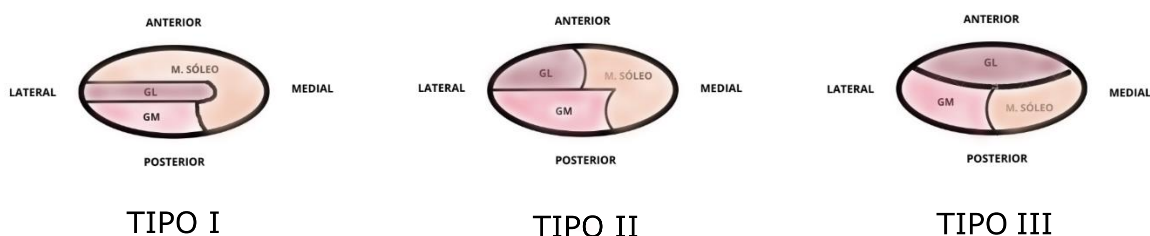

Figura 9. Imágenes que destacan diferentes patrones de "giro" en el tendón de Aquiles, vistas craneocaudales.

Los tipos I, II, III representan grados crecientes de torsión en el tendón, con esquemas que muestran ejemplos de estructuras tendinosas en cada grupo. El circulo debajo de cada fotografía ofrece un esquema de la sección transversal 1 cm por encima de la tuberosidad del calcáneo para mostrar el punto de inserción del subtendón que surge de cada cabeza del tríceps sural. Elaboración propia adaptada de M. Edama, M. Kubo, H. Onishi, et al. Scandinavian Med Sci Sports, Volume: 25, Issue: 5, Pages: e497-e503, First published: 30 December 2014. Nº de Licencia 5701470349831.

En todos los tendones observados se describe una rotación lateral en el sentido de las agujas del reloj para la extremidad izquierda y una rotación lateral al contrario en la extremidad derecha(94,132). La torsión o rotación de las fibrillas de colágeno hasta su inserción con el calcáneo es muy variable y aunque no hay una justificación clara se piensa que esta torsión depende de la postura y/o la posición que adopta el pie(131).

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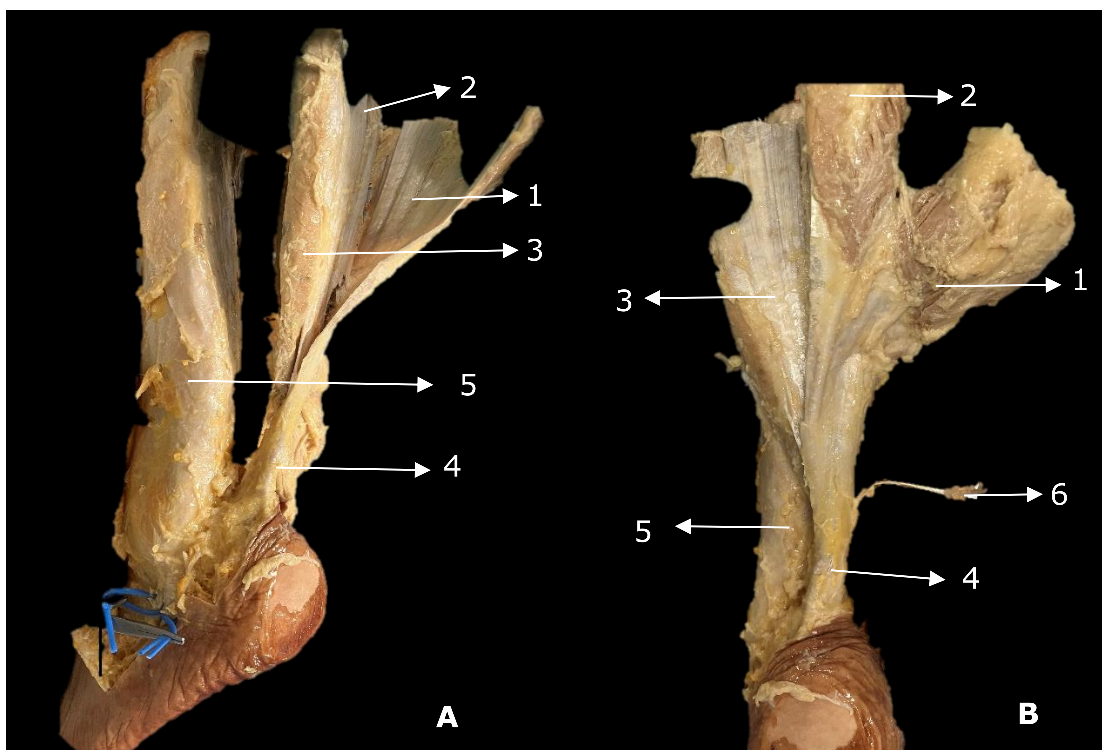

Figura 10.Disección propia realizada en el laboratorio de anatomía de la UMA siguiendo protocolo de disección de Edama.

Imagen A: Vista lateral de la pierna izquierda e imagen B: vista porterior de la pierna izquierda. Se observa disección en planos de los músculos GL (1), GM (2), MS (3), TA (4), Flexor largo del hallux (5), Delgado plantar (6).

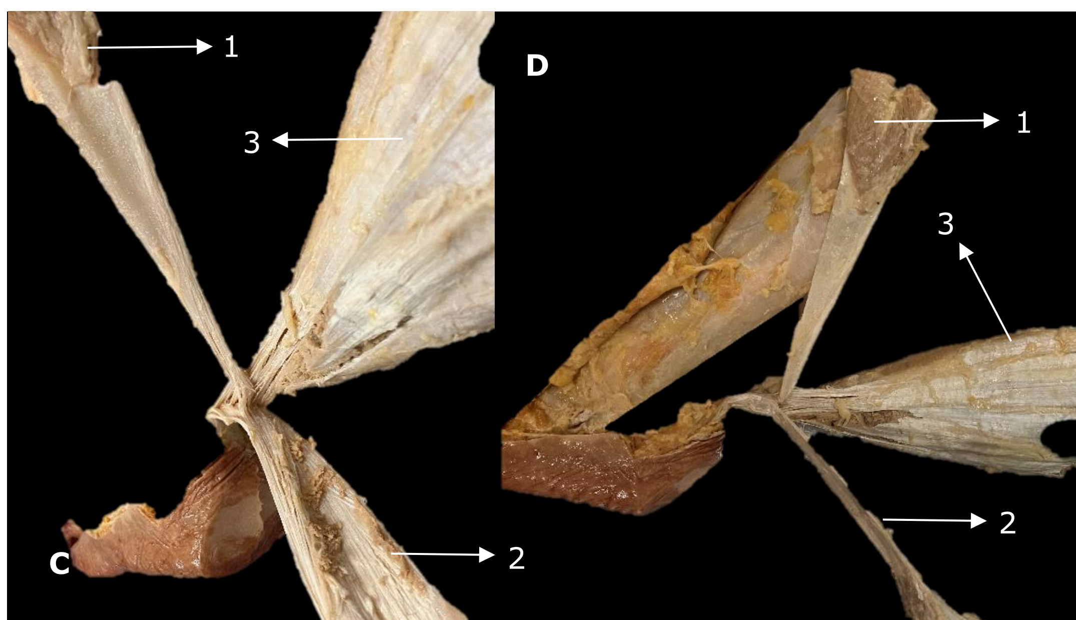

Figura 11. Disección propia realizada en el laboratorio de anatomía de la UMA siguiendo protocolo de disección de Edama.

Imagen C: vista latero-posterior e imagen D: vista lateral. Se observa el trazo de las fibrillas y la torsión de los subtendones del TA. Músculos GL (1), GM (2), MS (3).

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1.8.1. Propiedades biomecánicas del tendón de Aquiles.

El TA es el tendón más grueso, fuerte y grande del cuerpo (Laurent D, 2020). Su origen viene de los tres vientres musculares anteriormente descritos que al unirse en su parte más proximal forman el inicio del tendón de Aquiles hasta el hueso calcáneo(95,131,143).

Actúa como un muelle, almacenando y devolviendo la energía de la tensión (97). Debido a la variabilidad de las dimensiones entre los individuos (longitud de TA y área (CSA)), la curva de fuerza frente a la elongación se estudia habitualmente como una curva de tensión-deformación. La fuerza se normaliza con respecto al CSA del tendón y se expresa como tensión, y la elongación del tendón se normaliza con respecto a la longitud del tendón y se expresa como deformación(144).

Estas propiedades mecánicas del TA se han estudiado *in vitro* (30,145) mediante dispositivos electrónicos. Estas máquinas sujetan ambas extremidades del TA y se someten a tensiones hasta su completa rotura para calcular y observar la región de fallo (apartado 6.3. Figura 1). En el caso específico del TA la curva de tensión-deformación cambia respecto a la de los tendones en general; se inicia con una región inicial curvilínea, seguida de una región lineal antes de alcanzar el límite elástico que es de unos 500 MPa(31). Sin embargo, en estudios recientes sobre las propiedades mecánicas de los subtendones individuales han mostrado una variabilidad en sus

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propiedades, informando de tensiones de fallo de subtendones del 10,1 % (GL), 10,4 % (GM) 14,7 % (MS)(146).

Por otro lado, los estudios *in vivo* del TA no pueden investigar las propiedades de fallo, por lo que se centran en la rigidez y/o en la observación de su comportamiento y sus características morfológicas para explorar el impacto del envejecimiento(147) y la enfermedad(148). Los valores de rigidez *in vivo* notificados para el tendón de Aquiles durante las diferentes condiciones de carga oscilan entre 150 N/mm y 759 N/mm (148–151).

En general, se cree que estas enormes variaciones en los datos son el resultado de los diferentes enfoques experimentales que se adoptan en los diferentes estudios que existen en la literatura. Por esta razón hay que tener cuidado al comparar los estudios. Morgan et al. obtuvieron una correlación entre el peso corporal y el sexo en la mecánica de los tendones, con los tendones sintomáticos, indicando que la rigidez del TA es menor en las mujeres que en los hombres (82) y a su vez aparece una menor rigidez en los pacientes con tendinopatía que en los sanos(152). Sus conclusiones fueron que la edad, el sexo y el índice de masa corporal parecen tener cierta relación con las propiedades mecánicas del tendón.

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1.8.2. Epidemiologia y diagnóstico del tendón de Aquiles.

La incidencia anual de lesiones del TA ha aumentado progresivamente cada año(153,154). Las lesiones del TA son uno de los principales problemas entre los atletas, con una tasa de incidencia del 23,9% entre los atletas profesionales, pero también son cada vez más frecuentes en los deportistas no profesionales(155). Así pues, también son cada vez más comunes en la población general, con un 6% de probabilidad de padecer tendinopatía en el TA en las personas inactivas en algún momento de sus vidas(156).

En los deportistas de élite, los corredores son los más propensos a sufrir lesión, con una tasa de incidencia del 52%. Aunque dentro de los corredores, hay ciertos grupos que parecen más propensos, con una mayor incidencia en los corredores de media distancia(157).

En cuanto al género, Clayton y Court-Brown en su estudio prospectivo analizaron 2794 pacientes que presentaban lesiones ligamentosas o tendinosas durante 5 años. El 74,2% de los pacientes eran hombres, lo que da una incidencia de 166,6/100.000 por año para los hombres y 52,1/100.000 por año para las mujeres. Para el tendón de Aquiles, fue de 11,33/100.000 por año, habiendo una relación 68:32 (hombres, mujeres). La diferencia en las propiedades mecánicas del tendón de Aquiles entre hombres y mujeres parece estar correlacionada con la diferencia en la fuerza muscular, más que con el género (158). Esto puede deberse al menor número de participaciones

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femeninas en el deporte, a los cambios hormonales, a la edad o al volumen de masa muscular en comparación con los hombres(159).

En la práctica clínica, la investigación clínica existente para la tendinopatía de Aquiles se basa en cuestionarios que se centran en ciertas consideraciones como la gravedad del dolor, la amplitud del movimiento y la palpación de la superficie(160). En ocasiones, los resultados de estas investigaciones son sinónimos de otras afecciones médicas como el *tennis leg* (rotura del músculo GM), lesiones ligamentosas, fracturas y lesiones peroneales, lo que dificulta un diagnóstico certero de la tendinopatía del TA(161). Por esta razón, es importante como clínicos controlar el uso de técnicas de imagen por ultrasonidos, que actualmente se ha convertido en la herramienta diagnóstica más común en la clínica practica para abordar los tendones, dado que se obtiene una mayor sensibilidad para diagnosticar los cambios estructurales del tendón(162).

1.8.3. Deformación del Tendón de Aquiles.

La deformación a través del TA se distribuye de forma heterogénea. Los estudios *in vitro* en el tendón de Aquiles y el tendón flexor largo común de los dedos han indicado que la deformación es heterogénea y se debe a la conexión que hay en la matriz que conecta los haces de colágeno que permite el deslizamiento inter-subtendinoso (haz de fascículos) cuando el tendón se estira. Esta hipótesis se describe en el estudio de elementos finitos realizado por Handsfield en

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2017 (163), que demostró que existe desplazamiento no uniforme en el TA.

Los estudios *in vivo* (134,164–166)que investigan la deformación regional del tendón informan de una deformación durante la carga pasiva, la fuerza excéntrica máxima y la marcha. Estos estudios describen que las capas más profundas del TA desplazan las capas más superficiales, lo que afirma los diferentes grados de torsión y las diferentes tensiones que surgen de los subtendones de los diferentes músculos del tríceps sural(165). Los estudios *in vivo* también han observado que el grado de deformación no es uniforme a lo largo del tendón comparando a personas adultas con los jóvenes(165).

Estudios *in vitro* (16,167)demuestran que la matriz extracelular pierde agua y elastina y se vuelve más rígida con la edad, lo que reduce la capacidad de deslizamiento del fascículo o del subtendón, probablemente como resultado del aumento de la fricción y la reducción del estiramiento y el retroceso. En conjunto, los hallazgos indican que cabría esperar una reducción de la deformación no uniforme en las poblaciones de mayor edad, lo que puede ser la causa del mayor riesgo de lesiones en los individuos de mayor edad.

Couppé et al. han investigado el patrón de deformación entre individuos sanos e individuos con tendinopatía del TA, los hallazgos muestran patrones similares al envejecimiento, con una reducción de los desplazamientos no uniformes del tendón(168). En conjunto, con

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estos datos y el mecanismo de lesión de la patología tendinosa lleva a la idea que la capacidad de desplazamiento se ve reducida por una falta de movilidad dado a la deformación no heterogénea. Una capacidad reducida de desplazamiento está asociada a un mayor riesgo de lesión(165,168).

1.9. Teoría de Estrés de Tejidos (PST).

El estrés físico se define como la fuerza aplicada a un área de un tejido biológico (169). Se cree que muchas de las teorías y enfoques que existen en la actualidad en la terapia física se pueden organizar en una teoría general para guiar la prevención y el tratamiento de nuestros pacientes (170).

El movimiento puede ser definido por los componentes físicos básicos (Tabla 3):

Tabla 3.Componentes físicos básicos del movimiento.

MOVIMIENTO	DEFINICIÓN	FÓRMULA
Aceleración	La aceleración de un segmento o cuerpo se define como fuerza.	Fuerza = Aceleración. *2da Ley de Newton.*
Fuerza	La aplicación de una fuerza sobre un tejido durante un movimiento da como resultado una tensión en el tejido. ***Tipos de fuerza***: *tensión/ cizallamiento/ compresión.*	$Tensión = \frac{Fuerza}{Área}$

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Otras fuerzas generadas tanto en el interior del cuerpo, como pueden ser las contracciones musculares, o fuera del cuerpo, la gravedad, pueden producir estrés físico en los tejidos (170). El PST fue desarrollado para explicar cómo y porque los tejidos, órganos y sistemas se adaptan a niveles variables de estrés físico (Tabla 3), además de describir cómo otros factores (Tabla 4) pueden modificar tanto el nivel de estrés físico como la respuesta de los tejidos biológicos a un determinado nivel de estrés.

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Tabla 4. Resumen de los Principios Fundamentales en la Teoría de Estrés de Tejidos (PST).

PRINCIPIOS FUNDAMENTALES:

A	*Cambios en el nivel relativo de estrés físico causan una respuesta predecible en todos los tejidos biológicos.*
B	*Los tejidos biológicos presentan 5 respuestas al estrés físico. Se prevé que cada respuesta ocurra dentro de un rango definido. Umbrales específicos definen los niveles de estrés para cada respuesta tisular característica. Cualitativamente, las 5 respuestas tisulares al estrés físico son:* *1. Disminución de la tolerancia al estrés (atrofia).* *2. Mantenimiento.* *3. Aumento de la tolerancia al estrés (hipertrofia).* *4. Lesión.* *5. Muerte.*
C	*Los niveles de estrés físico que son más bajos que el intervalo de mantenimiento dan como resultado, una disminución a la tolerancia de los tejidos a tensiones (atrofia).*
D	*Los niveles de estrés físico que están en el rango de mantenimiento no producen ningún cambio en el tejido.*
E	*Los niveles de estrés físico que exceden el rango de mantenimiento (sobrecarga) aumentan la tolerancia de los tejidos a tensiones (hipertrofia).*
F	*Los niveles excesivamente altos de estrés físico producen lesiones en los tejidos.*
G	*Las desviaciones extremas del rango de estrés de mantenimiento que exceden la capacidad de adaptación de los tejidos resultan en la muerte del tejido.*
H	*El nivel de exposición al estrés físico es un valor compuesto, definido por la magnitud, el tiempo y la dirección de la aplicación del esfuerzo.*
I	*Las tensiones individuales se combinan de formas complejas para contribuir al nivel general de exposición al estrés. Los tejidos se ven afectados por la historia de tensiones recientes.*
J	*El estrés excesivo que causa lesión puede ocurrir a partir de uno o más de los 3 mecanismos siguientes:* *1. Una tensión de alta magnitud aplicada por un breve período.* *2. Una tensión de baja magnitud aplicada durante una larga duración.* *3. Un estrés de magnitud moderada aplicado al tejido muchas veces.*
K	*La inflamación ocurre inmediatamente después de la lesión del tejido y hace que la estructura lesionada sea menos tolerante al estrés que antes. Los tejidos lesionados e inflamados deben estar protegidos contra el excesivo estrés posterior hasta que la inflamación aguda desaparezca.*
L	*Los umbrales de estrés requeridos para lograr una respuesta tisular dad pueden variar entre individuos dependiendo de la presencia o ausencia de factores asociados (Tab. 5)*

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Los factores que pueden cambiar el nivel de estrés en los tejidos o los valores umbral para la adaptación o lesión incluyen (Tabla 5) (170):

Tabla 5. Factores que afectan el nivel de estrés físico en los tejidos o la respuesta adaptativa de los tejidos al estrés físico.

Factores de Movimiento y Alineación.	Rendimiento muscular (generación de fuerza). Control motor. Postura y alineación. Actividad física. Actividades ocupacionales, de ocio y de autocuidado.
Factores Extrínsecos.	Dispositivos ortopédicos. Calzado. Entorno ergonómico. Modalidades. Gravedad.
Factores Psicosociales.	
Factores Fisiológicos.	Medicación. Edad. Patología sistémica Obesidad.

A continuación, se describen los efectos producidos en el sistema musculoesquelético cuando se aumenta la carga (Tabla 6).

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Tabla 6. Efectos de la PST en los diferentes tejidos del sistema musculoesquelético.

		Nivel de Estrés			
Sistema	**Tejido**	**Bajo**	**Normal**	**Alto**	**Excesivo**
Musculo-esquelético	Hueso	↓ DMO ↓ Fuerza	Ningún cambio	↑ DMO ↑ Fuerza	Fractura
	Músculo	↓ Proteínas contráctiles ↓ Diámetro fibra ↓ Pico tensión ↓ Pico potencia	Ningún cambio	↑ Proteínas contráctiles ↑ Diámetro fibra ↑ Pico tensión ↑ Pico potencia	Distensión/ Rotura fibrilar
	Tendón	↓ CSA ↓ Rigidez ↓ Fuerza	Ningún cambio	↑ CSA ↑ Rigidez ↑ Fuerza	Distensión/ Rotura fibrilar
	Ligamento	↓ CSA ↓ Rigidez ↓ Fuerza	Ningún cambio	↑ CSA ↑ Rigidez ↑ Fuerza	Esguince
	Cartílago	↓ Proteoglicanos ↓Espesor cartílago ↓ Rigidez	Ningún cambio	↑ Proteoglicanos ↑Espesor cartílago ↑ Rigidez	Degeneración/ Desgarro

Fuerza se define como el máximo estrés, esfuerzo y/o energía antes del fallo. ↓ = disminución, ↑= aumento, DMO = densidad mineral ósea, CSA = corte seccional área.

