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# A retrospective study of isokinetic dynamometry parameters in patients diagnosed with unilateral Achilles tendinopathy

**Lloyd, Rohan**

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University of the Witwatersrand, Johannesburg

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# A RETROSPECTIVE STUDY OF ISOKINETIC DYNAMOMETRY PARAMETERS IN PATIENTS DIAGNOSED WITH UNILATERAL ACHILLES TENDINOPATHY

Rohan Lloyd
Student number: 482942

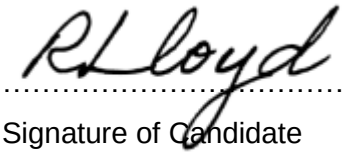
A research report submitted to the Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of MSc (Med) in the field of Biokinetics

Supervisor: Professor Philippe Gradidge and Professor Demitri Constantinou

Johannesburg, 2024

**Declaration**

I, Rohan Lloyd, declare that this research report is my own work. It is being submitted for the degree of MSc (Med) in the field of Biokinetics at the University of the Witwatersrand, Johannesburg. This submission is to fulfil the final research submission requirements outlined in the outcome letter, and per the acknowledgment of final research submission document checklist.



…… 2024/10/12

Signature of Candidate Date

**Dedication**

This work is dedicated to

**The Living God, Jesus Christ and The Holy Spirit.**

**Abstract**

Introduction: The Achilles tendon, the strongest tendon in the human body, is vital for locomotive activities like walking and running. Despite its strength, it is prone to Achilles tendinopathy (AT), a debilitating condition characterised by pain, swelling, and decreased performance. As a common foot and ankle disorder, AT's prevalence spans across athletes, recreational exercisers, and the sedentary population, with incidences up to 52% in former elite athletes with a lifetime incidence of six percent in the general population. The aetiology of AT involves both extrinsic- and intrinsic risk factors, including overuse, biomechanical irregularities, and muscular dysfunction, particularly in the gastrocnemius-soleus muscles. Research indicates that plantar flexor weakness often occurs before Achilles tendon pain develops. Weakness in the plantar flexor muscles is a key modifiable risk factor for AT issues. Conventional research on AT has primarily focused on peak torque (PT) derived from isokinetic dynamometry evaluations, leaving a gap in understanding the full spectrum of muscle performance affected by AT. Isokinetic dynamometry, with its versatile protocols and advanced software, can comprehensively evaluate muscle performance from both strength and endurance perspectives, addressing this gap.

Aim of study: This study aimed to investigate the effects of unilateral AT on various isokinetic dynamometry parameters, including torque, position, and time, in individuals diagnosed with this condition. The objectives were to determine the extent of dysfunction and weakness in the gastrocnemius-soleus muscles and to compare these parameters between symptomatic and asymptomatic extremities, thus enhancing the understanding of AT's unilateral nature. By expanding the analysis beyond PT, the study addresses the gap in current research, exploring a more comprehensive scope of muscle performance in AT.

Method: This retrospective study investigated the impact of unilateral AT on isokinetic dynamometry parameters. Participants were males and females, aged 18 years or older, diagnosed with unilateral AT. Initial isokinetic dynamometry evaluation reports from 2015 to 2022 were collected from a private biokinetics practice in South Africa. Although data on 54 participants initially met the inclusion criteria, the exclusion criteria, which required evaluations to be performed at an angular velocity of 60 degrees per second, reduced the number of suitable reports. Consequently, only the evaluations of n=21 participants (n=18 males and n=3 females, with a total sample mean age of 53.1 years) were included in the study. Isokinetic dynamometry evaluation, conducted by registered biokineticists, followed standardised protocols with the Humac Norm Cybex Testing and Rehabilitation System. Parameters analysed included torque, position, and time measures. Statistical analysis

involved paired t-Tests and Wilcoxon tests for normally and non-normally distributed data, respectively, with a significance level set at $p<0.05$.

Results: The analysis of PT between symptomatic- and asymptomatic extremities revealed no statistically significant difference, with symptomatic extremities demonstrating a mean PT of 38.81 foot-pounds (SD: ±10.97) compared to 40.91 foot-pounds (SD: ±11.48) for asymptomatic extremities ($p = 0.24$). However, a significant difference was noted in the joint angle at PT (JAPT), as determined by the Wilcoxon signed-rank test. Symptomatic extremities exhibited a lower mean joint angle of 1.8 degrees (SD: ±5.11) compared to 2.24 degrees (SD: ±3.89) in asymptomatic extremities ($p = 0.0001$). Time to PT (TPT) did not differ significantly between symptomatic- (0.20 seconds; SD: ±0.13) and asymptomatic (0.21 seconds; SD: ±0.11) extremities ($p = 0.16$). Similarly, time PT held (TPTH) showed no significant difference between symptomatic- (0.36 seconds; SD: ±0.33) and asymptomatic (0.34 seconds; SD: ±0.39) extremities ($p = 0.49$). The analysis of work per repetition (WPR) revealed marginal differences between symptomatic- (17.57 foot-pounds; SD: ±5.48) and asymptomatic (18.91 foot-pounds; SD: ±5.90) extremities, but these differences did not reach statistical significance ($p = 0.16$). The average power per repetition (APR) differed between symptomatic- (35.48 watts; SD: ±11.71) and asymptomatic (39.05 watts; SD: ±13.14) extremities, with a paired t-Test indicating a trend toward statistical significance ($p = 0.06$), though this did not meet the conventional threshold for significance in this sample.

Conclusion: The study provides an understanding of unilateral AT's impact on isokinetic dynamometry parameters. The study highlighted bilateral muscle dysfunction and weakness in individuals with unilateral AT. This was evidenced through the comparative analysis of PT, PT percentage body weight (PT%BW) and PT ratio (PTR) parameters against established norms. Achilles tendinopathy does not significantly affect the speed of muscle contraction or endurance in maintaining PT. This questions the notion of unilateral impairment in AT and highlights the necessity of a comprehensive approach in rehabilitation, focusing on strength, endurance, and biomechanics. The findings also suggest the need for further research with larger cohorts and varied isokinetic dynamometry parameters to validate these conclusions and enhance rehabilitation protocols in AT.