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1.10. Ecografía del tendón.

La ecografía es una técnica no invasiva, rápida, segura, no dolorosa y con una buena relación coste-beneficio, la cual permite obtener imágenes de alta resolución muy útiles para valorar el estado de los tejidos (171). Es una técnica de imagen precisa y económica que esta aceptada para evaluar la morfología de los tendones (172–175). Con la ventaja que es un método de obtención de imágenes con buena fiabilidad inter e intraevaluador (Coeficiente de variación (CV) de 1.5 a 4.9%; ICC de 0,89 a 0.97) (176) y con la capacidad de realizar imágenes en dinámica y durante el movimiento de la articulación(172,177,178).

En los últimos años, la ecografía musculoesquelética está siendo utilizada como un complemento al diagnóstico clínico. Permite detectar cambios en el grosor y en la ecogenicidad de los tejidos, detectar la presencia de calcificaciones, bursitis o roturas parciales o completas(171,179).

La ecografía musculoesquelética (US) y la resonancia magnética nuclear (RMN) se han utilizado para la investigación clínica de la tendinopatía, siendo la ecografía el gol estándar dado a la facilidad e inocuidad(180). Tiene muchas ventajas, como la accesibilidad clínica momentánea y la ausencia de radiación ionizante. Bien es cierto, que se necesita un manejo óptimo y es operador dependiente (181). Para

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un buen diagnóstico es necesario el movimiento pasivo y activo de las articulaciones en el tratamiento de los tendones.

La obtención de imágenes de los tendones mediante ultrasonidos puede utilizarse de varias maneras. Normalmente, se ha adoptado para visualizar la estructura del tendón. Sin embargo, en los últimos años se han desarrollado enfoques dinámicos para inferir la mecánica del tendón. En los últimos años ha aumentado el interés de la investigación en este campo, donde se están aplicando técnicas más avanzadas de imagen para comprender mejor la mecánica y la función de los tejidos (182).

1.10.1. Enfoques ecográficos para investigar el tendón.

Las imágenes estructurales para evaluar la anatomía son la base de la evaluación diagnóstica musculo-esquelética. La ecografía en modo B se ha utilizado para explorar la estructura del tendón. La orientación longitudinal de la sonda a lo largo de la longitud del tendón muestra los haces de fascículos del tendón, mientras que la orientación axial de la sonda revela la sección transversal del tendón. Ambas orientaciones de la sonda de ultrasonidos ayudan a evaluar las interrupciones de los fascículos tendinosos y los cambios en el área transversal respectivamente (183). El tendón se encuentra cerca de la superficie del cuerpo, por lo que pueden utilizarse altas frecuencias (~ 10 MHz) para mejorar la resolución de la imagen, por esta razón utilizamos una sonda lineal de alta frecuencia (184).

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A medida que ha mejorado la resolución de las imágenes, el análisis ha avanzado hasta abarcar mediciones de dimensiones anatómicas como la longitud y el diámetro, además de una representación muy detallada de las anomalías en la textura de los tejidos (185).

La consistencia del patrón de textura del tejido en US permite al clínico identificar trastornos tendinosos y enfermedades asociadas. Existen varios patrones morfológicos notables que se utilizan para diferenciar un tendón patológico de un tendón sano en la ecografía, como el ensanchamiento de la vaina tendinosa, la pérdida de eco fibrilar normal, forma irregular del margen tendinoso, edema peritendinoso, engrosamiento tendinoso, áreas hipoecoicas y micro o macro roturas(182). Comúnmente, un tendón humano sano y normal muestra un patrón de eco relativamente homogéneo con margen claro.

En la última década, los métodos convencionales de elastografia por ultrasonidos también se han adaptado para su uso en el diagnóstico de tendones, utilizándose para cartografiar la elasticidad del tendón (184–186), lo que ayuda en actividades como la comprensión de los cambios de elasticidad en un contexto posquirúrgico. Las imágenes Doppler también se utilizan ampliamente para evaluar los neovasos y los cambios en el flujo sanguíneo dentro del tendón. Aunque estas técnicas de imagen han permitido el diagnóstico y el tratamiento de las

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lesiones tendinosas, una limitación común de esta técnica es la capacidad de cuantificar los hallazgos con facilidad(173,187–189).

Los métodos para investigar y cuantificar los cambios estructurales en los tejidos han suscitado un gran interés. Actualmente, el más exitoso ha sido la caracterización tisular por ultrasonidos (UTC). La UTC cuantifica distintos parámetros a partir del patrón de ecogenicidad, clasificando el tejido en cuatro tipos diferentes (tipo I: haces intactos y alineados, tipo II: integridad fibrilar reducida, tipo III: integridad fibrilar disminuida en un barrido ecográfico, tipo IV: ausencia de fibrilar o rotura parcial intratendón), con estudios de validación que informan de una mayor fiabilidad interobservador (ICC < 0.92)(190). Hay varios estudios que utilizan el sistema de imágenes UTC para caracterizar tendón, informando de que los tendones sintomáticos muestran más tipo III y tipo IV.

Sin embargo, aunque hay pruebas fehacientes de que la técnica por US es fiable a la hora de detectar cambios estructurales, no proporciona la razón subyacente de que estos cambios estructurales en el tendón siempre sean patológicos(191). Además, sigue habiendo un claro desajuste entre los cambios estructurales del tendón y el dolor o la pérdida funcional de la tendinopatía(192).

Dado que los datos *in vivo* e *in vitro* respaldan que el patrón de deformación del TA humano puede utilizarse como biomarcador fundamental de la salud, resulta interesante disponer de métodos para

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detectar más claramente la falta de uniformidad en el tendón, y es necesario contar con una herramienta de imagen funcional para investigar este comportamiento de deformación a nivel tisular y el deslizamiento de los fascículos en el tendón de Aquiles libre.

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2. JUSTIFICACIÓN

La tendinopatía del tendón de Aquiles se encuentra entre las patologías más comunes en la medicina deportiva. Con una incidencia en aumento por cada 100.000 personas-año. aumentó de 2,1 (IC del 95%: 0.3 a 7.7) en 1979 a 21,5 (IC del 95%: 14.6 a 30.6) en 2011(193). Este incremento no sólo es debido a la creciente popularidad de la práctica deportiva (175,193–195), dado que el aumento medio anual de la incidencia fue de un 2,4% (IC 95%: 1.3-4.7) mayor para las roturas no relacionadas con el deporte que para las relacionadas con el deporte (p= 0.036). Por esta razón, es necesario entender cómo se estructura anatómicamente un tendón sano para tener una mejor comprensión de la lesión y/o rotura.

La ecografía es una técnica de imagen precisa, económica y rápida que esta aceptada para evaluar la morfología de los tendones (172–175). Con la ventaja que es un método de obtención de imágenes con buena fiabilidad inter e intraevaluador (Coeficiente de variación (CV) de 1.5 a 4.9%; ICC de 0,89 a 0.97) (176) y con la capacidad de realizar imágenes en dinámica y durante el movimiento de la articulación(172,177,178). Bien es cierto, que las alteraciones en el área de sección transversal y el espesor están más documentadas en la literatura con respecto a la patología del tendón de Aquiles, pero las mediciones ecográficas en individuos sanos según la edad o el sexo están más limitadas. Actualmente, existe poca evidencia científica

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sobre la asociación o relación entre las mediciones ecográficas del tendón de Aquiles (longitud del tendón libre, área, grosor y ángulo de peneación) y los datos demográficos, así como hábitos saludables (IMC, nivel de actividad física y dominancia del pie) (196–198).

Por otro lado, la anatomía de estructura musculo-tendón del complejo del tríceps sural tiene una función dinámica y postural (95), estas estructuras se deben de considerar en el manejo de la patología del tendón de Aquiles porque cuando aparece un déficit en la musculatura existe una alteración directa en la biomecánica de la marcha, carrera y salto (199). El complejo Aquileo-calcáneo-plantar está formado por el músculo GM con su vientre muscular medial y lateral, el músculo delgado plantar, el músculo sóleo (SM) y el Tendón de Aquiles (AT) (143). El MS se localiza en el compartimento posterior superficial, por debajo del GM; sin embargo, el vientre muscular de SM es más ancho y sus fibras musculares son las que se insertan de forma oblicua y más distales al AT, formando un ángulo (ángulo de peneación).

Este ángulo, también llamado ángulo de reposo del tobillo, tiene una relevancia clínica en el manejo de la patología del tendón de Aquiles (95,199–201) dado que está relacionado con la restauración de la longitud del tendón de Aquiles y su tensión. Por esta razón es importante comprender la variabilidad normal de este ángulo y determinar las correlaciones con los parámetros del tendón de Aquiles sano.

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El propósito de este estudio es valorar ecográficamente las estructuras que componen el complejo Aquileo-calcáneo-plantar y observar si existen cambios o variantes en la biomecánica en pacientes sanos, activos y sedentarios, sin patología previa para el manejo clínico en la prevención de las patologías más frecuentes en la consulta podológica.

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CHAPTER II

OBJETIVES

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2.OBJETIVES.

2.1. Main Objective

1. Describe the morphostructural parameters of the Achilles tendon and the Plantar Fascia in adult, healthy patients using ultrasound.

2.2. Secondary Objectives

1. Analyze the ultrasound changes experienced by the plantar fascia after subjecting it to controlled loading exercise.

2. Analyze the relationship between demographic variables and morpho-ultrasonographic variables of the Achilles tendon in adult and healthy patients.

3. Evaluate if there is a significant relationship between the pennation angle of the soleus muscle to the Achilles tendon and dorsiflexion of the TPA joint.

4. Develop a device as an ultrasound measurement tool to standardize the lack of uniformity in Achilles tendon measurement.

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CHAPTER III

VARIATIONS IN THE THICKNESS OF THE PLANTAR FASCIA

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3.1.INTRODUCTION.

Musculoskeletal tissues are subjected to constant workloads during daily activities (202). The tendons are commonly engaged in repetitive loading or overuse amongst both the athletic and non-athletic population (42), and there is evidence that this is closely associated with the development of tendinopathy. The Plantar Fascia (PF) is subjected to mechanical loads while walking or running, and degenerative changes are commonly observed in the morphology of the plantar fascia, leading to pathology characterised by an accumulation of damage (3).

Physical stress is defined as the force applied in an area of biological tissue (203). Mechanical theory, or Physical Stress Theory (PST), argues that: "changes in the relative level of physical stress cause a predictable adaptive response in all biological tissue" (170).

The PF plays a key role in the biomechanics of the foot; it interacts with the propulsion mechanisms distributing the forces and energies that involve the foot in conditions of repetitive load such as continuous running (130). During weight-bearing exercises, the arch of the foot lowers and stretches out, then recoils when the load is removed. PF injuries due to excessive traction forces directly involve the “Windlass” mechanism, behaving like a quasi-elastic tissue (112,113,204,205). This spring-like property of the foot arch helps to

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attenuate impact forces and store/release elastic strain energy leading to energy saving during running (206).

Each time the foot comes into contact with the ground while running, the PF experiences repeated tension as high as 0.6-3.7 times the bodyweight and longitudinal tension of up to 6% (207). Simulation studies have shown that tension and peak stress along the PF are concentrated at the proximal points. Accumulation of such repetitive and site-specific stress on the PF can induce mechanical fatigue (i.e., reduction of stiffness and increased strain upon loading) (206). This can be a key factor leading to increased thickness of the plantar fascia in regular runners.

This affects both athletes and people with sedentary lifestyles, making up 11–15% of foot problems requiring professional help (55). Every day people that do all kinds of sports receive medical treatment, but the most common patients are amateur runners (120). Amateur running is growing in popularity; however many people lack the appropriate physical preparation, which can lead to injuries. A systematic review showed a plantar fasciitis prevalence of between 5.2-17.5% among 3500 runners, with an incidence of 4.5-10 injuries per 1000 hours of running (208). Therefore, it is possible that experienced, long-distance runners may have a PF and a foot arch that are adapted to long-distance running (smaller changes in PF properties

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and arch deformation), compared to people that don't run. There is limited available knowledge on this issue (206).

Musculoskeletal ultrasound imaging (MSK US) is an emerging diagnostic tool in medicine and physical therapy which allows for dynamic visualisation of tissues in real time with devices that are often portable (17,208,209). Recent advances in ultrasound technology and the development of high-resolution ultrasound transducers have resulted in improved visualisation of soft tissues and bony structures. MSK US can be used to evaluate tissue properties such as the orientation and volume of fibres, as well as the presence of inflammatory processes, therefore it can be a valuable diagnostic and prognostic tool for the physical therapist (173). In addition, it can easily be repeated, which makes it an effective tool to monitor tissue changes over time (210).

Currently there is no consensus on average PF thickness (209,211–213), although there does exist an ultrasound classification that deems thicknesses greater than or equal to 4cm as pathological (214). Sometimes asymptomatic athletic subjects exceed this thickness. A relationship has been observed between mechanical stress and the fibrous morphology of the plantar fascia. This information is of clinical assistance in understanding the pathophysiological diseases of the plantar fascia.

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We sought to determine whether changes took place in the thickness of the plantar fascia as a result of physiological and mechanical adaptation after controlled exercise in the form of continuous running. We hypothesised that changes in the thickness of the plantar fascia would be observed under ultrasound. The aim of this study was to investigate the effect that continuous running has on the tissue stress generated in the PF in terms of thickness, measured under ultrasound.

3.2. PATIENTS AND METHODS

3.2.1. Design

The design is an experimental study. where the effect of an intervention (in this case, running for 15 minutes at a given speed) on a group of participants is observed and the change in a variable (in this case, the measurement of plantar fascia before and after running) is recorded.

3.2.2. Patients

The participants in this study were made up of 24 volunteer runners (male and female), who had taken part in the Picana-Paiporta half marathon in December 2018. This study was carried out between December 2018 and February 2019 in full accordance with the provisions of the Helsinki Declaration regarding ethical principles for medical research involving human subjects and was approved by the Ethics Committee (UCV/2017-2018/71). Written informed consent was

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obtained from all participants before data collection. All subjects were 18 or over and were amateur runners who took part in at least one quarter, half or full marathon per year, and who trained at least once a week. They had been running regularly for at least 10 km/week during that year, and their running experience ranged from 5 to 10 y. The exclusion criteria were heel pain and/or a history of diseases or injuries of the feet that had affected the musculoskeletal system in the previous 3 months, and neurological problems or surgical interventions in the lower limbs. All participants wore their usual sports clothing.

3.2.3. Sample size

The sample size was determined by application of the EPIDAT program, using the criterion of AT with a detectable difference of the mean of 0.039 to evaluate the statistical power (211). For a significance level of .05 and a power of 80%. The study was designed to detect changes exceeding 0.060 (large effect size). This calculation produced a necessary sample size of 21 subjects.

3.2.4. Protocol

Subjects were assessed in a foot clinic. The study was carried out in 3 phases. During the first phase, the study data (age, BMI, type of footwear (214), number of workouts per week, KM run per week, and sports injuries in the last year) was collected using a questionnaire, thus allowing the sample to be established by taking into account inclusion and exclusion criteria. In the second phase, a brief exploration

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was carried out using the Foot Posture Index (FPI), followed by measurements of the thickness of the medial, central and lateral fascicles of the PF, before and after race-based training. The FPI evaluates the multi-segmental nature of foot posture in all 3 planes and does not require the use of specialised equipment. Each item of the FPI is scored between -2 and +2, resulting in a total ranging from -12 (highly supinated) to +12 (highly pronated). The items of the index include talar head palpation, curves above and below the lateral malleoli, calcaneal angle, talonavicular bulge, medial longitudinal arch, and forefoot to hindfoot alignment. In all other respects, the protocol described by Redmond et al was followed. (215,216)

3.2.5.Ultrasound Measurements

A diagnostic ultrasound device was employed: the LOGIQ V2TM (GE Healthcare, EE. UU.), equipped with a 8 to 13 MHz linear transducer probe (12L-RS), with a contact surface area of approximately 7cm in length and 1cm in width and a weight of 390 grams. A dynamic range of 69bB and a scan depth of 2.5 cm (12L-RS) were used. The linear transducer parameters were the same in all measurements in this study: a frequency of 8Khz, a low filter setting and optimisation for low flow detection. The gain was adjusted to the highest possible level without background noise. The only setting that varied was focus, which was adjusted according to the level of the PF of each subject, with fixed depth. Each participant was assigned an

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identification number, which was the only information provided to the examiner. The ultrasound images were obtained by a single examiner. All participants received a standardised ultrasound on both feet. The data was recorded by a research assistant, who was unaware of the premeasurements. All ultrasound measurements are expressed in millimetres. Care was taken to maintain the same standardised foot position, to keep the same ultrasound scanner settings and to replicate the same measurements. The participants adopted a prone position with the knee in extension and the feet lying outside the stretcher (209,211). Guide lines for the transducer were indicated on the skin using a waterproof marker in order to ensure identical points of measurement. Once the subjects were in position, the width of the heel was measured and the mid-way point was marked with a line (central fascicle). Using this cutaneous reference point, 2 more lines were drawn at a distance of 1.5cm on either side, towards the inside of the foot (medial fascicle) and towards the outside (lateral fascicle) (217). The first measurement (thickness 1) was taken: the thickness at the insertion of the PF in the heel at each longitudinal section: medial (Figure 12A), central (Figure 12B) and lateral (Figure 12C). The probe was lined up precisely with the pen marks made on the heel. Three images were taken of each longitudinal section in the 3 fascicles of the FP and the average thickness in centimetres of each fascicle was calculated (209).

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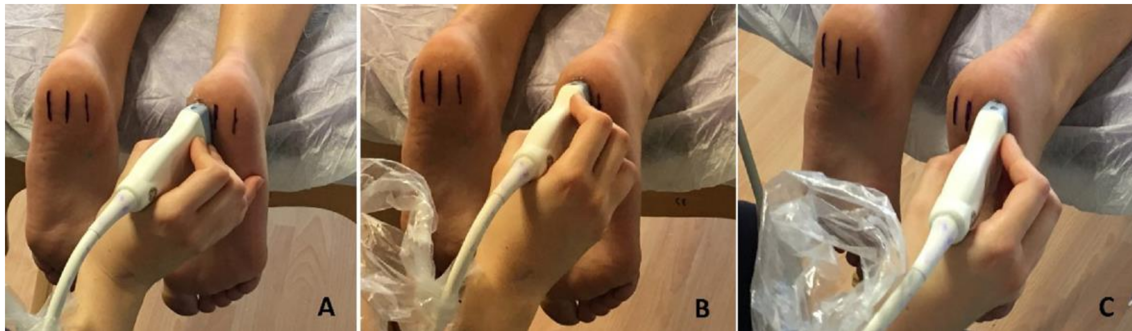

Figura 12.The thickness of the insertion of the plantar fascia to the heel in the longitudinal sections: medial (A), central (B), and lateral (C).

After the ultrasound measurement (pre), participants were asked to run at 12 km/h (+-2km/h; precision 98%) for 10 minutes (high-intensity exercise) on a treadmill (218). The race protocol was assumed to be identical for all runners in terms of mechanical loading as they all had a similar stature (Table 7). The foot strike pattern of participants was visually observed throughout the running task. All participants were able to complete the task without resting or walking. After running, participants underwent the same measurement to examine PF thickness (post).

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Table 7. Distribution of the mean, minimum, maximum and standard deviation of the variables.