Keywords: Achilles tendinopathy, Isokinetic dynamometry, Muscle dysfunction

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**Abbreviations**

| | |
|---|---|
| Achilles tendinopathy | AT |
| Peak Torque (Foot-Pounds - Best Repetition) | PT |
| Peak Torque Symptomatic extremity | PT-SYM |
| Peak Torque Asymptomatic extremity | PT-ASYM |
| Work per Repetition (Foot-Pounds - Best Repetition) | WPR |
| Work per Repetition Symptomatic extremity | WPR-SYM |
| Work per Repetition Asymptomatic extremity | WPR-ASYM |
| Average Power per Repetition (Watts - Best Repetition) | APR |
| Average Power per Repetition Symptomatic extremity | APR-SYM |
| Average Power per Repetition Asymptomatic extremity | APR-ASYM |
| Joint Angle at Peak Torque (Degrees) | JAPT |
| Joint Angle at Peak Torque Symptomatic extremity | JAPT-SYM |
| Joint Angle at Peak Torque Asymptomatic extremity | JAPT-ASYM |
| Time to Peak Torque (Seconds) | TPT |
| Time to Peak Torque Symptomatic extremity | TPT-SYM |
| Time to Peak Torque Asymptomatic extremity | TPT-ASYM |
| Time Peak Torque Held (Seconds) | TPTH |
| Time Peak Torque Held Symptomatic extremity | TPTH-SYM |
| Time Peak Torque Held Asymptomatic extremity | TPTH-ASYM |
| Force Decay Time (Seconds) | FDT |
| Force Decay Time Symptomatic extremity | FDT-SYM |
| Force Decay Time Asymptomatic extremity | FDT-ASYM |
| Peak Torque %BW | PT%BW |
| Peak Torque %BW Symptomatic extremity | PT%BW-SYM |
| Peak Torque %BW Asymptomatic extremity | PT%BW-ASYM |

| | |
|---|---|
| Peak Torque Ratio | PTR |
| Peak Torque Ratio Symptomatic extremity | PTR-SYM |
| Peak Torque Ratio Asymptomatic extremity | PTR-ASYM |
| | |
| Peak Torque Deficit | PT-D |
| Work per Repetition Deficit | WPR-D |
| Average Power per Repetition Deficit | APR-D |

# CHAPTER 1: INTRODUCTION

The Achilles tendon, also known as the calcaneal tendon, is the thickest and strongest tendon in the human body (1). The tendon has a remarkable response to stress and can be subjected to tensile loads of up to 12.5 times body weight during running, compared with the load of walking, which is approximately 3.5 times body weight (2) (3). With running activities the actual tensile load placed on the Achilles tendon is related to running speed (3). Injuries to the Achilles tendon, despite its robustness, are remarkably prevalent, which occur across diverse demographics —athletes, recreational exercisers, and the sedentary population (4).

The Achilles tendon is prone to overuse injuries due to the continuous high-magnitude stresses it experiences during locomotion (5). Despite its mechanical traits enabling it to endure substantial muscular force, these persistent stresses predispose the tendon to chronic injuries (5). Notably, tendon injuries contribute significantly to morbidity in the workforce, functionally impairing individuals (6).

Tendinopathy, a clinical diagnosis indicating impaired tissue healing above its normal capacity, is characterised by pain, swelling (diffuse or localised) and decreased performance (7). Achilles tendinopathy (AT), a common foot and ankle disorder, is believed to result from overuse, which is defined as repetitive strain acting on a tendon that impairs its ability to endure stress and tension (8). Achilles tendinopathy has a lifetime incidence of 6% in the general population and is a significant cause of morbidity and functional impairment (2) (9) (10).

Achilles tendinopathy is commonly diagnosed in active individuals, both men and women, particularly those aged 35 to 45 years, and are more prevalent in sports involving running or jumping (11). Running-based sports have an incidence of 7 to 9%, with a cumulative lifetime incidence of up to 52% in certain athletic populations (12). In the journal of Sports Medicine and Health Science, Wang Y. (2022) supported this stating that the risk of AT in runners are ten times higher than that of their inactive peers and that the cumulative lifetime incidence of AT in elite male runners is more than 50% (13). However, Van Der Vlist A. et al. (2019) noted that one-third of all patients with AT have a sedentary lifestyle (14). In addition, Prudêncio D. et al. (2023) cited that up to one in three sedentary individuals can develop AT (8). This diversity underscores the potential broad spectrum of risk factors for AT, with the precise aetiology remaining unclear.

The aetiology of tendon failure has been theorised to be multifactorial, resulting from a combination of extrinsic factors, which act on the body, and intrinsic factors, which act from within the body (15). In a cross-sectional, laboratory-based study, Janowski A. et al. (2023) endorsed this theory by asserting that a variety of factors contribute to both the development and the enduring nature of AT (16). These factors can decrease the tendon's load tolerance or overload the tendon through certain movement patterns (17). A common intrinsic factor, gastrocnemius-soleus function, is considered important for both sports performance and injury protection (18). The gastrocnemius-soleus muscles, also known as the triceps surae, are the main ankle plantar flexors.

Altered function of the plantar flexor muscles has been identified as a primary modifiable risk factor for AT (19). Evidence suggests plantar flexor weakness predates the onset of Achilles tendon pain (20). Pain, the most common symptom and complaint of patients with AT, leads to a reduction in plantar flexion strength, proprioception, and functional impairment in the symptomatic extremity. It is a widely accepted theory that pain perception may trigger the inhibition of neuromuscular activity of the plantar flexor muscles, thus decreasing their ability to generate force (21). Research has shown that plantar flexor muscle strength is impaired in runners with AT, and below normative data (22). Van Der Vlist A. et al. (2019) concluded that research funding agencies should prioritise research into modifiable determinants as it could prove useful for AT prevention and treatment (14).

A doctoral dissertation submitted by Sara L. (2021) stated that deficits in gastrocnemius-soleus muscle function are assumed in patients with AT, but evidence is limited and inconclusive (23). The consensus on the presence of plantar flexor strength deficits in AT is not well-established, and researchers are uncertain about the appropriate methods of assessment. They highlight the potential scope of additional methods of quantifying plantar flexor strength other than PT (24). Most studies examining plantar flexor strength deficits by means of isokinetic dynamometry, define muscle weakness in terms of PT only. There are few studies that have measured additional parameters of quantifying plantar flexion strength from an isokinetic evaluation report in patients with unilateral AT.