Characteristics	**Male**	**Female**	**Total**
Demographics			
Gender (n)	18	6	24
Age (y)	38 .05 (53-25) ± 7.81	38.66 (55-20) ± 14.21	38.20 (55-20) ± 9.44
Height (cm)	176.90 (167-192) ± 0.08	161.70 (158-165) ± 0.02	173.13 (158-192) ± 0.09
Weight (kg)	73.06 (58-94) ± 10.25	59 (52-67) ± 5.02	69.54 (52-94) ± 11.03
BMI /kg/m²)	23.23 (19.59-26.32) ± 1.79	22.60 (19.10-25.53) ± 2.21	23.07 (19.10-26.32) ± 1.87
Qualitative variables			
Training time/week (t/w)	3.33 (2-5) ± 0.77	3.83 (3-5) ± 0.98	3.46 (2-5) ± 0.17
*Km/week (km/w)**	2.61 (1-5*) ± 1.04	2.50 (1-4*) ± 1.23	2.58 (1-5*) ± 1.06
Foot Posture Index			
Left FPI	2.61 (-1-5) ± 1.50	2.33 (1-3) ± 0.82	2.54 (-1-5) ± 1.35
Right FPI	2.56 (-2-7) ± 2.01	4.00 (2-6) ± 1.55	2.92 (-2-7) ± 1.98
Quantitative variables			
Size (EU)	43.11 (40-46) ± 1.94	40.33 (38-41) ± 1.27	43.15 (38-46) ± 2.54
Shore (HA)	42.17 (27-61) ± 10.88	43.33 (32-58) ± 9.18	42.46 (27-61) ± 10.30
Sneaker weight (g)	297.06 (200-438) ± 65.76	219.67 (145-274) ± 53.29	277.70 (145-438) ± 70.61
Drop (mm)	11 (8-12) ± 1.41	10 (8-12) ± 1.26	10.75 (8-12) ± 1.42

*1: 5-10km/w; 2: 10-20 km/w; 3: 20-30 km/w; 4: 30-40km/w; 5: + 50 km/w.

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3.2.6. Statistical Analysis

The program SPSS v.25.0 (IBM Inc., Chicago, IL, USA) was used for statistical calculations using descriptive and inferential statistical tests. The normal distribution of the data was verified using a Shapiro-Wilk test and it was revealed that the ultrasound measurement data was normally distributed. The intraclass correlation coefficient was used to evaluate the reproducibility of PF thickness measurements, with a 95% Confidence Interval (95%CI) and a sample of ten subjects measured at baseline and after 24 hours. Estimation was carried out by calculating the intraclass correlation coefficient, using a one-way random effect model, and found to be excellent (ICC 0.94: 95% CI: 0.90-0.96) at baseline and at 60 minutes (ICC 0.87; 95% CI: 0.80-0.92). The null hypothesis (no differences between pre and post-measurement) was tested using bivariate analysis which was performed with a non-parametric test (the Mann-Whitney U test), in view of the non-normal distribution observed in most cases (one-way ANOVA) with a significance level of 0.05. The standard error of measurement (SEM) also provides a measure of variability. SEM values were calculated as follows: $SEM = SD \times \sqrt{(1 - ICC)}$, with SD representing the standard deviation of the measure. Minimal Detectable Change MDC values, which reflect the magnitude of change necessary to provide confidence that a change is not the result of random variation or measurement error, were calculated as follows:

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MDC = z-score (95% CI) × SEM × √2 [32], and it was shown as the effect size test with eta-square.

3.3. RESULTS

This experimental intra-subject analysis is based on a study population of 24 participants (N=24). Of these, 18 (75%) were male and 6 (25%) were female. Therefore 48 feet were available for analysis. The average age was 38.21 (9.44) years and the average body mass index was (BMI) 23.07 (1.87) kg/m2 (Table 7). The assessment of the dominant foot revealed that 93% of participants were right-footed, but we did not observe any significant differences between the right and left feet p=0.871.

The average type of foot according to the FPI was 2.54 (1.35) in the left foot and 2.92 (1.98) in the right foot.

Statistically significant differences were observed in all 3 left foot measurements (F (1;24) = 6.84, 9.77, 11.59, p = 0.015 0.005, <0.001). The difference is minimal between the base line and after physical activity, with an average difference of 0.4 mm in the central and medial fascicles, and 0.3 mm in the lateral fascicle (Table 8). In addition, high power is observed in all measurements.

Furthermore, no statistically significant differences were observed in average right foot measurements (F (1;24) = 3,60 and 3,65, p = 0.07 and 0.069) in the central and medial fascicles. However, significant changes were observed in the lateral measurements

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compared to the baseline, ($F (1;24) = 18.18$, $p \leq 0.001$) (Table 8), and high power was observed in all measurements.

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Table 8. **Distribution of the mean of pre-post running ultrasound measurements in both feet.**

	PRE-RUNNING				POST-RUNNING				
	Average (mm)	SD (cm)	CI 95% (mm)		Average (mm)	SD (mm)	CI 95% (mm)		P-Value
LMF	0.36	0.06	0.34	0.39	0.40	0.07	0.37	0.43	0.015
LCF	0.32	0.07	0.30	0.35	0.36	0.07	0.33	0.39	0.005
LLF	0.27	0.04	0.26	0.29	0.30	0.05	0.28	0.32	<0.001
RMF	0.37	0.06	0.34	0.39	0.39	0.07	0.36	0.42	0.070
RCF	0.32	0.06	0.30	0.35	0.35	0.05	0.33	0.37	0.069
RLF	0.28	0.04	0.26	0.29	0.31	0.05	0.29	0.33	<0.001

LMF, Left Medial Fascicle; LCF, Left Central Fascicle; LLF, Left Lateral Fascicle; RMF, Right Medial Fascicle; RCF, Right Central Fascicle; RLF, Right Lateral Fascicle; SEM, standard error of measurement; MDC, Minimal Different Changes; CI, Confidence Interval.

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3.4.DISCUSSION

Tissue stress is explained in many areas with the basic premise that changes in the relative level of physical stress causes a predictable adaptive response in all biological tissue (170). When there is an increase in stress tolerance, hypertrophy appears, followed by injury (204). After exercise, tendons demonstrate an increase in matrix metalloproteinases that contributes to an increased release of products due to collagen breakdown (19,23,219,220). Over the first 24 to 36 hours after exercise, the acute response results in a net loss of collagen (221–223).

In symptomatic subjects, a PF thickness greater than 4mm has been suggested as a diagnosis for plantar fasciitis (211,214). However, studies (209) in runners show great variability in thickness, 35% of the heels analysed (27 out of 77) among 41% of runners (16 out of 39) showed an abnormally thickened fascia above 4mm, and some asymptomatic patients had measurements over 7mm.

The aim of this study was to determine the effect that continuous running has on the tissue stress generated on PF in relation to thickness. The morphological changes in the insertion thickness of the PF were determined by analysing the ultrasound images of the participants to assess the differences in asymptomatic runners before and after a race-based training session.

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Our results showed a significant difference ($p \leq .001$) between the pre and postrace measurements of the thickness of the FP in the lateral fascicle, in both feet. However, although no statistically significant differences were observed, it should be noted that a difference in thickness of at least 2mm was observed on average across the 3 fascicles analysed at the medial, central and lateral points on the feet of all the participants. According to simulation studies, the proximal site of PF is where the mechanical loading is concentrated (102,224,225). Such site-specific stress accumulation during a race could be the cause of site-specificity of mechanical fatigue in PF. Mechanical overload and excessive strain can produce microscopic damage in PF which eventually leads to plantar fasciitis (144). Our findings support this pathogenesis.

These results are in line with those obtained by Hall et al in their analysis of asymptomatic runners aged 20 to 67, of whom 35% had a PF thickness greater than 4 mm. As with other studies carried out on asymptomatic runners (211), where the average thickness of the PF was 3.78 mm (range, 2.4-7.0 mm) for the right foot and 3.87 mm (range, 2.3-6.7 mm) for the left, it should be noted that the right foot was dominant among the study population. One earlier study (226) assessed the influence of sports on PF thickness in a population of healthy asymptomatic young adults, not strictly runners, between 20 and 30 years of age. The authors found no difference in thickness among those subjects with a physically active lifestyle. However, other

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studies that analysed the plantar fat pad (227) concluded that the impact of continuous running produces a fracture in the plantar fat due to the stress suffered in the heel during exercise.

In addition, the mechanical properties (thickness and elasticity) of the heel pad in the elderly differ from those found in young people. Older people have a thicker and stiffer heel fat pad in comparison (228). This greatly reduces the shock absorption capacity of the heel fat pad and as a result, makes it more susceptible to injury (217). Our research included participants aged between 20 and 55, which is why, due to the cumulative effects of age and the repetitive load and impact of running on asphalt, the PF may be more thickened, although the average is lower, at 4 mm.

It is necessary to rethink how to begin standardising and measuring the thickness of the PF. Fede et al (229) carried out a systematic review to explore current literature on obtaining homogeneous muscle data from ultrasounds. This revealed that there is no heterogeneity in measurement methods nor protocols and therefore, normal reference values cannot be established. Currently, there are 5 studies (211,212,229–231) that have collected non-pathological ultrasound data on PF. The thickness measurements of the PF varied from 3 to 4mm and the position of the participants was different in each study, thus the variability in thickness is determined by the position of the patient and the resulting muscle tension. Salehi et al (232) examined reliability in subjects with plantar fasciitis and healthy control subjects,

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whereas most previous studies have assessed reliability of PF properties using ultrasound only in either healthy groups or in clinical populations. Our study followed other similar investigations (230) by continuing to measure the thickness of the PF with the patient in the prone position with the knee extended, and using a similar measurement tool (232). The images clearly identified thickening and degenerative changes, thus supporting the conclusion that there were structural changes in the fascia. Therefore, US images would be an appropriate intervention to clinically address these tissue changes within the PF (211,231).

3.4.1. Clinical implications

There are clinical implications for our findings. First, most of the averages obtained in PF thickness are greater than 4mm in asymptomatic patients, therefore increased PF thickness is not the only criterion for diagnosis of plantar fasciitis. Second, long-distance running causes mechanical fatigue in the FP mainly at the insertion proximal to the calcaneus.

Future studies will offer a better understanding of the optimal training/conditioning that aid prevention of PF injuries while enhancing its spring function when running. Experienced runners can develop a resilient PF that minimises the risk of PF-related injuries. As clinical therapists, we must evaluate all risk factors, such as the type of patient and the stress or load supported by the PF which could lead to a

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possible PF injury, and act preventively whether we are dealing with biological tissue that is normal or susceptible to injury.

The main limitation of the study was the size of the sample. For this reason, there is no specific analysis according to gender or age. In the sample, the majority of subjects were men, given that they had all been recruited from the Picana-Paiporta half marathon (Valencia, Spain) where, out of 1327 participants, less than 20.5% were women. However, previous studies have shown a link between gender and the plantar fasciitis in runners (232,233). In addition, age can be the cause of changes in the fascia. It is perhaps necessary to include other types of impact sports to ensure that the absorption of impact by the plantar fat pad can prevent an increase in the thickness of the PF.

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3.5. CONCLUSION

The findings showed the effect that continuous running has on tissue stress generated in PF in relation to thickness. The morphological changes observed in the 3 fascicles had an average difference in thickness of at least 2mm. We observed PF thicknesses above 4mm in asymptomatic patients with no signs of vascularisation, proving that increased PF thickness is not the only criterion for diagnosis of plantar fasciitis. However, our sample size limits the extent to which definitive conclusions can be drawn. Future research of this type is needed, that ensures homogeneity in the study groups by size and composition, as well as in aspects such as different sports or the follow-up period considered and the description of main outcomes, in order to minimise the risk of bias.

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CHAPTER IV:

RELATIONSHIP BETWEEN DEMOGRAPHIC VARIABLES AND MORPHO-ULTRASONOGRAPHIC VARIABLES OF THE ACHILLES TENDON

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4.1.INTRODUCTION

The Achilles tendon (AT) is the thickest, strongest and largest tendon in the human body (131). It originates from the gastrocnemius muscle and soleus muscle until it inserts into the calcaneal bone. Its characteristics (TA free length, thickness and area) are highly variable between individuals (134) and its mechanical properties store and release energy. When a deficit in this structure appears, there is a direct alteration in the biomechanics of walking, running and jumping (143). For this reason, the strength, tension and stiffness of the TA is closely related to muscle activity, joint activity and tendon characteristics themselves (131,134,143).

Prospective studies indicate that risk factors for tendinopathy include female gender, black race, higher body mass index, previous tendinopathy or fracture, higher alcohol consumption, lower plantar flexion strength, higher weekly running volume, more years of running, use of spiked or cushioned shoes, cold weather training, use of oral contraceptives and/or hormone replacement therapy, reduced or excessive ankle dorsiflexion range of motion, and use of antibiotics in the fluoroquinolone class (234–236).

Achilles tendinosis is described to be a more frequent disorder in male runners who perform long duration and high intensity training (54,237). Deng et al. evaluated the myotendinous junction of the medial gastrocnemius with the AT and their findings conclude that

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gender differences exist in individuals who do not have regular exercise habits (238). However, an updated systematic review on the prevalence of AT injury and physical exercise concluded that for gender there was no significant difference (54).

The mechanical properties of human tendons in vivo are based on tensile testing to assess tendon longitudinal elongations (239–241). To obtain a measurement of the free TA, the anatomical reference point is the myotendinous junction of the soleus muscle, as this is a clear landmark that can be identified and traced by ultrasound scanning to its insertion with the calcaneus (240,242).

There are no known conclusive studies relating these morphological differences of the AT and gender in the general population (adult, healthy and with regular exercise habits) that provide clear data in the clinical management for the prevention of this pathology.

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4.2.PATIENTS AND METHODS

This study was conducted in full compliance with the provisions of the Declaration of Helsinki on Ethical Principles for Medical Research Involving Human Subjects and was approved by the Experimental Ethics Committee, registry Nº. 144-2021-H. Written informed consent was obtained from all participants prior to data collection.

4.2.1.Design

Cross-sectional study.

4.2.2.Patients

The inclusion criteria were men and women healthy young subjects between the ages of 18 and 30, physically active with an average of training sessions of 3 times a week, negative Lunge test (243). They were recruited from *L'Institut National de Podologie*, Paris from April to July 2022.

Persons presenting any of the following criteria were excluded from the study: osteo-degenerative disease, metabolic disease, neurological problems, surgical intervention in the lower limb, processes of an infectious, neoplastic, or metastatic origin, cognitive impairment, pregnancy, musculoskeletal lesions in the lower limbs during the last 3 months, and use of corticosteroids and/or oral antibiotics.

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4.2.3.Sample Size

Sample size was determined via power analysis (G*power, version 3.1.9.6, Kiel University, Kiel, Germany). The effect size was calculated using the results of the comparison of Achilles tendon CSA at rest between men and women in the study of Intziegianni et al. (244). The results showed that 8 participants in each group was enough (effect size: 1.34, significance level: 0.05, statistical power: 80%).

4.2.4.Procedure

The subjects who were evaluated by the team member in face-to-face interviews where the procedure was explained, the informed consent was signed and demographic history forms were collected (age, height, weight, sex, smoking, current injury status, allergies, medications, previous surgeries, type of sport and number of weekly workouts) that allowed the sample to be established in terms of inclusion and exclusion criteria.

4.2.4.1.Foot Posture Index

Then, a brief exploration was carried out in which the Foot Posture Index (FPI) and the Lunge test were performed. The FPI assesses the multi-segmental nature of foot posture in all three planes and does not require the use of specialised equipment. Each FPI item is scored between -2 and +2, resulting in a total ranging from -12 (very supinated) to +12 (very pronated). Index items include palpation of the talar head, curves above and below the lateral malleolus, calcaneal

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angle, talonavicular protuberance, medial longitudinal arch and forefoot to hindfoot alignment. In all other aspects, the protocol described by Redmond et al. (215,216) was followed. The FPI has proven adequately reliable in varied clinical settings (Intraclass correlation coefficients (ICC) = 0.62–0.91) (245).

4.2.4.2.Lunge test

The Dorsiflexion Lunge test was performed to assess ankle dorsiflexion range of movement (ROM). The test protocol followed the procedure described by Bennell et al. (243), starting position of the participant in weight bearing with the big toe of the foot being tested 10 cm from the wall and the knee is in line with the second toe, can lean on the wall using two fingers of each hand to maintain balance. The test consists of pushing the knee until it touches the wall without the heel lifting off the ground, at which point the investigator recorded the angle of the tibia to the vertical (to the nearest tenth of a degree) as a measure of ankle dorsiflexion ROM. Three measurements were taken and the mean was used for statistical comparisons. This test has been shown to have an intra-rater reliability of ICC = 0.98 (SEM = 1.1°) and an inter-rater reliability of ICC = 0.99 (SEM = 1.4°) (243).

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4.2.4.3.Gait Analysis

For the gait analysis ten optoelectronic cameras (Motion Analysis Corporation, Santa Rosa, CA, USA) recorded the trajectories of reflective markers, positioned on the lower limbs of the participant following the methods of Davis et al. (246). Markers were placed on the anterior superior iliac spines (ASIS), middle of posterior superior iliac spines (PSIS), greater trochanter, lateral thigh, medial and lateral femoral condyles, tibial tuberosity, head of fibula, lateral shank, medial and lateral malleoli, heel, first, second/third and fifth distal metatarsal heads. One AMTI force platform (Advanced Mechanical Technology Inc., Watertown, MA, USA) recorded the ground reaction forces. The 3D markers' trajectories and ground reaction forces were obtained synchronously with Cortex 1.3.0.562 software (Motion Analysis Corporation, Santa Rosa, CA, USA) with a sampling frequency of 100 Hz and 1000 Hz, respectively. The same operator positioned all the markers for each participant and carried out the whole 3D-gait analysis to limit variability (247). During these gait analyses, participants computed an overground barefoot walking along a 10 m walkway at a self-selected speed. Five gait cycles were processed, and gait events (heel strike and toe off) were detected when the vertical ground reaction force exceeded or fell below 10 N (248). The trajectories of skin markers were filtered using a fourth-order zero-lag Butterworth low-pass-filter with a cut-off frequency of 6 Hz. Joint kinematic were established using standard criteria (249). Briefly, the three orthogonal

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axes of the shank and foot coordinate system are defined from the coordinates of skin markers. The ankle joint coordinates system is defined from a sequence of successive rotations about mobile axes to obtain the ankle joint kinematics through Euler angles. In this study, we focused the kinematic analysis on two key parameters: the ankle dorsiflexion peak and range of motion during stance phase.

4.2.4.4. Ultrasound measurements

Measurements were taken by a single investigator with more than 5 years of ultrasound experience. Scans were obtained using a MyLab Sigma Elite portable musculoskeletal ultrasound system (Esaote, Italy) and a high-density linear probe (4-15 MHz). The depth of the image field was set at 3.5 cm, the gain was set at 85 dB, the probe frequency at 14 MHz and a single focal zone (set at a depth of 0.5 cm) was placed at the level of the AT. All other options (e.g., compress, mapping, smoothing, X-resolution) were maintained in all examinations performed for all participants in order to standardize the recorded images across all participants.

Ultrasound measurements of AT length, tendon thickness, CSA and pennation angle of the soleus muscle to the AT were performed. The first measurement of these values was in prone position with both legs under the stretcher at rest. After 5 min of rest, the same ultrasound measurements were taken with the knee flexed on the stretcher (to annul the force of the gastrocnemius) and exerting an

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active force on the sole of the foot until complete dorsiflexion of the ankle. (Figure 13 and Figure 14).

Figura 13. Ultrasound measurements at rest.

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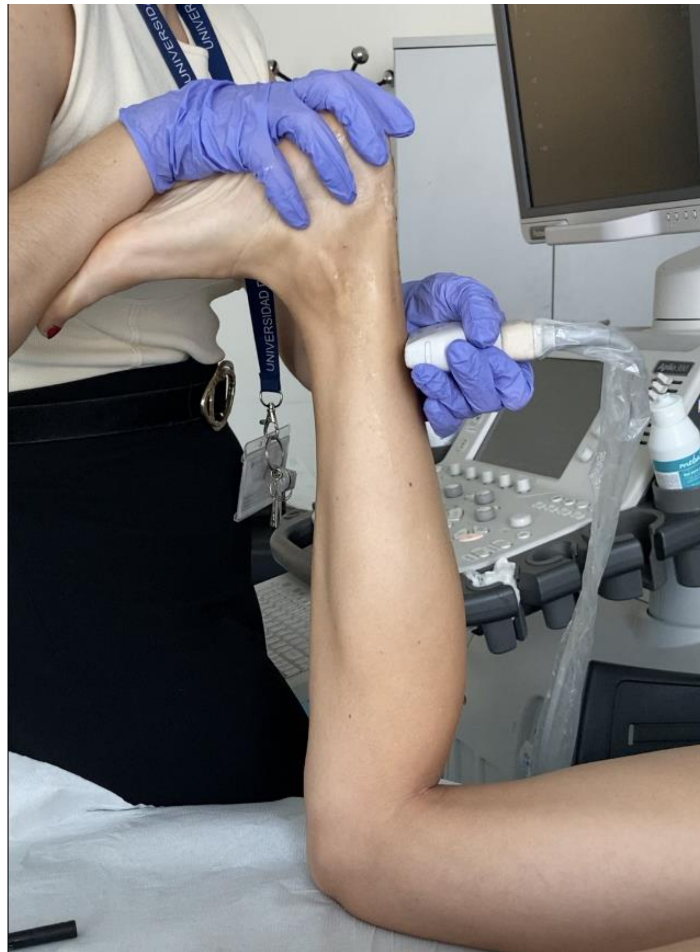

Figura 14. Ultrasound measurements with passive force.

The AT insertion over the calcaneus was located by ultrasonography. A mark was made on the skin at that level, 4cm from the calcaneus and at the proximal level when soleus musculature is no longer observed to record ultrasound images for the length of the AT (181). For thickness measurement the assessor aligned the transducer at the precise location marks (proximal and insertional) and recorded three images in longitudinal view by placing the caliper at the superior and inferior edges of the Achilles tendon (234). CSA was performed by positioning the transducer in a transverse view at the marks made and three images in transverse view the proximal CSA, medial CSA,

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insertional CSA were recorded (156,181). The mean of 3 repeated values was collected for each measurement. For each image the transducer was removed and repositioned over the skin tags. Following Padhiar et al. (242) for the measurement of the pennation angle of the soleus- Achilles tendon, the probe was placed in a transverse view in the distal third of the leg, a sweep was made towards the foot, until the end of the insertion of the soleus muscle was observed, at this level a 90º turn of the ultrasound probe was made, positioning the probe in a longitudinal view oriented along the medial longitudinal axis determined by the soleus fibers to the Achilles tendon, from there the measurement of the pennation angle was extracted.

The ICC of the ultrasound examiner was used with 10 participants to evaluate the reproducibility of measurement of the thickness and CSA of the AT and angle pennation of the soleus-AT measured at baseline and after 24 hours. They were estimated by calculating the ICC using a 1-way random effect model and found to be excellent (ICC = .94; 95% confidence interval, .90–.96) at 0 (baseline) and (ICC = .87; 95% confidence interval, .80–.92) at 24 hours.

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4.2.4.5. Statistical Analysis

The SPSS v.25.0 program (IBM Inc., Chicago, IL, USA) was used for statistical calculations using descriptive statistical tests. A Shapiro–Wilk test was used to test the normality of all data distribution. An independent t-test was used to quantify the gender differences in the architectural properties of the Achilles tendon and gait biomechanics if the data were normally distributed. On the other hand, a Mann–Whitney U test was used. All the results are shown as mean ± standard deviation. The significance level was set as 0.05.

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4.3. RESULTS.

Twenty-seven patients, who were Sixteen healthy women (thirty-two feet) and eleven healthy men (twenty-two feet) with normal Body Mass Index (BMI) (Table 10).

Table 9. Anthropometric characteristics of participants.

VARIABLE	GROUPS		P-VALUE
	Women (n=16)	Men (n=11)	
AGE (YR)	22.5 (2.4)	21.1 (1.7)	*0,022*
HEIGHT (CM)	163.0 (7.3)	178.7 (5.8)	*< 0.001*
WEIGHT (KG)	56.3 (5.7)	72.8 (5.0)	*< 0.001*
BMI (KG/M²)	21.1 (1.5)	22.8 (1.5)	*< 0.001*

Values are means (SD) and depict group average of data.

Gender differences in the architectural properties of AT gait biomechanics are given in Table 11. The women demonstrated a statistically significant lower proximal and median thickness both at rest (4.5 vs 5.1 mm with $p<0.001$ for proximal thickness; 4.4 vs 5.3 mm with $p<0.001$ for median thickness) as well as during maximum eccentric contraction (4.3 vs 4.8 mm with $p=<0.001$ for proximal thickness; 4.1 vs 4.8 mm with $p<0.001$ for median thickness). Moreover, the women demonstrated a statistically significant lower proximal and median CSA both at rest (52.4 vs 70.3 mm^2 with $p<0.001$ for proximal CSA; 55.3 vs 72.0 mm^2 with $p<0.001$ for median CSA) as well as during maximum eccentric contraction (55.4 vs 69.5 mm^2 with

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$p<0.001$ for proximal CSA; 53.0 vs 71.3 mm² with $p<0.001$ for median CSA).

Table 10. Architectural properties of Achilles tendon and gait biomechanics.

Variable	All (n=27)	Groups		p-value (ES)
		Women (n=16)	Men (n=11)	
Ultrasound Mesurements				
Proximal thickness at rest	4.7 (0.7)	4.5 (0.5)	5.1(0.8)	**< 0.001**
Median thickness at rest	4.7 (0.8)	4.4 (0.5)	5.3 (0.7)	**< 0.001**
Proximal thickness with passive force	4.5 (0.5)	4.3 (0.4)	4.8 (0.6)	**0.001**
Median thickness with passive force	4.4 (0.6)	4.1(0.4)	4.8 (0.6)	**< 0.001**
Proximal CSA at rest	59.7 (14.6)	52.4(9.3)	70.3 (14.4)	**< 0.001**
Median CSA at rest	62.1 (14.6)	55.3(9.9)	72(14.9)	**< 0.001**
Proximal CSA with passive force	61.1 (13.7)	55.4(10.3)	69.5(14)	**< 0.001**
Median CSA with passive force	60.50 (15.2)	53(9.8)	71.3(15.3)	**< 0.001**
Achilles tendon free length at rest	73.6 (14.6)	71.9 (11.3)	76.1 (18.5)	0.310
Achilles tendon free with passive force	91.6 (19.8)	90.2 (14.5)	93.6(25.9)	0.543
Angle pen at rest	13.1 (2.9)	13.2 (2.8)	13 (3.1)	0.791
Angle pen with passive force	10.6 (2.6)	10.7 (2.5)	10.4 (2.9)	0.758
Foot Posture and Gait Parametres				
FPI	5.8 (3.1)	5.5 (2.7)	6.3 (3.5)	0.321
Lunge test	38.5 (5.4)	39.4 (5.4)	37.2 (5.2)	0.139
FD MAX gait	13.3 (3.1)	13.9 (2.7)	12.4 (3.5)	0.091
FD RoM gait	18.5 (3.2)	19.4 (3.1)	17.2 (2.9)	**0.01**

CSA: cross sectional area; FPI: Foot posture index; FD MAX: maximal dorsi-flexion; FD RoM: Joint Range of Motion during gait.

Regarding both foot posture parameters and gait-related measurements, significant differences are evident solely in the Range of Motion (RoM) during the stance phase of gait (Women: 19.4°; Men: 17.2°; $p=0.01$, (Figure 15). However, no significate differences are observed in FPI and the Lunge test.

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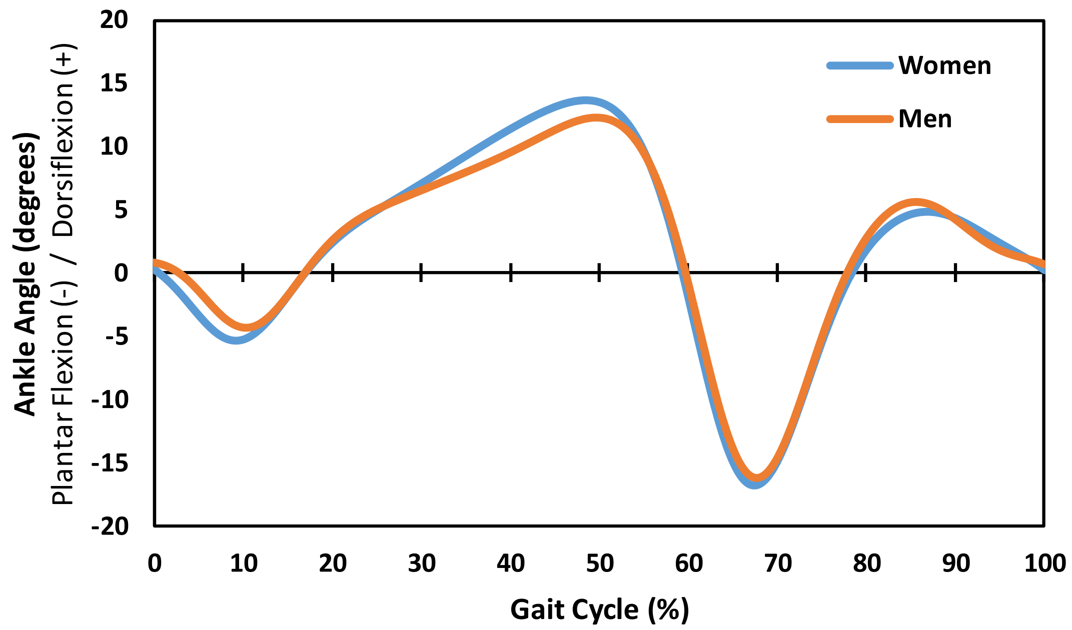

Figura 15.Comparison between groups of ensembles mean of ankle kinematic during the gait cycle.

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4.4.DISCUSION

The aim of this study was to describe and observe whether sonoanatomical changes in Achilles tendon tissue existed between men and women, without previous pathology, for clinical management in the prevention of Achilles tendinopathy.

The findings showed larger or longer measurements in men than in women; length and cross-sectional area (CSA) of the AT at rest and at maximal passive force and, in terms of mechanical properties, more joint stiffness in the RoM of dorsal flexion of the ankle (women: 19.4°; Men: 17.2°; $p=0.01$) (Figure 13).

Of the 54 Achilles tendons analyzed, the women demonstrated statistically significant lower proximal and medial thickness both at rest ($p<0.001$ for proximal thickness; $p<0.001$ for medial thickness) as well as during maximal eccentric contraction ($p=0.001$ for proximal thickness; $p<0.001$ for medial thickness). It is argued that these anatomical differences in tendon structure properties may be due to physical function (54,240,250) and/or tissue adaptations to the subjected load (191).

The scientific literature describes that there is a positive correlation between muscle strength, maximal strength capacity and maximal power (131,134,143,191,250–252). This could explain the anatomical and mechanical differences in gender given that individuals with greater muscle mass have greater connective tissue volume (250,252).

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Blackburn et al. assessed triceps sural plantarflexion strength and active ankle joint stiffness with a loading device between men and women. Apart from clear anthropometric differences (height, weight and BMI), men possessed greater muscle mass than women and therefore the structural stiffness and material modulus (the ratio of stress to strain) was higher in men than in women (253). Higher force capacity as a function of muscle mass volume will be important in the active endurance capacity of the muscle-tendon unit (252–254). Less movement in the RoM of dorsal ankle flexion may generate less stress-strain as our findings show. The difference in free AT was 18.3mm for women versus men's free AT 15.5mm; and proximal CSA was 3mm2 versus 0.8 mm2, with the women obtaining more deformation between rest and maximal passive force versus the men. Studies that investigated (238,244,255) gender-related differences in tendon properties under load are in line with our findings since they came to the same conclusion that there is a greater elongation/deformation in the tendon of females. There are morphological changes on ultrasound if we compare the tendon at rest and when in maximal dorsal flexion, showing less tendon stiffness, higher degrees of dorsal flexion in gait, compared to men. On the other hand, lower resting CSA was observed for proximal (52.4mm2 vs. 70.3mm2 with $p<0.001$) and medial (62.1mm2 vs. 72mm2 with $p<0.001$) slices of females vs. males. There are correlations between muscle-tendon properties and reproductive hormones (256) Generally, men present higher levels of

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testosterone, which leads to greater muscle hypertrophy due to the anabolic stimulation of the muscle (254). This muscle hypertrophy leads to tissue adaptation (257), and hence an increase in tendon thickness and CSA. Women have higher levels of estrogen, a hormone related to collagen synthesis. Higher quality collagen implies more compact and stiffer tissues that transmit force more quickly with greater elasticity and lower dissipated energy loss (244,256). However, Lemoine et al. in their histological study observed that women had significantly lower dry mass per tendon wet weight (37.6 ± 0.9 % vs. 34.3 ± 0.5 % dry mass) and a strong trend toward less collagen per tendon wet weight (33.9 ± 1.4 % and 30.6 ± 1.1 % collagen for men and women, respectively, P = 0.08). Females may synthesize less tendon material overall per tendon size, resulting in lower tendon dry mass and collagen content.

The strength of our study is the measurement protocol carried out which ensures the validity and reliability of the ultrasound measurements in living individuals.

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4.4.1. **Clinical implications**:

Our study contributes that gender should be considered in the clinical management of AT pathology given that there are significant differences with respect to the difference in CSA, thickness and greater ankle dorsiflexion range of motion during the stance phase of gait in the physically active, healthy population, with a normal BMI and IPF, ruling out the aging factor and collagen alterations that would be observed with age.

4.4.2. Limitations of the study:

Categorization by age range was not performed. Future research is needed to broaden the age range, as well as the sports activity performed, and even to be able to make a comparative control of the diet.

4.5. CONCLUSION:

The results obtained from this study show that the biomechanical properties and biological behaviour of the Achilles tendon are not the same in men and women. There are differences in the sonoanatomical characteristics of the AT both at rest and at maximum passive force. The female gender presents a greater strain deformation of the Achilles tendon in the ROM of dorsal flexion of gait.

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CHAPTER V:

ULTRASOUND VALIDATION OF A DYNAMIC PROBE FIXATION DEVICE

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5.1. INTRODUCCTION

In the last decade, ultrasound has become an important complementary tool to physical examination and other diagnostic techniques in the clinical management of musculoskeletal pathologies (173).

This surge has occurred because it presents unique advantages in very specific clinical scenarios. It has the advantage of being a non-invasive diagnostic technique, enabling a dynamic study and observation of muscular and tendinous behaviour (173,258–260).

Studies on the repeatability and reproducibility of dynamic ultrasound images focus on muscular architectural images, such as muscle belly length, pennation angle, cross-sectional area, thickness, etc. (189,258,261). This becomes more complex when evaluating a tendon, as there are more anisotropic phenomena. This phenomenon depends on the fibrillar arrangement of collagen bundles that make up the tendon (262).

In an ultrasound examination of the Achilles tendon (AT), the tendon's thickness and cross-sectional area, length, orientation of muscle fiber to its tendon insertion, and echogenicity are assessed (187). These parameters provide in vivo diagnostic information about the tendon. Typically, clinicians conduct these examinations with the patient lying prone on the examination table, with their feet hanging off the edge and a slight dorsal flexion of the ankle (90,263,264).

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From clinical experience, we consider that often evaluating a resting Achilles tendon is a disadvantage because it is a load-bearing tendon, and we might lose information in its assessment while lying down (263,265,266).However, performing an ultrasound in weight-bearing posture allows for observing and monitoring the functioning of that tendon under load, both static and/or dynamic, resulting in a diagnosis more closely aligned with the structure's functionality (267).

Ultrasound evaluations of the AT are commonly used in clinical settings to differentiate between tendons with and without tendinopathy (268,269). Despite the simplicity of visualizing the AT through ultrasound, there exists intra- and inter-rater error due to the examiner's experience and skill, which can lead to variation in results (270).

Measurement errors in ultrasound images can stem from the measurement protocol and the equipment used, as well as the variation within the subject caused by biological factors (271). The most common sources of variability between measurements include the pressure of the probe on the skin and the perpendicularity at which the tissue is cut (there can be biases in the angle of incidence), all of which can lead to changes in measurement. Another important consideration is the substantial operator dependence in ultrasound measurements, giving ultrasound measurements a reputation for poor repeatability or, more specifically, low intra- and inter-rater reliability (181,188,272,273). M. Reiman's study demonstrates high specificity

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and sensitivity of ultrasound in Achilles tendinopathy; however, it emphasizes how this can vary due to different factors such as the examiner's experience and the equipment used (270).

The aim of this study is to validate the reliability of fixed ultrasound in load-bearing versus manual acquisition by measuring the thickness of the AT in non-weight-bearing (patient at rest on the examination table) and weight-bearing (patient in a standing position performing maximum ankle dorsiflexion(243)) conditions.

5.2. PATIENTS AND METHODS:

5.2.1. Ethical approval:

This study was conducted in full compliance with the provisions of the Helsinki Declaration on Ethical Principles for Medical Research Involving Human Subjects and was approved by the Experimental Ethics Committee of the University of Malaga, registration No. 144-2021-H. Written informed consent was obtained from all participants prior to data collection. Appropriate measures will be taken to ensure the complete confidentiality of personal data, in accordance with the provisions set forth in Law 3/2018, of December 5, 2018, on the protection of personal data and guarantee of digital rights, and Regulation (EU) 2016/679 of the European Parliament and of the Council, dated 27/04/2016, regarding the protection of individuals concerning the processing of personal data and the free movement of

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such data, repealing Directive 95/46/EC (General Data Protection Regulation).

5.2.2. Design:

An observational study. An intra-rater reability and inter-rater concordance study.

5.2.3. Population:

The participants were students recruited from the University of Malaga from March to May 2023. Inclusion criteria were individuals over 18 years old, without previous Achilles tendon pathology, and capable of walking autonomously. Exclusion criteria included disorders of the lower extremities, systemic, vascular, and/or joint diseases affecting the musculoskeletal system (such as diabetes, rheumatoid arthritis, collagen disorders), pregnancy, prior surgeries involving the lower extremities, and the use of orthopaedic or non-orthopaedic treatments on the lower extremities at the time of data collection.

5.2.4. Procedure:

The subjects who were evaluated by the team member in face-to-face interviews where the procedure was explained, signed the informed consent, and completed a demographic history form (including age, height, weight, sex, smoking habits, current injury status, allergies, medications, previous surgeries, type of sport, and number of weekly workouts). This information allowed the establishment of the sample in accordance with the inclusion and exclusion criteria.

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The ultrasound examination of the participants was conducted by an experienced sonographer with 5 years of experience (RA) (examiner 1) and an evaluator without previous experience (AV) (examiner 2) who had undergone training in musculoskeletal ultrasound examination of the foot and ankle. Both examiners received instructions and training on test setup before the study began to ensure they followed the study protocol. The training, conducted for both operators, served as a refresher on the theoretical framework, including the physical foundations of the exams and the methods of palpation and measurement. Subsequently, the sonographers analysed the Achilles tendon (TA) following protocols defined in previous studies, which included patient and probe positioning, as well as the identification of tendon edges in the resulting images (174,231,268,274).

5.2.5. Protocol scanning:

The ultrasound images were collected using a portable musculoskeletal ultrasound system, the MyLab™ Sigma Elite (Esaote, Italy), equipped with a high-density linear probe (4-15 MHz). Each examiner independently conducted the scanning in a random order within the same session to assess inter-examiner reliability. Additionally, the expert examiner repeated the measurements one week later to evaluate intra-subject reliability. Researchers were blinded to any prior measurements during the scanning sessions.

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To assess the Achilles tendon (AT) thickness, images were captured at rest with probe fixation and manual acquisition. Subsequently, the same procedure was performed with the participant standing in a maximum ankle dorsiflexion position.

Examiner 1 initially performed a measurement at rest with manual acquisition, with the patient lying prone and feet hanging off the examination table in a resting position (178). To obtain measurements, the distance between the most proximal point of the posterior edge of the calcaneus and the distal end of the musculotendinous junction of the soleus was taken. The measurement process involved identifying reference anatomical points, marking them on the skin, capturing the tendon image to calculate its thickness, and repeating this process for both legs. Subsequently, the same Examiner 1 repeated the same procedure using fixed ultrasonography with marked anatomical reference points and then performed the same procedure with the patient weight-bearing in a standing position (174,178,191).

After a 5-minute rest for the subject, Examiner 2, in a separate adjacent room, replicated the same measurements as Examiner 1 using fixed ultrasonography.

Measurements of the AT thickness were obtained at 4 cm and 6 cm distances from the insertion of the AT to the calcaneus. These points had been previously marked on the skin (178,181,267). Following each scan, the skin marks were removed to ensure blinding

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of the results among researchers (172,178,198). All sonograms were stored in the ultrasound machine (MyLab™ Sigma Elite, Italy).

5.2.6. Sample Size:

The SPSS v.25.0 program (IBM Inc., Chicago, IL, USA) was used. Calculation of the minimum sample size required to detect a correlation coefficient significantly different from zero (10) for a minimum value of 0.7, with a 95% confidence interval, yielded a bilateral Type I error of 5% (α risk = 0.05), with a fixed power of 80% (Type II error, β = 0.2), resulting in a minimum size of 14 patients, considering a maximum subject loss of 30%. Finally, the number of participants was 20 subjects, each of whom underwent a complete measurement of both feet, 40 complete measurements (Figure 16).