An article by Wilk K. et al. (2024), published in the International Journal of Sports Physical Therapy, titled "Isokinetic Testing: Why it is More Important Today than Ever," advocates for a "Test, Don't Guess!" approach (25). This methodology is emphasised due to the proven effectiveness of isokinetic evaluations and the substantial number of patients who struggle to return to pre-injury activity levels. These difficulties often stem from significant deficits in strength, power, and endurance. Consequently, the data derived from isokinetic testing is

deemed a critical component of the return-to-play strategy. The article stresses the necessity of incorporating objective muscle performance data in rehabilitation and return-to-sport decisions to reduce re-injury risks and enhance patient outcomes.

Isokinetic dynamometry is considered the most accurate and reliable tool for measuring plantar flexor strength (26). Literature reports a strong association between Achilles tendon injuries and reduced plantar flexor power, with deficits often present pre-injury (26). This supports the notion that plantar flexor weakness may increase the risk of certain lower extremity disorders, emphasising the critical role of isokinetic dynamometry evaluations in identifying and addressing these weaknesses.

In this study, we investigated the impact of unilateral AT on the parameters measured by isokinetic dynamometry equipment, with a focus on plantar flexor weakness and gastrocnemius-soleus dysfunction.

### 1.1. Problem statement

Achilles tendinopathy remains a subject of significant research, particularly concerning plantar flexor weakness. However, the scientific background of most investigations has predominantly focused on a single parameter – PT – derived from isokinetic dynamometry evaluation reports. This limitation is evident across studies examining gastrocnemius-soleus dysfunction and plantar flexor weakness in AT. In this study, it is aimed to address this gap by incorporating additional parameters in torque measurements, position parameters, and time parameters of an isokinetic dynamometry evaluation.

To the researcher's knowledge, at the time of this study, there is a lack of comprehensive research applying all three parameters to AT, necessitating on-going investigation. In a systematic review and meta-analysis on altered strength profiles in AT by McAuliffe S. et al. (2019), the authors concluded that to optimise rehabilitation outcomes, clinicians may need to adapt their assessment of Achilles tendon function (24). This sentiment was echoed by Sara L. (2021), who recommended that future research should delve into additional evaluation of neuromuscular function in AT by assessing additional properties of gastrocnemius-soleus function (23).

This study addresses these recommendations by systematically evaluating torque, position, and time parameters through isokinetic dynamometry in patients with unilateral AT. The goal was to identify values from these additional measures that can potentially enhance clinical practice in the rehabilitation process of AT.

## 1.2. Aim of study

The primary aim of this study was to investigate the effects of AT on the isokinetic dynamometry parameters (torque, position, and time) in participants diagnosed specifically with unilateral AT. This study included both physically active and sedentary participants, irrespective of whether the affected extremity was the dominant or non-dominant extremity. By concentrating on the unilateral presentation, the study aimed to provide targeted insights into the biomechanical alterations associated with this condition.

## 1.3. Objectives

The objectives of this study were to:

1. Determine the magnitude of dysfunction and weakness in the gastrocnemius-soleus muscles in participants diagnosed with unilateral AT across various parameters (torque, position, and time).
2. Compare these parameters between the symptomatic and asymptomatic extremities in these participants to identify specific differences that may contribute to our understanding of the unilateral nature of AT.

# CHAPTER 2: LITERATURE REVIEW

The Achilles tendon, the largest- and strongest tendon in the human body, connects the gastrocnemius, soleus, and plantaris muscles to the calcaneus (27). Comprised primarily of collagen fibres, it plays a crucial role in facilitating plantar flexion —essential for activities such as walking, running, and jumping (27). However, it is prone to frequent injuries, making it one of the most commonly affected tendons (12).

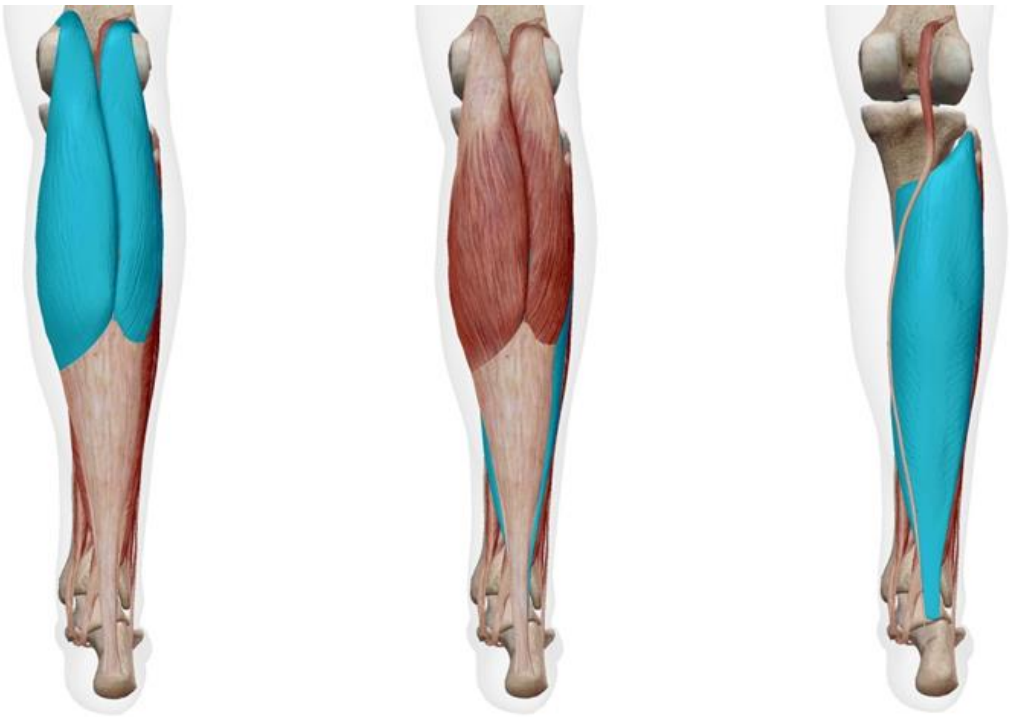
Measuring approximately 15 centimetres in length, the Achilles tendon originates at the myotendinous junction of the gastrocnemius and soleus muscles in the middle of the calf, (Figure 2.0.) (28) (29). It transitions from a flattened shape at the myotendinous junction to a rounded form approximately four centimetres above its insertion, where it flattens and expands becoming cartilaginous to insert at the posterior surface into the calcaneus. The tendon primarily receives fibres from the soleus on its anterior and medial aspects, and from the gastrocnemius on the posterior aspect. Variability exists in the contribution of fibres from the soleus and gastrocnemius to the tendon structure, with the soleus contributing 52% of fibres on average, while in some cadaver specimens, the gastrocnemius contributes over 60% (28) (30).