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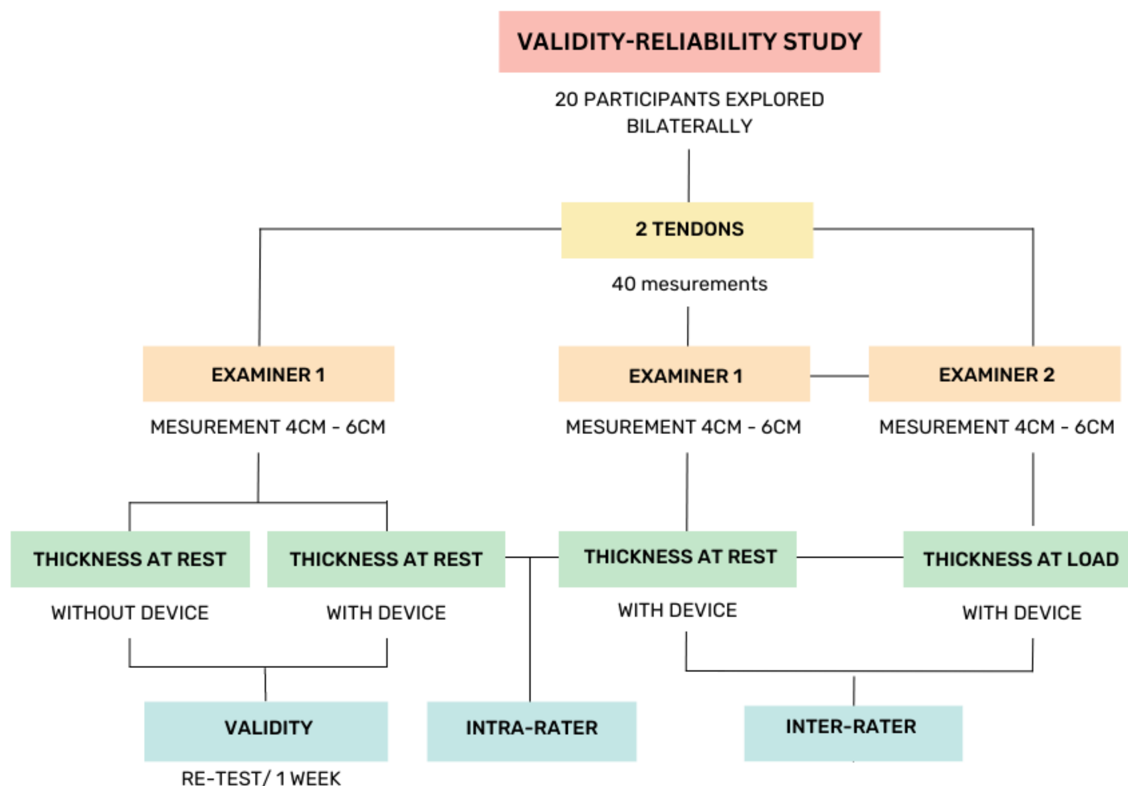

Figura 16. Sequence of the intra-rater reliability procedure.

5.2.7. Statistical Analysis

The statistical analyses were performed using Jamovi Project version 2.3, 2022. Mean and standard deviation were used for descriptive statistics with 95% confidence intervals (CI). The data were normally distributed, as confirmed by visual inspection of QQ plots, kurtosis and skewness coefficients, and the Kolmogorov-Smirnov test (174,181). To determine the reliability of measurements between evaluators, Intraclass Correlation Coefficients (ICCs) were calculated using a two-way random effects model and an absolute agreement type (172). The following criteria were used to assess reliability

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coefficients: very poor (<0.20), poor (0.21-0.40), moderate (0.41-0.60), good (0.61-0.80), and excellent (0.81-1.00) (172,275).

Additionally, in a Bland-Altman plot, 95% limits of agreement (LOA) were calculated. Bland-Altman plots were constructed to assess the presence of systematic errors. The difference between each pair of measurements (Y-axis) is plotted against the mean of both measurements (X-axis), with the overall mean difference and the 95% agreement limits completing the graphical information. LOA is presented as the difference between the mean difference and the upper and lower LOA to comprehend the result in a clinical context (276). Passing-Bablok regression analysis was applied to evaluate potential systematic bias in the measurement(276,277).

5.3. RESULTS:

The sample consisted of fourteen women and six men (mean age of 22.55 ± 2.32 years and mean BMI of 23.61 ± 2.97) (Table 11).

The ultrasound data for the thickness of the Achilles tendon by the two examiners are shown in Table 12. Mean comparisons between examiner 1, who was more experienced, and examiner 2 at rest were 4.58 mm and 4.66 mm for the thickness at 4 cm from the calcaneal insertion and 4.67 mm and 4.66 mm at 6 cm from the insertion, respectively.

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Table 11. Characteristic of population

GENRE(N)	AGE(a) (MEAN/SD)	WEIGHT(k) (MEAN/SD)	HEIGHT (cm) (MEAN/SD)	BMC (MEAN/SD)
Male (6)	22.5 ± 3.12	79.8 ± 13.91	167 ±6.79	25.1 ± 2.99
Female (14)	22.6 ± 1.95	63.8 ± 6.94	178 ± 6.16	23 ± 2.77
Total (20)	22.55 ± 2.32	68.6 ± 12.51	170 ± 8.07	23.61±2.97

N(number); SD(standard deviation);K(kilogram),Cm(centimeter),BMI(body mass index)

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Table 12. Descriptive variable Achilles thickness with manual acquisition and with fixed ultrasonography.

		INTRA-RATER				**INTER-RATER**		
Variables	**US Acquisition**	**EXAMINER 1** Mean (SD) 95% CI	**EXAMINER 2** Mean (SD) 95% CI	**$ICC_{(1-1)}$ (95% CI)**	***P*-value**	**Mean (SD) 95% CI**	**α Cronbach**	***Mean difference 95% LOA**
4 cm At rest	manual acquisition	4.50 (0.54)	4.49 (0.60)	0.91 (0.86 - 0.95)	<0.001	4.51 (0.528)	0.998	0.005 (-0.104 to 0.094)
6 cm At rest	manual acquisition	4.63 (0.455)	4.66 (0.611)	0.895 (0.861- 0.945)	<0.001	4.63 (0.450)	0.996	0.02 (-0.0905 to 0.13)
4 cm At rest	fixed ultrasonography	4.58 (0.556)	4.66 (0.579)	0.926 (0.882- 0.957)	<0.001	4.58 (0.543)	0.997	0.000 (-0.109 to 0.109)
6 cm At rest	fixed ultrasonography	4.67 (0.461)	4.66 (0.510)	0.909 (0.861- 0.945)	<0.001	4.67 (0.460)	0.997	0.01 (-0.0872 to 0.1072)
4 cm At load/DF	fixed ultrasonography	4.24 (0.624)	4.36 (0.614)	0.894 (0.826- 0.94)	<0.001	4.24 (0.626)	1.000	-0.005 (-0.0483 to 0.0383)
6 cm At load/DF	fixed ultrasonography	4.39 (0.531)	4.36 (0.631)	0.876 (0.802- 0.928)	<0.001	4.39 (0.533)	0.999	-0.0025 (-0.0725 to 0.0675)

Variables: Achilles tendon Thickness in centimetres (cm). SD: standard deviation. 95% CI: 95% confidence Interval; *Mean differences in millimetres (mm); LOA: Limit of agreement. DF:measurement was taken in a standing position with maximum ankle dorsiflexion.

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The ICC for all measurements taken at 6 cm from the insertion was 0.909 (95% CI = 0.861 to 0.945). The ICC was 0.926 (95% CI = 0.882 to 0.957) for measurements at 4 cm from the insertion. For weight-bearing measurements, an ICC of 0.876 (95% CI = 0.802 to 0.928) was obtained at 6 cm from the insertion, and an ICC of 0.894 (95% CI = 0.826 to 0.940) was obtained at 4 cm from the insertion (Table 13).

Regarding inter-rater reliability, Cronbach's alpha coefficient was used, resulting in α = 0.996 for measurements at 6 cm from the calcaneal insertion and α = 0.998 for measurements at 4 cm using manual acquisition. α = 0.997 for measurements with fixed ultrasound at rest, and for weight-bearing measurements with ankle dorsiflexion, they were excellent (α = 0.999 and α = 1.000) (Table 12).

Figure 17 and 18 show the Bland-Altman plot where the agreement between manual acquisition and fixed ultrasound measurement under load with maximum ankle dorsiflexion is evaluated. The difference in measurements has an amplitude of -0.0025 (-0.0725 to 0.0675) and -0.005 (-0.0483 to 0.0383), respectively. Figure 19 displays the plot evaluating the agreement of fixed ultrasound measurements by two different examiners, with a difference amplitude of 0.0175 (0.488 to 0.523).

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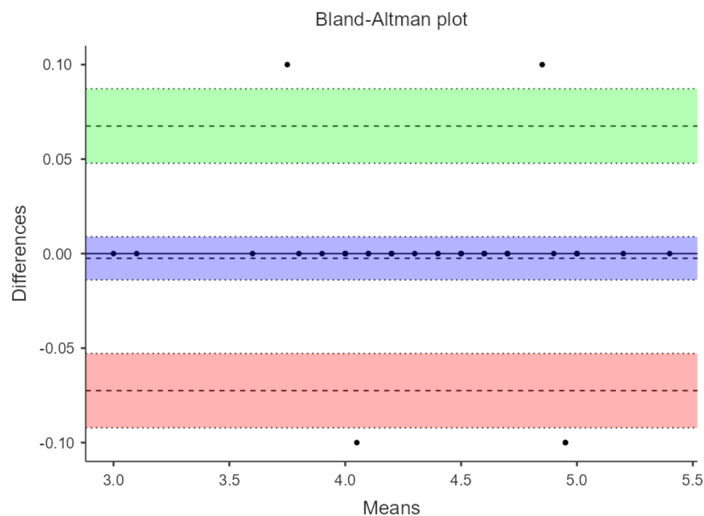

Figura 17. Bland-Altman plot at 6cm from the AT to load with fixed ultrasonography vs. manual acquisition.

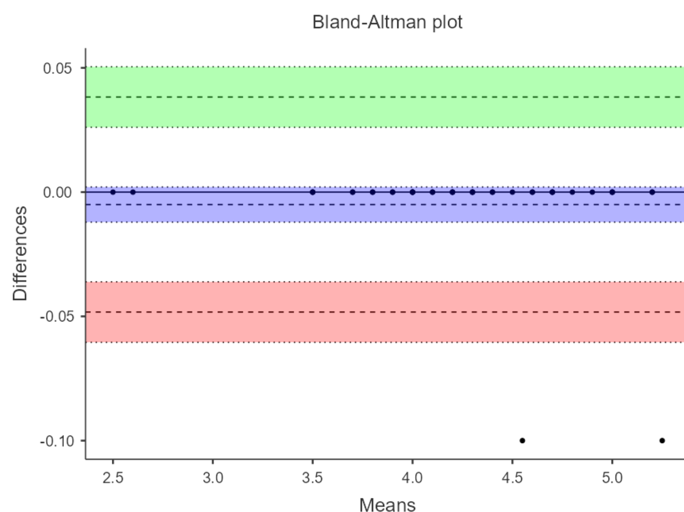

Figura 18. Bland-Altman plot at 4cm from the AT to load with fixed ultrasonography vs. manual acquisition.

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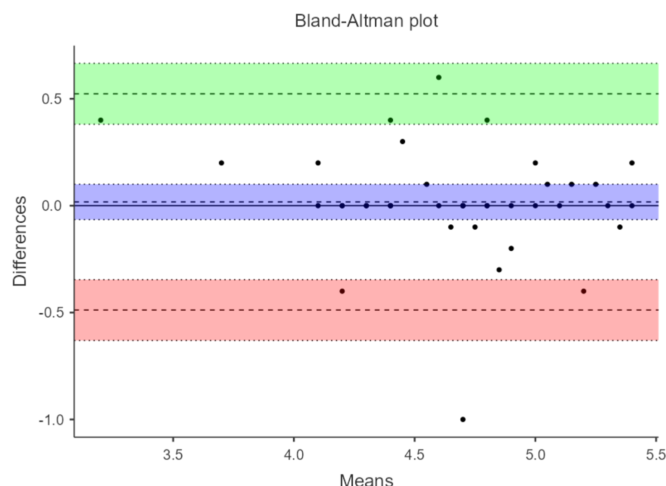

Figura 19. Bland-Altman plot at 6cm from the AT to load with fixed ultrasonography examinator 1 vs examinator 2.

5.4. DISCUSION:

The objective of this study was to validate the reliability of fixed ultrasound in load-bearing versus manual acquisition by measuring the thickness of the AT in non-weight-bearing (patient at rest on the examination table) and weight-bearing (patient in a standing position performing maximum ankle dorsiflexion conditions.

The findings indicate that ultrasound measurements of the Achilles tendon (AT) thickness, taken from healthy adult participants without any prior AT pathology, exhibit excellence, even when conducted by different evaluators and under load. Additionally, the results from the three figures demonstrate minimal differences between measurements and narrow ranges, implying a reasonably high level of agreement among the methods or examiners assessed in these measurements.

When comparing these findings with the literature regarding measurements at rest, Ríos-Díaz et al. (2010) found an excellent ICC

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for inter-rater reliability but with a wider confidence interval (ICC = 0.94; 95% CI = 0.58 to 0.98)(174), and Baño-Aledo ME et al. obtained an ICC of (ICC=0.98; 95% CI = 0.96–0.99)(278). An explanation for why our study obtained lower reliability could be that these authors obtained measurements in a transverse view of the AT, whereas the present study explored the tendons longitudinally. These measurements were obtained in the longitudinal section because it is the only method that allows the examiner to record the distance from the point where the thickness is measured to the bony insertion.

On the other hand, Heres et al. evaluated the lateral vastus muscle freehand and with ultrasound probe fixation, showing inconclusive reliability data, but they concluded that probe fixation enhances the field of view (FOV), and their measurements yielded significant values (p=<0.05)(261). Concerning our results, our findings contribute a different way of assessing the AT and enhance the clinical applicability of quantitative musculoskeletal ultrasound in settings other than the clinic and assessments beyond the examination table.

Our study considers it highly useful to assess the anatomical structures of the foot under load, given that the foot is designed to bear body weight and allow walking(54,56,229). Bruno F. et al. describe a protocol for Weight-bearing MR Imaging of Knee, Ankle, and Foot, concluding in their research that the main advantage is the ability to obtain imaging that faithfully represents the biomechanical conditions of the joint. (279,280)

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At a clinical level, sonographers encounter difficulties in obtaining good tendon images due to anatomical differences among subjects and image acquisition technique (174,262). The most common anatomical difficulties include the presence of a thick subcutaneous adipose layer that blurs the tendon boundary or bone morphology that might create acoustic shadowing (172,174). On the other hand, technical difficulties that can distort images in thickness measurements include probe pressure and probe inclination (172). It's important to be aware that ultrasound has variability depending on the operator. In a study comparing magnetic resonance imaging of the Achilles tendon, Kruse et al. demonstrated alterations in tendon morphology, and resulting measurements depended on the amount of pressure applied to the transducer. For this reason, we consider that taking measurements with fixed ultrasonography could minimize errors.

5.4.1. Clinical implications:

The reliability demonstrated in fixed acquisition of ultrasound images could prove appealing in many medical fields and sports, not only to reduce ergonomic problems related to the work of sonographers but also to conduct assessments of more complex structures with greater reproducibility.

The main bias in this study has been the operator-probe-plane pressure in measurements without a device between subjects, as it could not be quantified. The measurements were only taken in longitudinal sections as it was the only quantitative way to measure

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the thickness at the correct distance from the calcaneal insertion without losing the cutting point**.**

The strength of the study lies in using fixed ultrasonography to eliminate the bias of probe-plane pressure, resulting in excellent measurement reliability.

5.5. CONCLUSION:

An excellent intra-and inter-rater reliability has been demonstrated in the acquisition of ultrasound images of the Achilles tendon (AT), supported by the consistency of measurements obtained by the examiners. This indicates that the results are uniform and consistent. A better understanding of the normal anatomy of the Achilles tendon and the characterization of its variations in the healthy population will potentially allow for better pathological diagnosis and surgical repair.

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CHAPTER VI:

SONOANATOMIC ANALYSIS OF THE FREE PORTION OF THE ACHILLES TENDON

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6.1. INTRODUCCTION

The tendinopathy of the Achilles tendon is among the most common pathologies in sports medicine, with an increasing incidence rate per 100,000 person-years rising from 2.1 (95% CI: 0.3 to 7.7) in 1979 to 21.5 (95% CI: 14.6 to 30.6) in 2011 (193). These findings are associated with the growing popularity of sports practice (175,193–195). It is necessary to understand the anatomical structure of a healthy tendon to gain a better comprehension of the injury.

On the other hand, partial ruptures of the Achilles tendon are often misunderstood. Diagnosis should be based on the patient's history with a typical acute onset of pain and inability to fully load the tendon, but this symptomatology is not always present(281). Therefore, with the assistance of ultrasound examinations, the clinician can assess the tissue quality of the Achilles tendon in vivo(279).

Ultrasound is a precise, economical, and rapid imaging technique that is accepted for evaluating tendons (172–175). One advantage is that it is a method for obtaining images with good inter- and intra-rater reliability (ICC= 0.98; 95% CI = 0.96-0.99) (278) and with the capability to capture images dynamically and during joint movement (172,177,178). Changes in cross-sectional area and thickness are more extensively documented in the literature concerning Achilles tendon pathology (34,156,161,194,282), but ultrasound measurements in healthy individuals based on age or gender are more

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limited (175,263). Currently, there is limited scientific evidence regarding the relationship between ultrasound measurements of the Achilles tendon (free tendon length, area, thickness, and angle of pennation) and demographic data, as well as healthy habits (BMI, level of physical activity, and foot dominance), and biomechanical tests (196–198,263).

Injuries to the Achilles tendon are often associated with poor ankle flexibility and strength, as well as overuse. Elderly individuals are also susceptible to tendon ruptures, which can be due to degeneration of tendon structures (12,34,104,156,196,283). Additionally, chronic kidney insufficiency, rheumatoid arthritis, and thyroid disorders may also correlate with tendon degeneration and rupture(196). Age-related changes in the thickness of the Achilles tendon are seldom considered. However, potential sonoanatomic changes related to age in the Achilles tendon are scarce(196,263).

The main objective was to perform a more detailed characterization of measurements obtained by ultrasound of the Achilles tendon in healthy individuals spanning a wide age range without pathologies. Additionally, the goal was to determine which factors could be significantly associated with these Achilles tendon measurements.

6.2. PATIENTS AND METHODS

6.2.1. Ethical approval

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This study was conducted in full compliance with the provisions of the Helsinki Declaration on Ethical Principles for Medical Research Involving Human Subjects and was approved by the Experimental Ethics Committee of the University of Malaga (CEUMA), registration Nº. 144-2021-H Informed written consent was obtained from all participants.

6.2.2. Desing:

Observational cross-sectional study.

6.2.3. Population:

The study population consisted of healthy individuals without previous foot and ankle pathology from the provinces of Málaga, Sevilla, Granada, and Valencia. Data collection took place from March 2022 to March 2023 with the authorization of the Ethics Committee for Experimentation of the University of Málaga (Annex 1) and the research committee of the Faculty of Health Sciences (Annex 2).

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6.2.4. Selection criteria:

All voluntary participants meeting the following criteria were included:

- Men and women aged between 18 and 55 years.
- Physically active, with training of 2 hours or more per week.
- Signed informed consent.

Exclusion criteria applied were:

- Individuals experiencing painful symptoms in the Achilles tendon at the time of the study.
- Subjects with antidegenerative disease, metabolic disorders, or neurological issues.
- Individuals who underwent lower limb surgery, had infectious, neoplastic, or metastatic processes, and/or cognitive impairment.
- Pregnancy.
- Subjects with musculoskeletal injuries in the lower limbs within the last 3 months.
- Subjects undergoing oral corticosteroid and/or antibiotic treatment.

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6.2.5. Procedure:

The subjects who were evaluated by the team member in face-to-face interviews where the procedure was explained, the informed consent was signed (Anexo 3) and demographic history forms were collected (age, height, weight, sex, smoking, current injury status, allergies, medications, previous surgeries, type of sport and number of weekly workouts) that allowed the sample to be established in terms of inclusion and exclusion criteria.

In Table 13 lists all variables included in the data collection.

Table 13. Description of variables by type and characteristic.

VARIABLE	VALUES	SELECTED METHOD
Age	18-55	**Administrative form designed for the study.**
Genre	Men/Women	
Weight	Kg	
Height	cm	
BMI	weight/height^2	
Smoker	Yes/No/Ex-Smoker	
Hours of training/week.	1 once/week. 2-3 once/week. +3 once/week.	

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Position of the foot in different planes and segments	To -12 a 0 y to 0 a +12.	**Foot Posture Index Test**
Foot of the start of the march.	Right /left	**Out Leg**
Dorsal ankle flexion	degrees	**Test de Lunge**
TA length at rest	Mm	**Ultrasound MyLab Sigma Esaote.**
TA length at maximum passive force	Mm	
Thickness of the AT at rest.	Mm	
TA thickness at maximum passive force	Mm	
Area of AT at rest	Cm^2	
Area of TA at maximum passive strength	Cm^2	
Pennation angle of soleus muscle at TA at rest	degrees	
Pennation angle of soleus muscle at TA at maximum passive strength	degrees	

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6.2.5.1. Foot Posture Index

Then, a brief exploration was carried out in which the FPI and the Lunge test were performed. The FPI assesses the multi-segmental nature of foot posture in all three planes and does not require the use of specialised equipment. Each FPI item is scored between -2 and +2, resulting in a total ranging from -12 (very supinated) to +12 (very pronated). Index items include palpation of the talar head, curves above and below the lateral malleolus, calcaneal angle, talonavicular protuberance, medial longitudinal arch and forefoot to hindfoot alignment. In all other aspects, the protocol described by Redmond et al. (215,216) was followed. The FPI has proven adequately reliable in varied clinical settings (Intraclass correlation coefficients (ICC) = 0.62–0.91) (245).

6.2.5.2. Lunge test

The Dorsiflexion Lunge test was performed to assess ankle dorsiflexion range of movement (ROM). The test protocol followed the procedure described by Bennell et al. (243), starting position of the participant in weight bearing with the big toe of the foot being tested 10 cm from the wall and the knee is in line with the second toe, can lean on the wall using two fingers of each hand to maintain balance. The test consists of pushing the knee until it touches the wall without the heel lifting off the ground, at which point the investigator recorded the angle of the tibia to the vertical (to the nearest tenth of a degree) as a measure of ankle dorsiflexion ROM. Three measurements were

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taken and the mean was used for statistical comparisons. This test has been shown to have an intra-rater reliability of ICC = 0.98 (SEM = 1.1°) and an inter-rater reliability of ICC = 0.99 (SEM = 1.4°) (243).

6.2.6. Ultrasound Measurements.

The scans were obtained using a portable musculoskeletal ultrasound system, MyLab Sigma Elite (Esaote, Italy), and a high-density linear probe (4-15 MHz). The image field depth was set at 3.5 cm, gain at 85 dB, probe frequency at 14 MHz, and a single focal zone (set at a depth of 0.5 cm) was placed at the level of the Achilles tendon. All other settings (e.g., compression, mapping, smoothing, X resolution) were kept constant for all examinations performed on all participants to standardize the recorded images. Measurements were taken by a single investigator with over 5 years of experience in ultrasound.

Ultrasound measurements of Achilles tendon length, tendon thickness, (CSA), and soleus muscle pennation angle to the Achilles tendon were performed, following the protocol described by Alabau et al. (263). The initial measurements were taken in the prone position with both legs beneath the examination table. After 5 minutes of rest, the same ultrasound measurements were taken with the knee flexed on the table (to negate gastrocnemius force) while exerting passive force on the sole of the foot until complete ankle dorsiflexion.

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The Achilles tendon enthesis on the calcaneus was located via ultrasound, marked on the skin at that level, 4 cm from the calcaneus, and at the proximal level where the soleus musculature is no longer visible to record the ultrasound images for Achilles tendon length (181) For thickness measurement, the evaluator aligned the transducer at precise location marks (proximal and insertion), capturing three images in a longitudinal view by placing the calliper on the upper and lower edges of the Achilles tendon (181,263). CSA was measured by positioning the transducer in a transverse view at the marked locations, recording three images in proximal, medial, and insertion cross-sectional views (181). The mean of three repeated values was recorded for each measurement. For each image, the transducer was removed and repositioned on the skin marks. Several studies indicated a higher incidence of AT this level (34,234). Following Narici et al. (89,92) for measuring the Achilles-soleus pennation angle, the probe was positioned in a transverse view at the distal third of the leg, scanning towards the foot until the end of the soleus muscle insertion was observed. At this point, a 90º rotation of the ultrasound probe was made, positioning it in a longitudinal view along the medial longitudinal axis determined by the soleus fibers to the Achilles tendon, from where the pennation angle measurement was obtained.

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6.2.7. Statistical Analyse.

The SPSS v.25.0 program (IBM Inc., Chicago, IL, USA) was used for statistical calculations using descriptive statistical tests. A Shapiro–Wilk test was used to test the normality of all data distribution. An independent t-test was used to quantify the differences in the group and T-students if the data were normally distributed. A correlation matrix was calculated using Pearson and Spearman coefficients to observe potential relationships between variables social-demographic and ultrasound measure. The significance level was set as 0.05.

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6.3. RESULTS.

In total, 154 subjects were analysed (table 14), 62 males (40.3%) and 92 females (59.7%). The participants are mean age was 32.25 years (SD ±10.32).

Table 14. Characteristic of population. (Classified by age group).

					Shapiro-Wilk	
	GROUP	**N**	**Mean**	**SD**	**W**	**p**
GENRE	19 a 25	51	1.67	0.476	0.595	< .001
	26 a 39	51	1.55	0.503	0.633	< .001
	40 a 54	52	1.58	0.499	0.628	< .001
AGE	19 a 25	51	21.24	1.464	0.937	0.009
	26 a 39	51	30.24	3.575	0.892	< .001
	40 a 54	52	45.04	3.559	0.954	0.042
WEIGHT	19 a 25	51	67.02	15.793	0.883	< .001
(kg)	26 a 39	51	69.43	17.537	0.852	< .001
	40 a 54	52	74.37	15.970	0.974	0.303
HEIGHT	19 a 25	51	169.78	10.118	0.959	0.077
(cm)	26 a 39	51	169.73	8.514	0.970	0.228
	40 a 54	52	169.65	7.931	0.958	0.065
BMI	19 a 25	51	23.09	4.406	0.741	< .001
	26 a 39	51	23.91	4.775	0.849	< .001
	40 a 54	52	25.71	4.605	0.973	0.284

N=154 subjects; SD: Standard Deviation; Kg(kilogram); Cm(centimeter); BMI(body mass index)

The sample was divided into three groups: 51 participants in Group 1 aged between 19 and 25 years with a mean age of 21.24 years (SD ±1.46); 51 participants in Group 2 aged between 26 and 39 years, and 52 participants in Group 3 aged between 40 and 54 years.

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Descriptive variables such as smoking status, sports participation, FPI and Lunge Test are presented in Table 15 categorized by age groups.

Table 15. Descriptive variables: smoker, sport, IPF, beat loss and Lunge test by age group.

					SHAPIRO-WILK	
	GROUP	N	Mean	SD	W	p
SMOKER	19 a 25	51	0.490	0.925	0.570	< .001
	26 a 39	51	0.490	0.857	0.600	< .001
	40 a 54	52	0.673	1.080	0.633	< .001
SPORT	19 a 25	51	0.745	0.440	0.543	< .001
	26 a 39	51	0.588	0.497	0.625	< .001
	40 a 54	52	0.635	0.486	0.610	< .001
FPI_LEFT	19 a 25	51	6.176	3.491	0.964	0.119
	26 a 39	51	5.490	3.152	0.929	0.004
	40 a 54	52	3.731	3.361	0.969	0.200
FPI_RIGHT	19 a 25	51	5.745	3.298	0.943	0.016
	26 a 39	51	5.314	3.184	0.875	< .001
	40 a 54	52	3.231	3.227	0.942	0.014
OUT_LEG	19 a 25	51	1.235	0.428	0.526	< .001
	26 a 39	51	1.216	0.415	0.507	< .001
	40 a 54	52	1.365	0.486	0.610	< .001
LUNGE_LEFT	19 a 25	51	37.878	5.518	0.966	0.152
(degree)	26 a 39	51	38.284	3.896	0.962	0.106
	40 a 54	52	38.427	4.950	0.929	0.004
LUNGE_RIGHT	19 a 25	51	38.012	6.376	0.852	< .001
(degree)	26 a 39	51	39.027	4.627	0.953	0.042
	40 a 54	52	39.337	4.533	0.955	0.048

(N=154 subjects); SD: Standard Deviation

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The 66.9% of the sample were non-smokers, 22.1% were smokers and 11% were people who had smoked but were no longer current smokers. Figure 20.

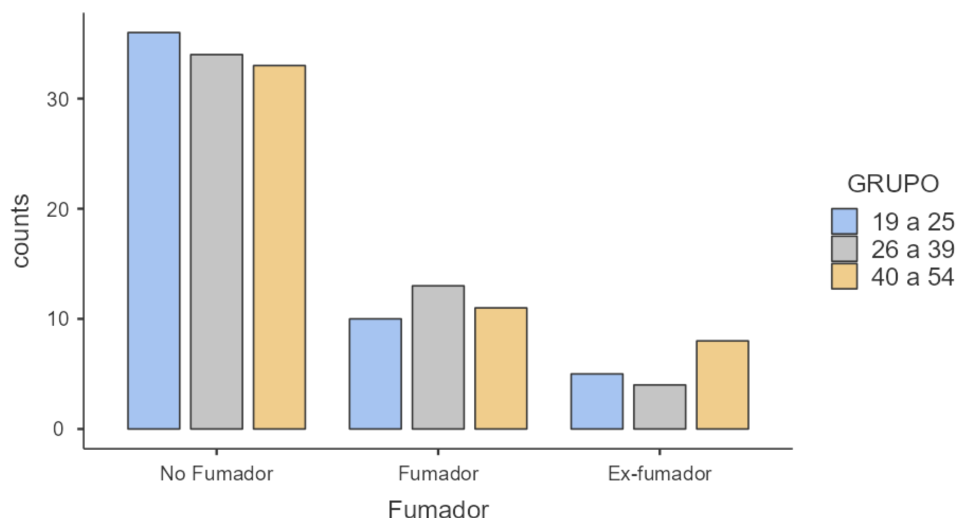

Figura 20. Smoker by age group.

The total of 34.4% of the sample did not engage in sports activities, whereas 65.6% participated in some form of sport, with the most active group being the 19 to 25-year-olds, comprising 24.7% of the total sample. Figure 21.

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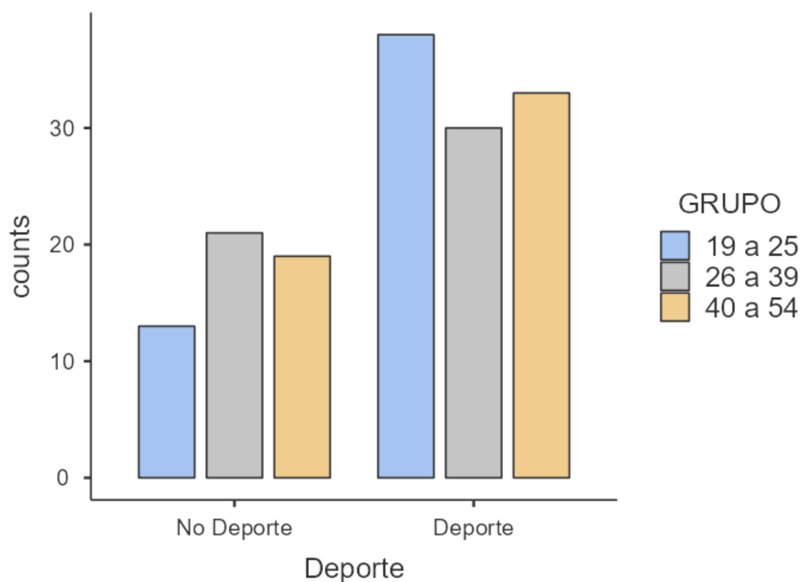

Figura 21. Sport Practice by age group.

The mean (FPI) for the left foot compared to the right foot is similar for groups (19 to 25 and 26 to 39 years). There appears to be a lower FPI in the population aged 40 to 54 years compared to the population aged 19 to 25 years (3.73 left and 3.23 right vs. 6.18 left and 5.75 right). The mean FPI values were higher in the left leg for all age groups (Table 15).

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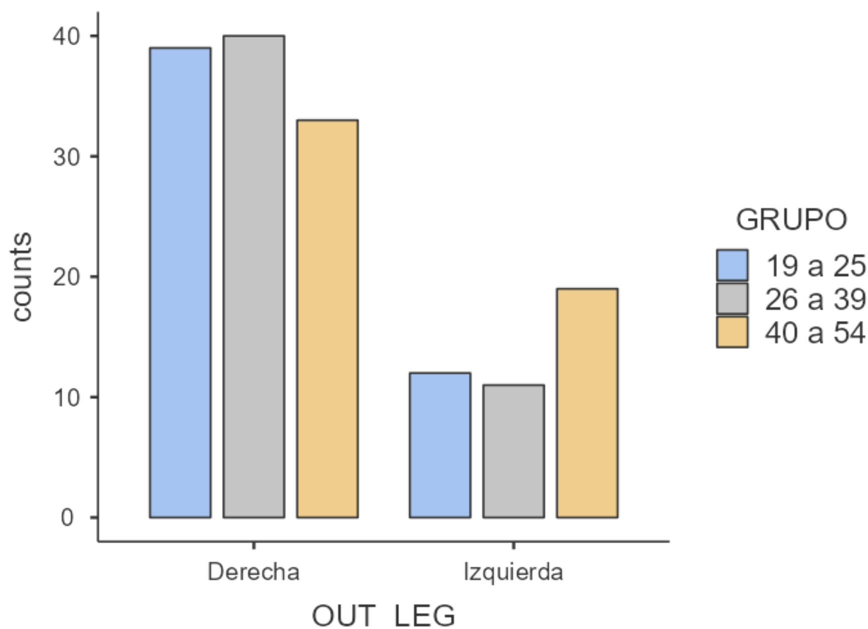

Figura 22. Out Leg variable by age group.

The variable out leg figure 17 shows the leg with which the subject starts the step. 72.7% of the sample initiates the step with the right leg.

The mean (FPI) for the left foot compared to the right foot is similar for both groups (19 to 25 and 26 to 39 years). There appears to be a lower FPI in the population aged 40 to 54 years compared to the population aged 19 to 25 years (3.73 left and 3.23 right vs. 6.18 left and 5.75 right). The mean FPI values were higher in the left leg for all age groups (Table 15).

Figure 22 shows a normal distribution of the Lunge test variable in different age groups, as per the normal distribution graph. Higher ankle angles are observed in women in the 19 to 25-year-old and 40 to 55-year-old groups. The mean for men overall is 38°, and broken down by age groups: 19 to 25 years; 36.8°, 26 to 39 years; 39.2°, 40

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to 54 years 37.6°. The mean for women overall is 39°: 19 to 25 years 39°, 26 to 39 years 38.2°, 40 to 54 years 39.8°.

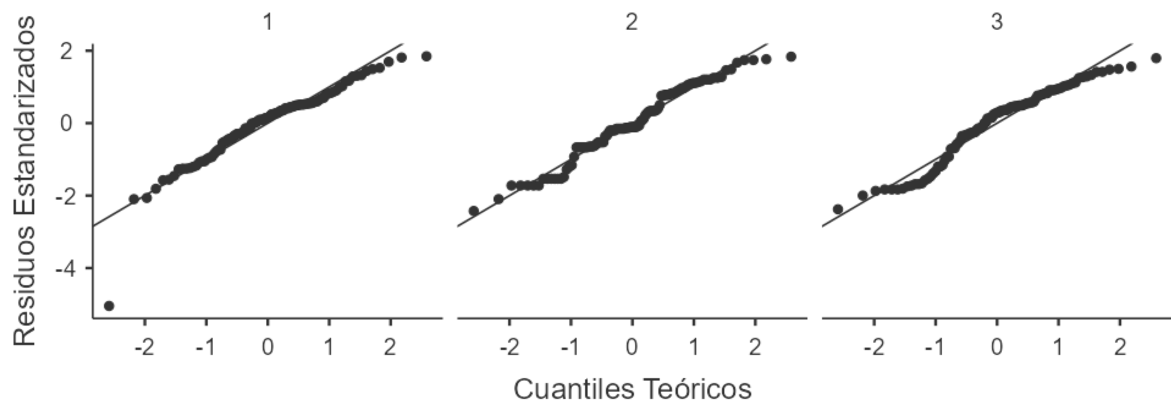

Figura 23. Q-Q graph of the Lunge variable by age group.

Higher ankle angles are observed in women in the 19 to 25-year-old and 40 to 55-year-old groups. The mean for men overall is 38°, and broken down by age groups: 19 to 25 years; 36.8°, 26 to 39 years; 39.2°, 40 to 54 years 37.6°. The mean for women overall is 39°: 19 to 25 years 39°, 26 to 39 years 38.2°, 40 to 54 years 39.8°. (Table 15, Figure 24).

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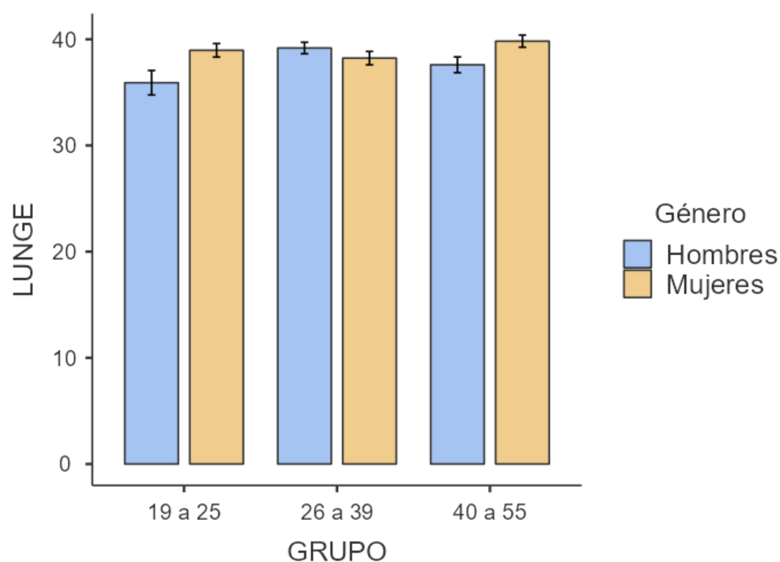

Figura 24. Lunge test variable by age group and gender.

In table 16, the variables observed are the free length of the Achilles tendon and the pennation angle of the soleus muscle to the Achilles tendon, both at rest and during maximum passive force. A similar mean is observed across the three age groups for the free length of the Achilles tendon, with a difference of 2.04 cm (19 to 25 years); 1.91 cm (26 to 39 years); 2 cm (40 to 54 years) between the means obtained at rest and maximum passive force. Regarding the means of the pennation angle variable, it is observed that the angulation decreases when applying force: -2.35° (19 to 25 years); -2.21° (26 to 39 years); -2.01° (40 to 54 years).

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Table 16. Descriptive variables of Achilles tendon free length and pennation angle at rest and passive strength by age group.