Tenocytes, which produce type I collagen, make up 90% of the tendon's cellular content. In pathological states, an increase in type III collagen production may compromise tensile strength (30). Gender and age differences are notable, with male tendons demonstrating greater rupture force and stiffness compared to females, while younger individuals tend to have tendons with higher tensile rupture stress and lower stiffness (30).

The gastrocnemius, the most superficial muscle on the posterior aspect of the lower leg, originates from the femoral condyles above the knee through its medial and lateral heads, contributing to knee flexion (Figure 2.1. a) (28) (29). In contrast, the soleus, located beneath the gastrocnemius (Figure 2.1. b), is a broad, flat muscle originating from the tibia's oblique line, the fibrous arch between the tibia and fibula, and the posterior surface of the fibula's head (Figure 2.1. c) (29). It primarily functions at the ankle joint, and has been suggested as the main plantar flexor during normal gait (28). Together, the gastrocnemius and soleus form the triceps surae, facilitating ankle plantar flexion via the Achilles tendon (30).



**Figure 2.0:** Posterior view of the lower leg highlighting the Achilles tendon (blue) connecting the gastrocnemius and soleus muscles to the calcaneus (29).



a b c

**Figure 2.1:** Posterior view of the lower leg highlighting (blue): a. gastrocnemius; b. soleus deep to the gastrocnemius; c. soleus with the gastrocnemius dissected (29).

Given the critical functions of the Achilles tendon, it is essential to examine the prevalence and causes of its injuries. According to Sommer B. et al. (2022), the incidence rate for Achilles tendon injuries ranges from 2.5 to 37.3 per 100,000 persons per year exhibiting an upward trend in recent years (31). The growing incidence is thought to be linked to an increase in physical activity among older patients (32). The tendon's significance lies in its ability to transmit forces generated by the calf muscles to the foot during movement. An injury to the Achilles tendon can lead to serious consequences, ranging from mild strains to complete ruptures, often resulting from overuse, sudden acceleration, or direct trauma.

Achilles tendon injuries are a prevalent issue among runners, and its statistics in South Africa can be illuminated by related study by Young, J (2020) (33). Although specific data on AT are scarce, this study on the epidemiology and associated risk factors for Achilles tendon overuse running injuries in the Two Oceans Marathon among runners provides relevant insights. Over a four-year period, 106,743 runners participated, with 61,374 providing written informed consent for pre-race medical screening, including injury data in the last 12 months for research purposes. The study found an annual incidence of 1.2% for gradual onset Achilles tendon injury (GoATI), with over half of these injuries severely affecting running activities. Symptoms persisted for more than seven months in over 50% of cases, yet only half of the affected runners utilised strengthening exercises, the most effective treatment for GoATI according to this study. Key risk factors identified included age, longer race distances, male gender, years of running, a high chronic disease composite score and a history of allergies.

The study's limitations include the self-reported nature of the data, which may introduce recall bias, and injuries were not diagnosed by a trained clinician. Injury severity data relied on the participants' subjective experience of pain to determine severity grade. Due to the cross-sectional nature of the study, it could not infer a cause-effect relationship between identified risk factors and GoATIs. Despite these limitations, the study's large sample size and good response rate provide valuable insights into the risk factors and prevalence of Achilles tendon injuries in South African runners.

The severity of Achilles tendon injuries stresses their impact on mobility and overall musculoskeletal function. Notably, athletes engaging in sports requiring explosive movements or rapid direction changes are more susceptible to Achilles tendon injuries, but sedentary individuals are not immune (34). The prevalence of Achilles tendon injuries highlights the importance of understanding preventive measures and implementing tailored rehabilitation strategies to address this impactful musculoskeletal structure.

Investigating and comprehending AT, and its association with overuse are crucial, given its widespread occurrence. Chronic tendinopathy, defined by symptoms persisting for at least three months, has a cumulative lifetime prevalence of 23.9% among specific athletic groups (35). However, Griffen C. et al. (2021) reported the prevalence reaching up to 52% among specific athletic groups, while in the general population, this figure is 2% (12) (35). Recent findings revealed that 66% of runners diagnosed with AT exhibited a decline in running performance in the inaugural year following the injury, encompassing factors such as frequency, speed, and duration of running (36).

However, due to aetiology of AT remaining debateable, an article by Egger A. et al. (2017) on Achilles tendon injuries, referenced that 31% of patients reviewed with AT did not participate in vigorous physical activity (37). More recently, a systematic review by Quamby A. et al. (2023), found that 65% of AT cases do not involve sport (38). Thus, AT is a prevalent musculoskeletal condition observed in both athletic and non-athletic populations.

### 2.1. Achilles tendinopathy

Achilles tendinopathy is a condition affecting the Achilles tendon, characterised by degenerative changes in the tendon structure, often accompanied by pain, swelling, and impaired function. This non-inflammatory disorder, distinguished from Achilles tendonitis by the absence of histologic inflammation in the Achilles tendon, can result in a prolonged absence from health-promoting activities (39). Histological studies of AT's have revealed a disorganised collagen structure, indicating the primarily degenerative and non-inflammatory nature of this condition (37). Achilles tendinopathy involves structural changes in the Achilles tendon, typically manifesting in both microstructural- and macro-structural alterations. To better understand AT and its pathophysiology, it is crucial to examine these structural changes in detail.

Microscopically, there is evidence of collagen disorganisation, increased ground substance, and neovascularisation. The collagen fibres, normally aligned in a parallel fashion, become more haphazard and disoriented in tendon pathology. This disorganisation compromises the tendon's mechanical strength and resilience. At the cellular level, tenocytes, responsible for maintaining tendon structure, may undergo degenerative changes. Increased apoptosis (cell death) and alterations in the metabolic activity of tenocytes contribute to the overall breakdown of the tendon matrix (40). This increases the vulnerability of the tendon to injury.

Macro-structural changes are also evident, often seen as thickening of the tendon. This thickening is a result of both increased ground substance and attempts at repair, including

the formation of a disorganised collagen matrix. However, this response does not restore the tendon's normal architecture, leading to reduced mechanical properties. The altered structure of the Achilles tendon in tendinopathy not only impairs its mechanical properties but also predisposes it to a higher risk of partial or complete ruptures (40).

Understanding these structural changes is crucial for developing effective interventions and rehabilitation strategies tailored to address the specific challenges presented by AT. To further understand the clinical implications of these structural changes and the progression of AT, it is essential to explore the stages of tendinopathy.