	GROUP	N	Mean	SD	Shapiro-Wilk W	Shapiro-Wilk p
LENGTH T. ACHILLES REST (CM)	19 a 25	102	7.33	1.42	0.914	< .001
	26 a 39	102	7.37	1.19	0.974	0.038
	40 a 54	104	7.57	1.22	0.979	0.092
LENGTH T. ACHILLES PASSIVE FORCE (CM)	19 a 25	102	9.37	1.93	0.927	< .001
	26 a 39	102	9.28	1.46	0.975	0.054
	40 a 54	104	9.57	1.46	0.989	0.594
ANGLE OF PENEATION REST	19 a 25	102	13.52	3.29	0.909	< .001
	26 a 39	102	12.98	2.30	0.923	< .001
	40 a 54	104	12.75	2.55	0.946	< .001
ANGLE OF PENEATION PASSIVE FORCE	19 a 25	102	11.17	2.96	0.947	< .001
	26 a 39	102	10.77	1.85	0.968	0.014
	40 a 54	104	10.56	2.14	0.937	< .001

Cm (centimeter); Angle of pennation (degrees); (N=304 tendons; subjects=154); SD: Standard Deviation

Figure 25 show the variables in Table 16 by gender. Men have a longer free tendon length an increase of 2.16cm (group 1); 2cm (group 2) and 2.01cm (group 3) in the free length of the Achilles tendon at maximum passive force; that woman 1.99cm (group 1); 1.83cm (group 2) and 1.99cm (group 3).

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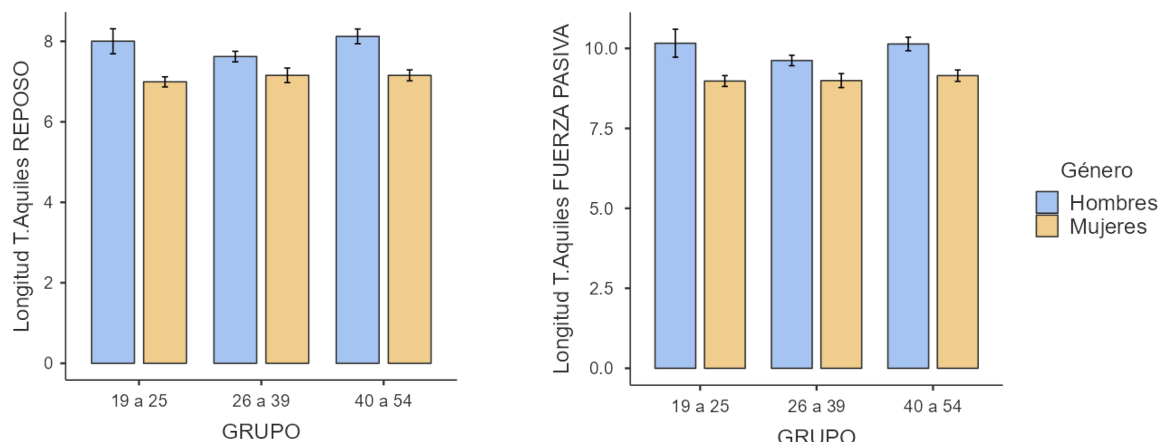

Figura 25. Achilles tendon free lenght bt gender by age group, at rest and passive strength.

Figure 26 show the pennation angle by gender. Group 1: women are 15.7º at rest vs 11.6º at passive strength and men are 12.5º at rest vs 10.4º at passive strength. Group 2: women are 13.4º at rest vs 10.9º at passive strength and men are 12.5º at rest vs 10.6º at passive strength. Group 3: women are 12.6º at rest vs 10.5º at passive strength and men are 13º at rest vs 10.6º at passive strength.

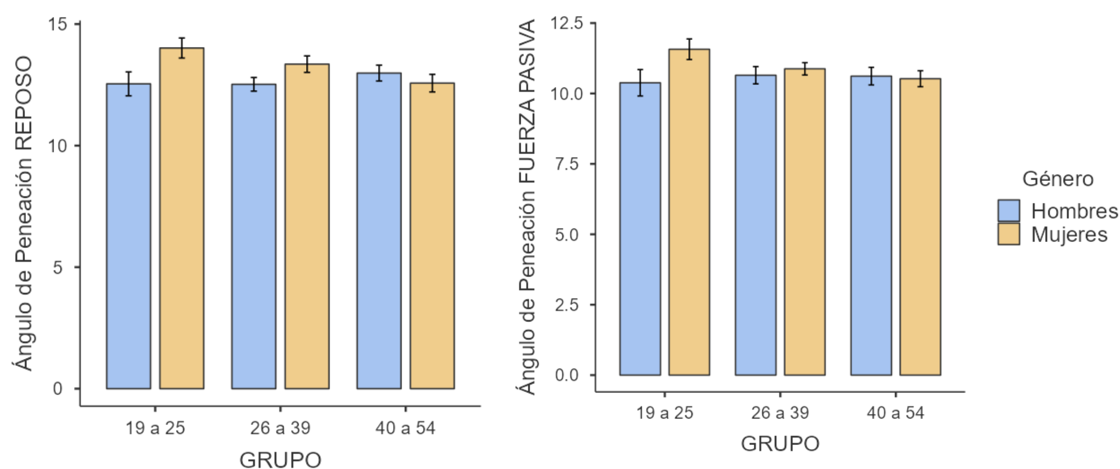

Figura 26. Pennation angle by gender by age group, at rest and in passive strength.

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Table 17. Student's t-test for paired samples.

			estadístico	gl	p
Length T. Achilles REST	Length T. Achilles PASSIVE FORCE	T de Student	-53.0	307	< .001
Angle of Peneation REST	Angle of Peneation PASSIVE FORCE	T de Student	19.7	307	< .001

Nota. H_a $\mu_{\text{Medida 1 - Medida 2}} \neq 0$

According to Table 17, we can see how there are significant differences between the measurement of the length of the Achilles tendon at rest and in passive force with a p value <0.001 (Table 17), finding a difference of two and a half degrees in the angle of penation, and 2 cm in the free length of the Achilles tendon. (Figure 27).

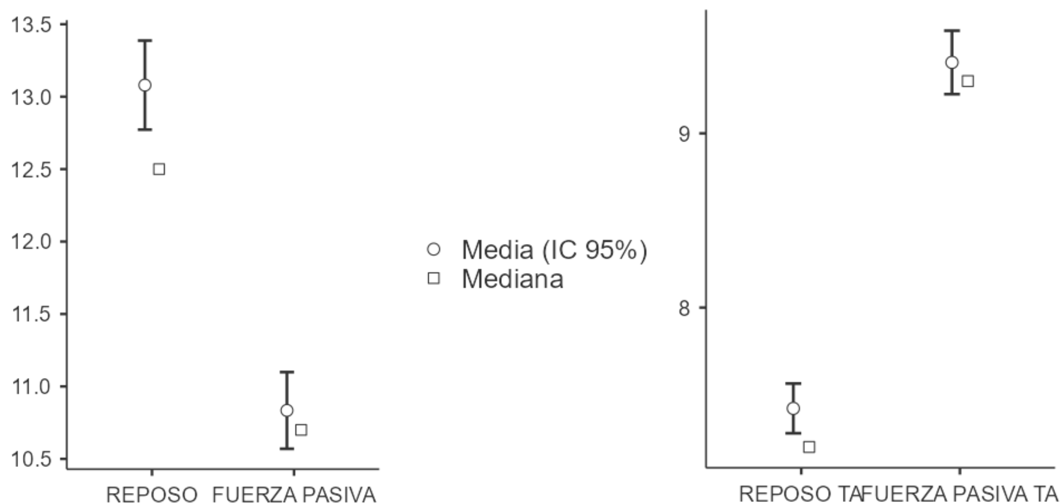

Figura 27. T Student mean difference between penile angle (LEFT) and Achilles tendon free length (right) at rest and passive force.

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Table 18. Person's correlation coefficient for the correlation between Achilles tendon parameters and demographic variables.

	GÉNERO	ALTURA	PESO	IMC	DEPORTE	LUNGE
Length T. Achilles REST	-3.111 **(<.001)**	0.348 **(<.001)**	0.204 **(<.001)**	0.061 (0.287)	0.020 (0.731)	-0.033 (0.589)
Length T. Achilles PASSIVE FORCE	-2.275 **(<.001)**	0.349 **(<.001)**	0.216 **(<.001)**	0.073 (0.204)	0.096 (0.094)	0.019 (0.744)
Angle of Peneation REST	0.116 **(0.042)**	-0.167 **(0.003)**	0.170 **(0.003)**	0.299 **(<.001)**	-0.130 **(0.022)**	-0.148 **(0.009)**
Angle of Peneation PASSIVE FORCE	0.094 (0.099)	-0.089 (0.118)	0.239 **(<.001)**	0.339 **(<.001)**	-0.128 **(0.025)**	-0.137 **(0.016)**

(N=304 tendons; subjets=154).

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6.4. DISCUSION.

The aim of this study was to examine the free length of the Achilles tendon and the pennation angle, along with demographic and functional variables in a healthy population. The sample was divided into three age groups to observe the effect of aging. Specific changes in tendons during aging are poorly understood due to the complexity of the process and the lack of age-related markers for tendon tissues(284). It has been shown that age-related changes in tendons can increase susceptibility to degeneration and injuries, as well as the risk of treatment failure and long-term rehabilitation (284–286).

The sonoanatomic measurements obtained in this study of the Achilles tendon at rest and during maximum passive force showed a statistically significant correlation (p-value 0.001) with gender, height, weight, BMI, sports practice, and the Lunge test. Measurements were taken at rest and during maximal ankle dorsiflexion (passive force) to observe potential sonoanatomic changes. Unlike muscle, the tendon is mechanically passive and stretches or contracts according to the applied load, suggesting that the direction of muscular movement may not have a singular effect on tendon tissue.(285,287). In fact, it has been observed that the elongation of the Achilles tendon in humans is similar both during the upward (concentric) and downward (eccentric) phases while lifting and lowering the heel in relation to the body weight.(285,287,288). The cellular responses to concentric or eccentric

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muscle contractions, at the same level of force, exhibit similarities in terms of collagen expresión (289)

To justify the three groups created and initiate discussions with other authors, Pang and Ying in 2006 studied 40 subjects (14 men and 26 women) and found no significant differences in tendon length among subjects in different age groups ($P > 0.05$). However, their results were not based on well-distributed age groups. Nevertheless, they found a low positive correlation between body height and tendon length (dominant ankle, $r = 0.26$; $p > 0.05$; non-dominant ankle, $r = 0.28$; $p > 0.05$)(196). In our study, this correlation is both positive and significant for height ($r=0.348$ (<.001)) as well as for weight ($r=0.204$ (<.001)) across all three age groups, owing to the sample size and data uniformity.

In the other hand, the main difference found was that male subjects had statistically different parameters compared to female subjects. The mean length of the free portion of the Achilles tendon increased more in males than in females during maximum passive force across all age groups. (191,196,263,284). The correlation between the length of the Achilles tendon and gender resulted in a negative correlation ($p < .001$) in both the data obtained at rest and during passive force. This difference in the length of the Achilles tendon between both genders could be attributed to the morphological characteristics of height and weight, which also significantly correlate with the Achilles tendon. (196,263). However, the pennation angle varied more in women than

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in men. Clinically, the pennation angle is not usually measured during an Achilles tendon ultrasound. The mean angle for each age group was 13.52° (19 to 25 years), 12.98° (26 to 39 years), and 12.75° (40 to 54 years). Additionally, this study demonstrated a significant inverse correlation of the pennation angle with sports practice and the Lunge test ($p=0.022$ and $p=0.025$) at rest, and ($p=0.009$; $p=0.016$) during passive force.

Strength tends to decrease with age; therefore, a reduction in tendon tension may result from lower applied force on the tendon (and consequently, reduced tension). Hence, it is essential to evaluate strain under a common force when comparing mechanical properties between age groups. Couppe et al. demonstrated that older subjects (66 years) had a lower modulus compared to younger subjects (26 years), but when older and younger subjects were matched for activity level, there were no differences in mechanical properties(60).

Scientific literature, some studies indicate an increase in the tendon's cross-sectional area (CSA) with age, both in animals (5,57) and humans (138,168,285). Conversely, there are also studies suggesting no ultrasound changes in CSA in tendons with age (290). Evidence indicates that young and older men, with similar height, weight, and activity levels, exhibit similar tendon CSAs (60,168,175), suggesting that unlike muscle, there isn't a reduction in tendon tissue with aging. This finding aligns with our study, where the observed mean free length of the Achilles tendon was quite similar among all

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groups: 7.33cm (19 to 25 years), 7.37cm (26 to 39 years), and 7.57cm (40 to 54 years).

Among the well-studied intrinsic risk factors for Achilles tendonopathy, reduced ankle dorsiflexion stands out in both active/sporting and inactive/sedentary individuals (170,175,190,196). Ankle mobility during gait is influenced by the pure dorsiflexion and plantar flexion movements of the soleus muscle, being a postural activation muscle due to its high proportion of slow-twitch fibers resistant to fatigue (170).

Zhu S et al. found a positive correlation between muscle thickness and pennation angle via ultrasound in a sarcopenic population across different body muscles to assess muscle strength. Their study concludes that the pennation angle is a noteworthy parameter in determining maximal contraction force (291). Prior studies have shown reduced pennation angle in the gastrocnemius muscle in the pathology group compared to younger individuals (287,293). In our study, the angle decreases with age, suggesting an aging-related factor.

On another note, Carmont et al. and Patel N et al. proposed measuring ankle resting angle for intraoperative Achilles tendon repair and subsequent rehabilitation(175,201). Their findings indicated an average resting ankle angle of 43° in non-pathological tendons and 45° in healthy individuals, respectively. In our study, the Lunge test, which measures maximum ankle dorsiflexion under load, averaged 38.6°±4.7° (n=154). However, in another study (227) with the same

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methodology, it was 38.2 ± 4.5° (n= 20). Lower ankle dorsiflexion was observed to correlate with a higher pennation angle ($p=0.022$ and $p=0.025$) at rest and ($p=0.009$; $p=0.016$) during passive force. From a biomechanical and anatomical perspective, a longer tendon allows for greater ankle dorsiflexion and consequently a lower pennation angle of the soleus muscle fibers to the Achilles tendon. Therefore, individuals maintaining activity exhibit a reduced pennation angle $r=-0.130$ ($p=0.022$), elucidating mechanical force alignment along the muscle axis, as seen in pennate or feathered muscles, such as the soleus muscle (73,74,86). These findings offer significant insights for understanding Achilles tendonopathy recovery management from a different standpoint.

6.4. **(196)(191,196,263,292)(196,263)(86)(286,293)**(227)(73,74,86)**CONCLUSION:**

The free length of the Achilles tendon does not vary with age, but it does with gender. Women tend to have a shorter length of the Achilles tendon. However, the pennation angle is greater in women than in men and decreases with age. A significantly inverse correlation is observed between the pennation angle, physical activity practice, and the Lunge test.

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CHAPTER VII:

LIMITATIONS AND PROSPECTIVE

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7.1. LIMITATIONS.

The primary limitation of the first study was the sample size. Consequently, there is no specific analysis based on gender or age. In the sample, most subjects were males, as all were recruited from the Picaña-Paiporta half marathon (Valencia, Spain), where out of 1,327 participants, less than 20.5% were women. However, previous studies have shown a link between gender and plantar fasciitis in runners (231,232). Additionally, age can also cause changes in the thickness of the plantar fascia. It might be necessary to include other types of impact sports to ensure that impact absorption by the plantar fat could prevent an increase in PF thickness.

In the second study, there was no categorization by age range, consideration of the performed sports activity, or inclusion of the ability to make a comparative control of the diet.

In general, when addressing healthy tendons, reproducibility of pathological findings has not been achieved. Healthy tendons often have better-defined edges, and the collagen pattern is more easily visualized. Therefore, a reliability study of individuals with healthy tendons might result in inflated reliability estimates that would not translate to tendons with tendinopathy, which might be more challenging to image. Moreover, only quantitative analyses have been considered; other interesting data to assess reproducibility could include echogenicity, echo-variation, or echotexture (174,177). Intra-

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rater reliability differed slightly based on the sonographer's level of experience; therefore, standardization of measurement protocols and continuous training of operators is crucial. The primary bias of this study has been the operator-probe-plane pressure in measurements without a device among subjects, which could not be quantified. In addition, as they are observational studies, they do not allow causality to be studied, nor do they control the conditions under which exposure to the independent variable takes place.

7.2. PROSPECTIVE.

7.2.1. PUBLICATIONS BEING WORKED ON.

Two articles have been published with positive results. These studies on a healthy population establish a baseline, meaning a reference for how healthy tendons are and how they appear.

These data serve as a precedent to compare them with similar studies in individuals with tendon injuries or tendon-related diseases.

7.2.1.1. PREDICTIVE STUDY.

Following this research, a predictive study could be proposed to investigate risk factors associated with tendon injuries in a future line of research.

The objective could be to identify the risk factors associated with Achilles tendon injury. To achieve this, a group of healthy individuals will be evaluated, studying variables of interest: age, gender, physical

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activity along with the sonoanatomic ultrasound characteristics of echogenicity, echostructure, and echo-variation of the Achilles tendon. Logistic regression analysis will be used to determine the relative risk of injuries based on these risk factors.

A robust predictive study can provide an important foundation for future research in the field of tendon injuries and potentially contribute to the development of more effective prevention and treatment strategies.

7.2.1.2. OBSERVATIONAL CROSS-SECTIONAL CASE STUDY.

One could consider a cross-sectional cohort study, which is a type of research that combines elements from two study designs. Cases would involve individuals with a confirmed diagnosis of Achilles tendon tendinopathy. Controls would consist of healthy individuals without Achilles tendon tendinopathy. These controls should be matched with the cases in terms of age, sex, and other factors that may influence tendinopathy.

This type of study is useful for exploring the association between exposures and specific diseases or conditions at a single point in time. However, it does not establish causal relationships and is subject to biases, such as recall bias, as participants may not accurately remember their past exposure. The results of a cross-sectional case-control study can generate hypotheses that should then be tested in prospective studies or clinical trials.

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CHAPTER VIII:

CONCLUSIONS

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CONCLUSIONS

1. **Describe by ultrasound the morphostructural parameters of the Achilles tendon and the plantar fascia in healthy adult patients.**

Parameters of normality were described with a mean thickness for the plantar fascia of 0.37 cm for the medial fascicle, 0.32 cm for the central fascicle, and 0.27 cm for the lateral fascicle, with an excellent correlation coefficient (ICC 0.94: 95% CI: 0.90-0.96).

2. **Analyzing the ultrasound changes experienced by the plantar fascia after subjecting it to controlled loading exercise.**

Continuous running presents changes in the tissue stress generated in the Plantar Fascia (PF) in relation to thickness. The morphological changes observed in the three fascicles had an average thickness difference of at least 2 mm. PF thickness greater than 4 mm was observed in asymptomatic patients without signs of vascularization, demonstrating that increased PF thickness is not the only criterion for diagnosing plantar fasciitis.

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3. Analyzing the relationship between demographic variables and morpho-ultrasonographic variables of the Achilles tendon in healthy adult patients.

The free length of the Achilles tendon does not vary with age, but it does with gender. Women tend to have a shorter length of the Achilles tendon. However, the pennation angle is greater in women than in men and decreases with age. A significantly inverse correlation is observed between the pennation angle, physical activity practice, and the Lunge test.

4. Evaluate if there is a significant relationship between the soleus muscle penetration angle in the Achilles tendon and dorsiflexion of the TPA joint.

A significant inverse correlation was observed between the soleus muscle penetration angle into the Achilles tendon and the Lunge test. It was observed that the lower ankle dorsiflexion, the greater the obliqueness of the soleus muscle fibers to the Achilles tendon ($p=0.022$ and $p=0.025$) at rest and ($p=0.009$; $p=0.016$) during passive force.

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5. Develop a device as an ultrasound measurement tool to standardize the lack of uniformity in measuring the Achilles tendon.

A device for securing the ultrasound probe was developed to make measurements dynamically without the bias of pressure exerted by the operator-probe-plane. Obtaining an ICC of 0.99 (95% CI: 0.90-0.96) with the device at rest and an ICC of 0.94 (95% CI: 0.90-0.96) with the device under load.

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CHAPTER IX:

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CHAPTER X:

ANEXOS

UNIVERSIDAD DE MÁLAGA

ANEXO 1. INFORME COMITÉ ÉTICA: CEUMA.

Vicerrectorado de Investigación y Transferencia
Comité Ético de Experimentación de la Universidad de Málaga
(CEUMA)

Nº: 56	Nº de Registro CEUMA: 144-2021-H

INFORME DEL COMITÉ ÉTICO DE EXPERIMENTACIÓN DE LA UNIVERSIDAD DE MÁLAGA

CEUMA

Reunido el Comité Ético de Experimentación en Málaga, el 28 de febrero de 2022 ha evaluado la solicitud del proyecto denominado: **"Valores ecográficos de las fibras musculares del músculo sóleo en su unión miotendinosa con el tendón de Aquiles y sistema aquíleo calcáneo plantar"** cuya investigadora principal es **Dª Ana Belén Ortega Ávila.**

Una vez examinada la documentación presentada y verificados aquellos aspectos relacionados con la ética y la legislación en materia de investigación que se indican:

-Se cumplen los requisitos necesarios de idoneidad del protocolo en relación con los objetivos del estudio y están justificados los riesgos y molestias previsibles para el sujeto, teniendo en cuenta los beneficios esperados.