A review by Cook J. and Purdam C. (2009) proposed a three-stage continuum of pathology model to explain the clinical presentation of load-induced tendinopathy (41). This model, based on evidence from lower extremity tendons, has been cited extensively in the literature (42). It allows for the rational placement of tailored interventions (exercise and load management) along the continuum by staging tendinopathy based on the extent/presence of disorganisation within the tendon. The stages of the continuum will be discussed to guide the clinical assessment of tendinopathy and assist in interpreting and applying the findings in this study. This study utilises an adapted tendon pathology model to illustrate the progression from a normal tendon to degenerative tendinopathy, omitting the 'stress shielding' component for clarity and relevance (Figure 2.2).

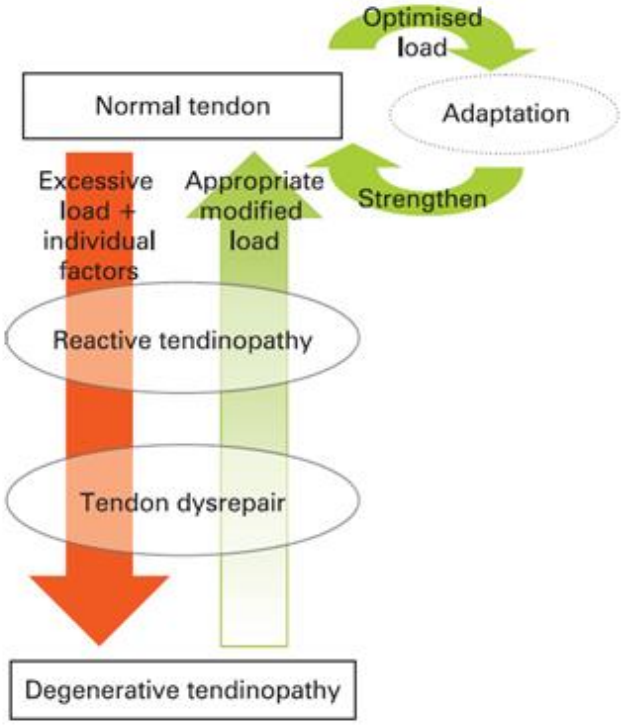



**Figure 2.2**: Adapted from Cook J., Purdam C. Is tendon pathology a continuum? A pathology model to explain the clinical presentation of load-induced tendinopathy. British Journal of Sports Medicine. 2009 Jun 1;43(6):409-16. The figure illustrates the pathology continuum from normal tendon through to degenerative tendinopathy, with a simplified presentation excluding the 'stress shielding' component to improve clarity and contextual relevance.

The authors defined tendinopathy as an overuse injury in tendons under load, leading to pain, reduced exercise tolerance, and decreased function. They emphasised that the volume, duration, and frequency of intense load are crucial for both normal and pathological tendons to adapt, with sufficient recovery time being essential. The load is identified as a major patho-aetiological factor influenced by an interaction between individual intrinsic risk factors like age, gender, and body composition. Adjusting the load is key to moving the tendon along the pathology continuum, particularly in the early stages.

Stage 1: Reactive tendinopathy

Reactive tendinopathy is a non-inflammatory proliferative response of the tendon cells and matrix to acute overload, often caused by a sudden increase in unaccustomed physical activity, and is more common in younger individuals. It results in a short-term adaptive thickening of a portion of the tendon, which reduces stress by increasing the cross-sectional area or allows adaptation to compression. Unlike normal tendon adaptation to tensile load,

which typically involves tendon stiffening with minimal change in thickness, reactive tendinopathy's initial changes may occur for quick adaptation until long-term structural or mechanical changes (true adaptation) occur. The tendon can revert to normal if the overload is sufficiently reduced or if adequate recovery time is allowed between activities.

Stage 2: Tendon disrepair

Tendon disrepair represents an attempt at tendon healing that is similar to reactive tendinopathy but involves greater matrix breakdown. This stage is best detected with imaging and is observed in chronically overloaded tendons across various ages and loading environments. The frequency, volume, or duration of the load applied are critical variables. Older individuals with stiffer tendons that have less adaptive ability may develop this stage with relatively lower loads. Some reversibility of the pathology is possible with proper load management and exercise to stimulate the matrix structure.

Stage 3: Degenerative tendinopathy

Degenerative tendinopathy involves progression from tendon disrepair, with significant matrix and cell changes, including areas of cell death due to apoptosis or tenocyte exhaustion. At this stage, there is little capacity for reversibility of the focal pathological changes, and imaging often shows a compromised matrix with extensive vascular changes. This stage is primarily seen in older individuals but can also affect younger individuals or elite athletes with chronically overloaded tendons. The typical presentation includes focal Achilles tendon swelling and pain in middle-aged recreational athletes. Extensive degenerative changes can lead to tendon rupture, consistent with findings that 97% of ruptured tendons show degenerative changes.

These stages of tendinopathy highlight the importance of understanding the interaction of individual risk factors in the development and progression AT. Key aetiological factors to consider, either alone or in combination, are the interplay of both intrinsic- and extrinsic risk factors (43).

- Intrinsic risk factors encompass overuse and overload, where repetitive stress from activities like running and jumping can contribute to tendinopathy. Biomechanical factors, such as abnormal foot pronation and leg length discrepancies, further influence the load distribution on the Achilles tendon, increasing the risk of injury. Age and gender also play a role, with tendinopathy more prevalent in individuals aged 30 to 50 years and potentially exhibiting a higher incidence in males (44). Patients diagnosed with AT report impairments and an inability to engage in

functional activities that could be due to an altered strength profile or persistent weakness (24). Due to their diminished capacity for shock absorption, individuals displaying muscle weakness face an elevated risk of sustaining injuries (45). Plantar flexor weakness has been identified by experts as an important modifiable intrinsic risk factor for athletic tendinopathy (46).

- Extrinsic risk factors, including inappropriate footwear lacking proper support and training errors like rapid increases in intensity without adequate recovery, contribute significantly to the development of AT.

In consensus, the scientific community acknowledges that AT arises from a combination of intrinsic- and extrinsic factors, commonly associated with overuse and mechanical overload. Contreras-Harnandez I. et al. (2022) supported the notion that the aetiology of AT remains debateable, and is often idiopathic, but known to be multi-factorial (21). While consensus exists on the importance of a comprehensive approach to management, including load management, biomechanical assessments, and targeted rehabilitation exercises, specific treatment protocols may vary. Individualised approaches, considering the unique characteristics of each patient, are often recommended for optimal outcomes.

Re-injury rates are high, likely attributable to incomplete restoration of muscle-tendon unit function, with symptoms persisting for several years in some cases; an eight-year follow-up study revealed that 20% of patients still experienced impaired physical activity (12). The heightened prevalence and re-injury rates underscore the significance of researching and understanding AT to develop effective prevention and management strategies for individuals engaged in athletic and physical activities.

Presently, a lack of consensus prevails in the literature regarding strength deficits in AT, contributing to uncertainty among researchers regarding suitable assessment methods for guiding rehabilitation in clinical practice (24).

## 2.2. Overview of isokinetic dynamometry

The term itself, derived from Greek, signifies "iso," meaning equal, and "kinetic," denoting motion (47) (48). Isokinetic dynamometers are devices that accurately measure muscular forces that produce rotational moment about a uniaxial joint. They are considered the gold standard for muscle force testing in clinical practice, due to their accuracy and reliability (49) (50) (51). They are intrinsically accurate in their measurements of torque, and possess significant test and retest reliability, contingent upon strict adherence to testing protocols (49)

(52) (53). Habets B. et al. (2018) highlighted that isokinetic dynamometry is often used as a reference standard for other strength assessments (54). Payton C. and Burden A., authors of "Biomechanical evaluation of movement in sport and exercise: the British Association of Sport and Exercise Sciences guide" (2017), emphasise its safety and precision (55). Given these advantages, it is crucial to understand the broader clinical relevance of isokinetic dynamometry.

These devices are viewed to be the most reliable, accurate, and objective method of evaluating single-joint muscle strength, and may be clinically relevant in confirming a diagnosis of joint function and musculoskeletal health (56). Isokinetic devices are computerised, providing swift access to rehabilitation and testing protocols, and they are equipped with a variety of attachments. Numerous studies demonstrate a positive correlation between isokinetic dynamometry and functional performance (inferential value) (49). The concept of inferential value implies that the outcomes of muscular performance tests serve as valuable information, allowing us to draw inferences about a patient's ability to engage in common human functional tasks.

Isokinetic dynamometry testing was developed in the 1960s, and gaining prominence in the 1980s due to an increasing body of evidence demonstrating its effectiveness and reliability in clinical research, and as an assessment method for guiding rehabilitation in clinical practice (57) (58). The introduction of electrical motors as the power source enabled the measurement of muscular strength. Muscular strength refers to the capacity of a muscle to develop tension actively, regardless of the specific conditions under which this tension is measured (49). A muscular contraction occurs when the muscle develops tension. In concentric contractions, muscle tension is developed to accelerate a lever arm. As the muscle undergoes concentric contraction, its fibres undergo shortening, causing the origin and insertion points to draw closer together. This process is commonly referred to as positive work (59).

Unlike traditional strength testing methods, such as manual muscle testing (MMT), where there are concerns over the lack of quantifiable data, isokinetic dynamometry operates on fundamental principles that contribute to its efficacy in biomechanical assessments that gives a clinician a valid, objective and reliable test that is dynamic and safe (52) (59). One key principle involves maintaining a constant speed during muscle contractions. This consistent movement speed allows for precise control and accurate measurement of muscle performance. Additionally, the dynamometer adjusts resistance dynamically based on the

force applied by the individual, allowing maximal effort throughout the entire range of motion (ROM).

This accommodative resistance feature is pivotal in providing an accurate representation of muscle strength ensuring a thorough evaluation. Increased muscular output produces increased resistance rather than increased acceleration and inertia (59). In contrast, any reduction in muscular output due to pain or weakness results in an immediate reduction of resistance, reducing the risk of overloading the tested joint (60). Thus, as the velocity of movement is limited to a predetermined maximum angular velocity, the device's resistance consistently matches the applied muscle torque. This is the primary advantage of isokinetic dynamometry compared to other forms of muscle contraction, rendering it a highly safe testing method by reducing risk of injury (52).

Muscle contractions producing an angular velocity lower than that of the device would consequently yield no opposing resistance (60). Conversely, if the contraction aims to accelerate the extremity beyond the device's pre-set value, the applied force encounters an equal and opposite force or resistance. This method of dynamic testing, which keeps or restricts the velocity of body movement at a predetermined and consistent level, is known as an assessment of isokinetic muscular performance (49).

Thus, an isokinetic muscular performance evaluation is referred to as a mode of dynamic testing that maintains or limits velocity of body movement at a preselected, constant level.

Isokinetic dynamometers play a crucial role in providing baseline data and quantitative information on various muscle groups (61). Quantifying muscle strength allows for the identification of weaknesses, extremity imbalances, or asymmetries in different muscle groups. Clinically, isokinetic dynamometry evaluations enable the monitoring of progress, customisation of rehabilitative protocols, and evaluation of an individual’s readiness for return to activity (62). Moreover, through quantifiable and standardised measures, it significantly contributes to scientific research focused on muscle function, injury prevention, and performance optimisation across diverse populations.

### 2.2.1. Parameters studied in isokinetic dynamometry

The integration of microprocessors with isokinetic dynamometers has facilitated swift quantification of multiple muscle function parameters. In the context of isokinetic dynamometry evaluation, a "parameter" refers to a specific and measurable quantity or characteristic that is assessed to gain insights into various aspects of muscle function and

performance. The three main parameters on an isokinetic dynamometry evaluation report are torque, position and time. Torque parameters focus on the force generated by the muscle, position parameters provide insights into the joint angle dynamics, and time parameters offer information about the temporal aspects of muscle performance.

Overuse pathologies regularly lead to changes in muscular performance, and a quality evaluation is crucial for quantifying anomalies and imbalances. The isokinetic assessment quantifies several parameters defining muscular performance. In our study, we are focusing on the isokinetic dynamometry evaluation of the ankle joint in plantar flexion. One intrinsic factor that we consider crucial with reference to AT is the function of the gastrocnemius-soleus muscles. These muscles serve as the primary ankle plantar flexors and are integral to both sports performance and injury prevention (18). These parameters serve as quantitative indicators, providing valuable information about strength, endurance, and other relevant attributes of muscles during isokinetic contractions. Isokinetic dynamometers typically provide several parameters in torque, position and time, each offering distinct insights into muscle performance:

**Torque parameters**

***2.2.1.1. Peak torque (foot-pounds – best repetition) (PT)***

Peak torque (PT), the highest torque value developed throughout the range of motion, is a crucial indicator of maximum muscular tension capability (55) (63) (59). Measured in Foot-Pounds (ft-lbs), PT is determined by identifying the peak point on the isokinetic torque curve (61). Commonly used in isokinetic dynamometry, PT is a thoroughly investigated strength testing parameter applicable in both research and clinical settings (53). Focusing on maximal force generation and excluding submaximal repetitions, PT provides a reliable metric for assessing maximal strength (64). In the presence of pathology, comparing the Maximum Achievable Peak (MAP) curve with the asymptomatic side is recommended. To provide a more comprehensive analysis, the peak torque deficit (PT-D) percentage is also considered.