- El procedimiento para obtener el consentimiento informado, incluyendo la hoja de información al sujeto son correctos.

- La idoneidad del procedimiento experimental, especialmente la posibilidad de alcanzar conclusiones válidas de acuerdo con los objetivos establecidos.

- La capacidad del investigador principal y sus colaboradores los medios y las instalaciones previstas son apropiados para llevar a cabo dicho estudio.

- El alcance de las compensaciones y motivaciones previstas no interfiere con el respeto a los postulados éticos.

Acuerda por consenso emitir Informe Ético **FAVORABLE** para dicho proyecto.

Una vez instruido el procedimiento, y en base a lo dispuesto en el artículo 82 de la Ley 39/2015, de 1 de octubre, del Procedimiento Administrativo Común de las Administraciones Públicas, se le da audiencia para qué en un plazo de 10 días, contados a partir de la recepción/publicación del presente informe, pueda formular alegaciones y presentar los documentos y justificaciones que estime pertinentes.

Para que así conste D. TEODOMIRO LÓPEZ NAVARRETE, Vicerrector de Investigación y Transferencia y Presidente del Comité Ético de Investigación de la Universidad de Málaga lo firma en Málaga a 4 de marzo de 2022.

Fdo: Teodomiro López Navarrete.

Pabellón de Gobierno, planta 3ª. Campus El Ejido. 29071. Tel.: 952 13 42 04
E-mail- ceuma@uma.es

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ANEXO 2: AUTORIZACIÓN COMISIÓN INVESTIGACIÓN.

UNIVERSIDAD DE MÁLAGA
Facultad de Ciencias de la Salud

AUTORIZACIÓN DE LA COMISIÓN DE INVESTIGACIÓN DE LA FACULTAD DE CIENCIAS DE LA SALUD

D. José Miguel Morales Asencio, Vicedecano de Investigación y Posgrado de la Facultad de Ciencias de la Salud y Secretario de la Comisión de Investigación,

HACE CONSTAR:
1. Que la Comisión de Investigación de la Facultad ha valorado el estudio titulado

VALORES ECOGRÁFICOS DE LAS FIBRAS MUSCULARES DEL MÚSCULO SÓLEO EN SU UNIÓN MIOTENDINOSA CON EL TENDÓN DE AQUILES Y EL SISTEMA CALCÁNEO PLANTAR.

con código **RaqAla74**
cuyo/a investigador/a principal es **Alabau Aldasi Raquel**
Institución: *Universidad de Málaga*

2. Que la persona investigadora principal, así como el resto del equipo, reúne las características de competencia necesarias y la metodología específica para que el estudio sea viable.

3. Que la persona investigadora principal y los miembros del equipo han firmado el compromiso de realización de la investigación en los términos y condiciones estipuladas en el protocolo.

4. Que la Comisión de Investigación de la Facultad de Ciencias de la Salud ha revisado el proyecto y determinado las modificaciones que hubieran sido necesarias para garantizar el cumplimiento de la legislación vigente en materia de investigación y de protección de datos.

En virtud de lo cual, la Comisión de Investigación AUTORIZA la realización de este proyecto en los términos y condiciones establecidos en el protocolo revisado. Esta autorización queda supeditada a cualquier resolución derivada del Comité Ético de Investigación al que pudiera corresponder la autorización ética del mismo.

Lo que firmo, a los efectos oportunos en Málaga a 6 de julio de 2022

Fdo.: José Miguel Morales Asencio
Vicedecano de Investigación y Posgrado
Facultad de Ciencias de la Salud
Secretario de la Comisión de Investigación

Facultad de Ciencias de la Salud. Universidad de Málaga
C/Arquitecto Francisco Peñalosa 3
Campus Universitario de Teatinos. 29071 Málaga

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ANEXO 3. CONSENTIMIENTO INFORMADO

Se solicita su autorización para utilizar los datos clínicos obtenidos durante el proceso de exploración del miembro inferior, para el proyecto de Tesis Doctoral de Raquel Alabau Dasí, cuya finalidad es evaluar a través de un estudio de investigación descriptivo observacional las alteraciones morfoestructurales de la fascia plantar antes y después de un esfuerzo.

La participación en el estudio es voluntaria por lo que puede retirarse en cualquier momento que lo desee. Así mismo, no se percibirá ninguna compensación económica o de otro tipo por participar. Los datos serán estrictamente confidenciales y se asignará un código único a cada participante para mantener el anonimato. Al término del trabajo toda la información recogida para el estudio será destruida mecánicamente bajo la supervisión de los investigadores.

Sus datos personales y de salud serán incorporados a una base de datos de acuerdo con lo estipulado en la Ley Orgánica 15/1999 de Protección de datos de Carácter Personal, de 13 de diciembre (LOPD).

Si deciden participar en este proyecto, rellenen y firmen el formulario de consentimiento informado que aparece a continuación.

D./Dña ____ de _________años de edad, con domicilio en ____________________________ DNI ________________.

DECLARO:

- Que he leído la hoja de información que se me ha entregado.
- Que he comprendido las explicaciones que se me han facilitado.
- Que puedo revocar el consentimiento en cualquier momento.
- Que de forma libre y voluntaria cedo los datos que se hallan recogidos para el estudio que se me ha propuesto
- Que puedo incluir restricciones sobre el uso de las mismas.

CONSIENTO: Que se utilicen los datos recogidos para el estudio y que el investigador pueda acceder a ellos en la medida en que sea necesario y manteniendo siempre su confidencialidad.

Fdo.: D./Dña En _______________a _____ de __________________ de 20_____

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ANEXO 4. CONSENTIMIENTO INFORMADO

Nos dirigimos a usted para informarle sobre el estudio clínico al que le invitamos a participar. Nuestra intención es tan sólo que usted reciba la información correcta y suficiente para que pueda evaluar y juzgar si quiere o no participar en este estudio. Para ello lea esta información y si tiene alguna duda, nosotros le aclararemos las dudas que puedan surgirle.

Debe saber que su participación en este estudio es voluntaria y que puede decidir no participar y retirar el consentimiento en cualquier momento. Usted va a ser seleccionado para participar en un estudio clínico cuya finalidad es realizar un trabajo para optar a la titulación de doctorado.

El estudio consiste en identificar los grados de angulación normales de las fibras musculares del musculo sóleo al tendón de Aquiles. Para ello, se realizarán dos estudios sucesivos en un mismo día, el primer estudio consiste en una breve exploración básica del pie para clasificar el tipo de pie. El segundo, consiste en realizar una exploración ecográfica de las estructuras anatómicas que se van a evaluar en este trabajo de investigación. Los datos serán estrictamente confidenciales y se asignará un código único a cada participante para mantener el anonimato.

Al finalizar el trabajo toda la información recogida para el estudio será destruida mecánicamente bajo la supervisión de los investigadores. Sus datos personales y de salud serán incorporados a una base de datos de acuerdo con lo estipulado en la Ley Orgánica 3/2018, de 5 de diciembre, de Protección de Datos Personales y garantía de los derechos digitales BOE» núm. 294, de 6 de diciembre de 2018, páginas 119788 a 119857.

Al pulsar siguiente usted CONSIENTE que se utilicen los datos recogidos para el estudio y que el investigador pueda acceder a ellos en la medida en que sea necesario y manteniendo siempre su confidencialidad.

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ANEXO 5. CUESTIONARIO DEL ESTUDIO

Lee atentamente y rellene todos los espacios de este cuestionario, si duda en alguna de las respuestas consulte antes de preguntar.

Código del paciente:	
Género(rodee con un circulo): hombre / mujer	**Edad**:
PESO:	**Altura:**
¿Fumador? (rodee con un circulo): SI / NO / EXFUMADOR	
¿Realizas algún tipo de deporte? (rodee con un circulo): SI / NO **¿Qué deporte realizas?** Fútbol Baloncesto Deportes de Raqueta Fitness Natación Carrera Balonmano Otros:______________________________	
¿Cuántas veces por semana entrenas? 1 vez/sem 2-3veces/sem 4-7 veces/sem Ninguna	
¿Has tenido alguna lesión o enfermedad en el tendón de Aquiles? SI NO	
¿Hace cuánto tiempo tuviste la lesión? Rellenar sólo si ha tenido lesión de T. Aquiles. Menos de 3 meses Menos de 6 meses Menos de 1 año Más de 1 año **¿Recibiste algún tratamiento oral, infiltraciones, EPI, etc, para el Tendón de Aquiles?** SI NO **¿Cuál?**______________________________	
¿Estas tomando algún tratamiento hormonal (progesterona, estrógenos, testosterona)? SI / NO	
Toma alguno de los siguientes fármacos: Antibióticos / Anticoagulantes / Tranquilizantes / Antiinflamatorios / Cortisona / Insulina / Anticonceptivas	

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ANEXO 6. RECOGIDA DE DATOS (EXPLORACIÓN)

Código del paciente:		
FPI	**Pie IZQ**	**Pie DRCH**
Posición del calcáneo (PF)		
Curvatura supra e inframaleolar externa (PF y PS)		
Prominencia de la región talonavicular (PT)		
Palpación de la cabeza del astrágalo (PT)		
Congruencia del ALI (PS)		
ABD/ADD del AP vs RP (PT)		
DF TPA (test de Lunge)	**IZQ**	**DRCH**
Rodilla en flexión a 10 cm		
Dolor a la presión: (palpación)	**IZQ**: Si / No	**DRCH**: Si / No

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CHAPTER XI:

PUBLICATIONS

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Research article 1: Variations in the Thickness of the Plantar Fascia After Training Based in Training Race. A Pilot Study.

The Journal of Foot & Ankle Surgery 61 (2022) 1230–1234

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The Journal of Foot & Ankle Surgery

journal homepage: www.jfas.org

Variations in the Thickness of the Plantar Fascia After Training Based in Training Race. A Pilot Study

Raquel Alabau-Dasi, MSc[1], Pilar Nieto-Gil, PhD[2], Ana Belen Ortega-Avila, PhD[3,4], Gabriel Gijon-Nogueron, PhD[3,4]

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ARTICLE INFO

Level of Clinical Evidence: 2

Keywords:
plantar fascia
runners
tissue stress
ultrasound measurement

ABSTRACT

Plantar fascia (PF) is a connective tissue made up of mostly type 1 collagen that is subjected to constant loads. This study evaluated the effect of continuous running on tissue stress in the PF by measuring changes in the thickness of the PF using ultrasound scans. It was a cross-sectional study involving 24 runners from the University of Valencia, recruited as volunteers between December 2018 and February 2019. A variety of data was recorded: (age, body mass index, type of footwear, number of workouts per week, KM run per week, sports injuries in the last year, pre and postrace ultrasound PF measurements). There were significant differences in the 3 postrace measurements of the left foot (<0.001). PF thicknesses were measured before and after running, with a minimal average difference of 0.4 mm in the medial and central fascicles, and 0.3 mm in the lateral fascicle. We observed PF thicknesses above 4mm in asymptomatic patients with no signs of vascularisation, proving that increased PF thickness is not the only criterion for diagnosis of plantar fasciitis.

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Musculoskeletal tissues are subjected to constant workloads during daily activities (1). The tendons are commonly engaged in repetitive loading or overuse amongst both the athletic and non-athletic population (2), and there is evidence that this is closely associated with the development of tendinopathy. The plantar fascia (PF) is subjected to mechanical loads while walking or running, and degenerative changes are commonly observed in the morphology of the PF, leading to pathology characterised by an accumulation of damage (3).

Physical stress is defined as the force applied in an area of biological tissue (4,5). Mechanical theory, or Physical Stress Theory (PST), argues that: "changes in the relative level of physical stress cause a predictable adaptive response in all biological tissue" (6).

The PF plays a key role in the biomechanics of the foot; it interacts with the propulsion mechanisms distributing the forces and energies that involve the foot in conditions of repetitive load such as continuous running (7). During weightbearing exercises, the arch of the foot lowers and stretches out, then recoils when the load is removed. PF injuries due to excessive traction forces directly involve the "Windlass" mechanism, behaving like a quasi-elastic tissue (8-11). This spring-like property of the foot arch helps to attenuate impact forces and store/release elastic strain energy leading to energy saving during running (12).

Each time the foot comes into contact with the ground while running, the PF experiences repeated tension as high as 0.6 to 3.7 times the bodyweight and longitudinal tension of up to 6% (13-15). Simulation studies have shown that tension and peak stress along the PF are concentrated at the proximal points. Accumulation of such repetitive and site-specific stress on the PF can induce mechanical fatigue (i.e., reduction of stiffness and increased strain upon loading) (12). This can be a key factor leading to increased thickness of the PF in regular runners.

This affects both athletes and people with sedentary lifestyles, making up 11% to 15% of foot problems requiring professional help (16). Every day people that do all kinds of sports receive medical treatment, but the most common patients are amateur runners (17). Amateur running is growing in popularity; however, many people lack the appropriate physical preparation, which can lead to injuries. A systematic review showed a plantar fasciitis prevalence of between 5.2% and 17.5% among 3500 runners, with an incidence of 4.5 to 10 injuries per 1000 hours of running (18). Therefore, it is possible that experienced, long-distance runners may have a PF and a foot arch that are adapted

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Conflict of Interest: None reported.
Funding for open access charge: Universidad de Málaga / CBUA

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Research article 2. How susceptible are our Achilles Tendons? Sonoanatomical assessment. A cross-sectional study.

Contents lists available at ScienceDirect

Journal of Tissue Viability

journal homepage: www.elsevier.com/locate/jtv

How susceptible are our Achilles Tendons? Sonoanatomical assessment. A cross-sectional study

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ARTICLE INFO

Keywords:
Achilles tendon
Ultrasound
In vivo

ABSTRACT

Objective: the aim of this study is to observe whether there are ultrasound changes between men and women in the Achilles tendon at rest, at maximum passive force is applied and during walking.
Material and methods: it was a cross-sectional study involving 27 healthy young participants recruited as volunteers between April to July 2022. A variety of data was recorded: (age, Body Mass Index, sex, smoking, current injury status, allergies, medications, previous surgeries, type of sport, and number of weekly workouts) and ultrasound measurements at rest and at passive force (Cross Sectional Area Achilles Tendon length, tendon thickness, Cross Sectional Area and pennation angle of the soleus muscle to the Achilles Tendon).
Results: women demonstrated a statistically significant lower proximal and median thickness both at rest (4.5 vs 5.1 mm with $p < 0.001$ for proximal thickness; 4.4 vs 5.3 mm with $p < 0.001$ for median thickness) as well as during maximum eccentric contraction (4.3 vs 4.8 mm with p=<0.001 for proximal thickness; 4.1 vs 4.8 mm with $p < 0.001$ for median thickness).
Conclusion: there are significant sonoanatomical differences *in vivo* Achilles tendon between men and women.

1. Introduction

The Achilles tendon (AT) is the thickest, strongest and largest tendon in the human body [1]. It originates from the gastrocnemius muscle and soleus muscle until it inserts into the calcaneal bone. Its characteristics (TA free length, thickness and area) are highly variable between individuals [2] and its mechanical properties store and release energy. When a deficit in this structure appears, there is a direct alteration in the biomechanics of walking, running and jumping [3]. For this reason, the strength, tension and stiffness of the TA is closely related to muscle activity, joint activity and tendon characteristics themselves [1–3].

Prospective studies indicate that risk factors for tendinopathy include female gender, black race, higher body mass index, previous tendinopathy or fracture, higher alcohol consumption, lower plantar flexion strength, higher weekly running volume, more years of running, use of spiked or cushioned shoes, cold weather training, use of oral contraceptives and/or hormone replacement therapy, reduced or excessive ankle dorsiflexion range of motion, and use of antibiotics in the fluoroquinolone class [4–6].

Achilles tendinosis is described to be a more frequent disorder in male runners who perform long duration and high intensity training [7, 8]. Deng et al. [9] evaluated the myotendinous junction of the medial gastrocnemius with the AT and their findings conclude that gender differences exist in individuals who do not have regular exercise habits. However, an updated systematic review on the prevalence of AT injury and physical exercise concluded that for gender there was no significant difference [8].

The mechanical properties of human tendons *in vivo* are based on

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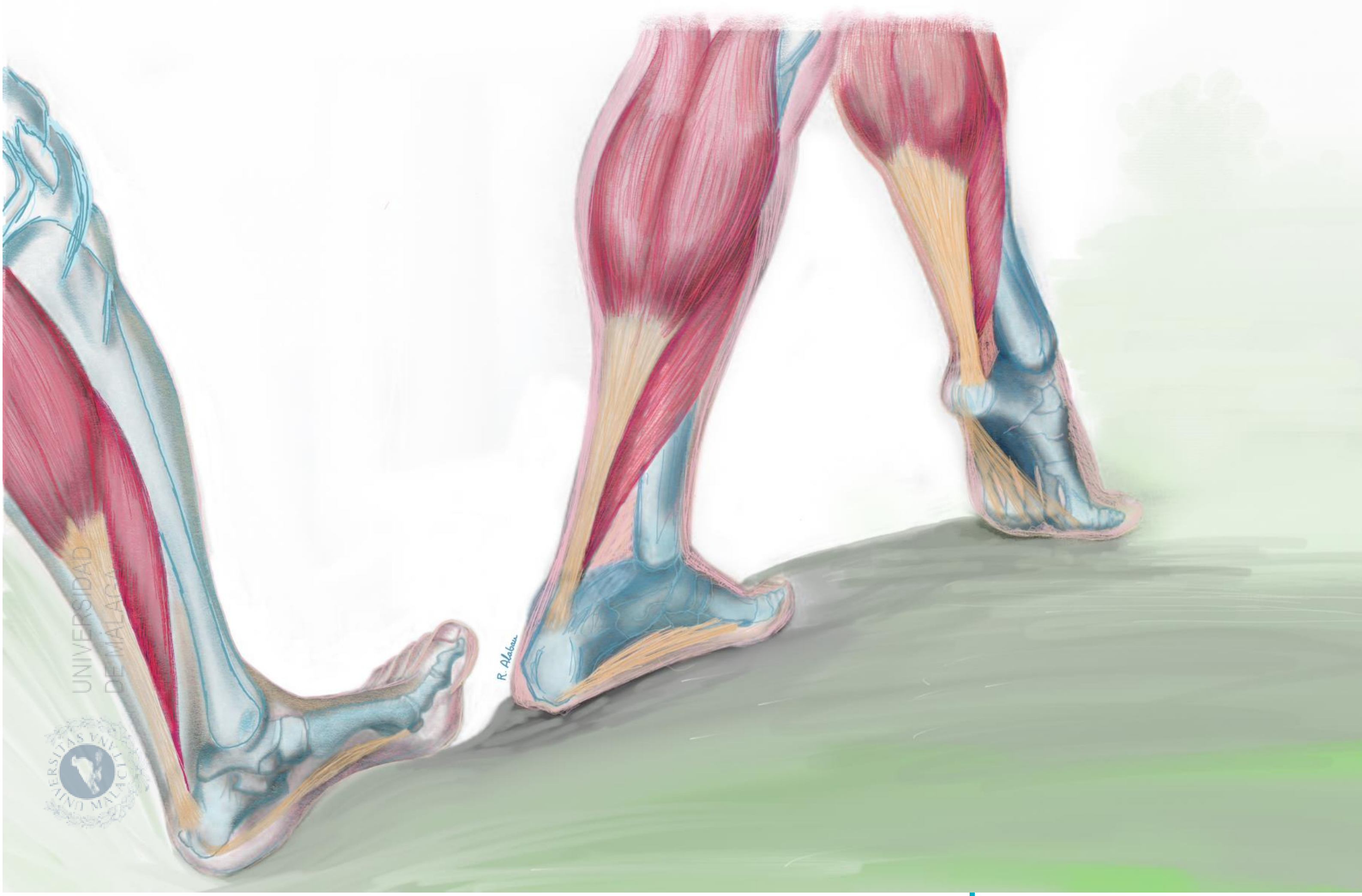
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