Peak torque deficit percentage is the PT-D expressed as a percentage of the PT of the asymptomatic extremity.

*PTD% = (PT of asymptomatic extremity - PT of symptomatic extremity) / PT of asymptomatic side * 100*

#### *2.2.1.2. Peak torque to % body weight ratio (foot-pounds – best repetition) (PT%BW)*

The ratio of PT to body weight serves as a valuable tool for inter-individual comparisons and evaluating the functional strength of weight-bearing musculature. This ratio allows comparisons to normative data (65). Peak torque to body weight is expressed as a percentage and calculated from the body weight and PT developed during the same mode of contraction and identical angular velocity.

*Peak torque to body weight ratio percentage = (Peak torque in foot-pounds / Body weight in pounds) * 100*

Measuring lower extremity strength relative to body weight facilitates individualised data interpretation, considering the influence of body weight on strength levels. (61).

#### *2.2.1.3. Peak torque ratio (foot-pounds – best repetition) (%) (PTR)*

Assessing muscle balance and joint function, the PTR (agonist/antagonist) strength ratio compares PT between opposing muscle groups during concentric contractions (55). Opposing muscle group torque ratios express the normally weaker muscle group torque as a percentage of the normally stronger muscle group torque. The PTR is expressed as a percentage and calculated from the PT developed during the same mode of contraction and identical angular velocity (66). This serves as an important factor regardless of the torque capabilities of the individual muscle groups (65). This ratio is vital for rehabilitation, emphasising the importance of maintaining a balanced muscle strength profile (67).

*Peak torque ratio (agonist/antagonist ratio) = Peak torque of agonist muscle group / Peak torque of antagonist muscle group*

In ankle plantar flexion, the agonist muscles are primarily the gastrocnemius and soleus muscles along with the plantaris muscle. These muscles work together to produce the movement by contracting and exerting force to push the foot downward (28). The antagonist of ankle plantar flexion is primarily the tibialis anterior muscle and the extensor digitorum longus muscle. These muscles contract to pull the foot upward and toward the shin (28).

#### *2.2.1.4. Work per repetition (foot-pounds – best repetition) (WPR)*

Work is typically defined as force multiplied by the distance. For rotational systems (i.e. systems which measure torques and angles), work is defined as torque multiplied by the angle, where the torque is in foot-pounds and the angle is in radians (65).

#### *2.2.1.5. Average power per repetition (watts – best repetition) (APR)*

Power is defined as work per unit time. Given the work per repetition in foot-pounds and the time per repetition in seconds, power (watts) is computed as (65):

*Power (Watts) = {Work (foot-pounds) / Time (seconds)} * 1.3558179*

*Average power per repetition = Total work done (watts) / Time taken to complete the repetition (seconds)*

Power, unlike PT, increases with velocity, making it valuable for assessing timed periods of work and differences in elite subjects where PT figures may be problematic (68) (69) (49).

**Position parameters**

#### *2.2.1.6. Joint angle at peak torque (degrees) (JAPT)*

The point in the ROM where PT first occurs, frequently referred to as the angle of occurrence, is important in the assessment of muscle function as it provides information about the mechanical properties of the activated muscle group (65). Research found that weaker muscles show PT later in the ROM (69). It measures the angular position to the PT and expresses in degrees (66).

**Time parameters**

#### *2.2.1.7. Time to peak torque (seconds) (TPT)*

Time to peak torque represents the time taken to reach a predetermined variable, such as PT, in isokinetic contractions characterised by a consistent speed of joint movement and maximal force exertion at every angle (65). Time to peak torque, measured in seconds, provides valuable insights into an athlete's performance capabilities, considering their current physiological condition (70).

In participants without abnormalities, PT typically emerges within the initial one-third of the ascending torque curve. If maximum torque appears in the middle or final third of the curve due to a lengthening of the upward slope, it suggests challenges in generating torque at the onset of muscle contractions. This scenario may indicate reduced acceleration capability, implying the patient may not be ready to resume functional activities (71). Research indicates that a prolonged TPT may signify reduced recruitment of type II muscle fibres (55) (53) .

#### *2.2.1.8. Time peak torque held (seconds) (TPTH)*

Time peak torque held indicates the duration for which PT is maintained. Typically applied in isometric testing, the duration for which PT is sustained provides the most accurate representation of true isometric strength. With isokinetic dynamometry testing, TPTH is tested throughout the range of motion, compared with isometric testing which focuses on a single angle in the range of motion that PT is held.

#### *2.2.1.9. Force decay time (seconds) (FDT)*

Force decay time refers to the downslope of the torque curve, indicating the subject's ability to sustain force production throughout the entire range of motion until the end of the predetermined range (61). Consequently, FDT represents the time from the end of PT production to the conclusion of the motion, revealing the actual endurance potential of the muscle fibres. A concave downslope, in contrast to a straight or convex downslope, may suggest challenges in force production as the patient approaches terminal extension, indicating potential pathology (71).

Each parameter serves as a distinct measure, contributing to a comprehensive understanding of the biomechanical aspects of muscle performance during isokinetic dynamometry testing.

### 2.2.2. Normative data for ankle joint isokinetic dynamometry in dorsi flexion and plantar flexion

This section examines normative data for ankle joint isokinetic dynamometry, specifically focusing on dorsi flexion and plantar flexion. The aim is to provide benchmarks for evaluating dysfunction and weakness in key parameters such as PT, PTR, and PT%BW in research and clinical settings. We referenced "A Compendium of isokinetics in clinical usage and rehabilitation techniques" (4th edition) by Davies G. (1992) for normative data on isokinetic dynamometry parameters in a presumably healthy population, as presented in Tables 2.0 and 2.1 (72).

Table 2.0 presents normative isokinetic dynamometry PT values for ankle dorsi flexion and plantar flexion across various velocities (30, 60, 120, and 180 degrees per second), detailing the PT values for both actions. For males, the PT for plantar flexion decreases from 136 foot-pounds at 30 degrees per second to 47 foot-pounds at 180 degrees per second. Female participants exhibit a similar decline in PT values, with plantar flexion values decreasing from 103 foot-pounds to 38 foot-pounds over the same angular velocities.

Additionally, the Table 2.0 includes PT%BW, which contextualises strength output relative to participants body weight. For instance, at 60 degrees per second, males exhibit a plantar flexion PT that represents 65% of body weight, while females show a slightly lower percentage of 60%. The PTR values presented indicate the relationship between dorsi flexion and plantar flexion strength, which is crucial for understanding muscle balance and function around the ankle joint. Table 2.0 emphasises the differences in isokinetic dynamometry performance between genders and highlights the impact of angular velocity on muscle strength.

**Table 2.0:** Normative isokinetic peak torque values for ankle dorsi flexion and plantar flexion by velocity, body weight percentage and ratio

| Velocity | Body weight | Action | PT | % Body weight | DF / PF Ratio |
|---|---|---|---|---|---|
| **Male** | | | | | |
| **30° / sec** | 75 (± 6) | **DF**<br>**PF** | 26<br>136 | 16%<br>82% | 1:5.23 |
| **60° / sec** | 75 (± 6) | **DF**<br>**PF** | 20<br>107 | 12%<br>65% | 1:5.35 |
| **120° / sec** | 75 (± 6) | **DF**<br>**PF** | 15<br>70 | 9%<br>42% | 1:4.67 |
| **180° / sec** | 75 (± 6) | **DF**<br>**PF** | 13<br>47 | 8%<br>28% | 1:3.62 |
| **Female** | | | | | |
| **30° / sec** | 63 (± 5) | **DF**<br>**PF** | 19<br>103 | 14%<br>74% | 1:5.42 |
| **60° / sec** | 63 (± 5) | **DF**<br>**PF** | 16<br>83 | 12%<br>60% | 1:5.19 |
| **120° / sec** | 63 (± 5) | **DF**<br>**PF** | 11<br>55 | 8%<br>40% | 1:5 |
| **180° / sec** | 63 (± 5) | **DF**<br>**PF** | 9<br>38 | 6%<br>27% | 1:4.22 |

**Test position:** Supine with knee in terminal extension (0°)
**Body weight:** Kilograms Mean (± SD)
**Sample Size:** n = 25

**PT:** Peak torque (foot-pounds)
**SD:** Standard deviation
**DF:** Dorsi flexion
**PF:** Plantar flexion

Table 2.1 provides comparative isokinetic dynamometry PT and PTR values for ankle dorsi flexion and plantar flexion across athletic and sedentary populations at various angular velocities for male and female participants. The data is stratified by gender, allowing for an understanding of how physical activity levels influence muscle performance in the ankle joint. For both male and female participants, athletic participants consistently demonstrate higher PT values than sedentary participants across all tested velocities. For example, at 60 degrees per second, male athletes exhibit a PT of 20 foot-pounds for dorsi flexion and 107 foot-pounds for plantar flexion, compared to sedentary males, who show values of 19 foot-pounds and 71 foot-pounds, respectively. This trend persists at higher velocities, indicating the benefits of regular physical activity on muscular strength.

Table 2.1 includes PTR values for athletes compared to sedentary participants, further emphasising the performance disparity. For instance, at 60 degrees per second for males, the PTR is 1:5.4 for athletes and 1:3.7 for sedentary participants, highlighting the substantial difference in strength and performance capabilities between these two populations. Table 2.1 serves as a critical resource in research by illustrating the significant impact of physical activity on isokinetic dynamometry performance in the ankle joint.

**Table 2.1:** Comparative isokinetic peak torque values for ankle dorsi flexion and plantar flexion in athletic vs. sedentary populations

| Velocity | Action | PT Athletes | PT Sedentary | DF / PF Ratio |
|---|---|---|---|---|
| **Male** | | | | |
| **30° / sec** | **DF**<br>**PF** | 26 (± 4)<br>135 (± 21) | 24 (± 5)<br>93 (± 15) | (A) 1:5.2<br>(S) 1:3.9 |
| **60° / sec** | **DF**<br>**PF** | 20 (± 3)<br>107 (± 18) | 19 (± 5)<br>71 (± 16) | (A) 1:5.4<br>(S) 1:3.7 |
| **120° / sec** | **DF**<br>**PF** | 15 (± 2)<br>70 (± 22) | 13 (± 4)<br>44 (± 12) | (A) 1:4.7<br>(S) 1:3.4 |
| **180° / sec** | **DF**<br>**PF** | 13 (± 2)<br>47 (± 8) | 9 (± 4)<br>30 (± 9) | (A) 1:3.6<br>(S) 1:3.3 |
| **Female** | | | | |
| **30° / sec** | **DF**<br>**PF** | 19 (± 3)<br>103 (± 16) | 19 (± 7)<br>62 (± 11) | (A) 1:5.4<br>(S) 1:3.3 |
| **60° / sec** | **DF**<br>**PF** | 16 (± 4)<br>83 (± 13) | 15 (± 5)<br>47 (± 10) | (A) 1:5.2<br>(S) 1:3.1 |
| **120° / sec** | **DF**<br>**PF** | 11 (± 2)<br>55 (± 11) | 11 (± 4)<br>29 (± 7) | (A) 1:5.0<br>(S) 1:2.6 |
| **180° / sec** | **DF**<br>**PF** | 9 (± 2)<br>38 (± 8) | 9 (± 5)<br>20 (± 5) | (A) 1:4.2<br>(S) 1:2.2 |

**Test position:** Supine with knee in terminal extension (0°)
**PT:** Peak torque (foot-pounds) Mean (± SD)
**(A):** Athletes (Sample size n = 25)
**(S):** Sedentary (Sample size n = 30)
**SD:** Standard deviation
**DF:** Dorsi flexion
**PF:** Plantar flexion

In addition, we referenced our data with findings from the Biodex isokinetic normative data sheet referenced from "Maximal isokinetic and isometric muscle strength of major muscle groups related to age, body mass, height, and sex in 178 healthy subjects" by Harbo T. et al. (2012), as presented in Tables 2.2, 2.3 and 2.4 (73). This comparison was crucial for understanding how our results on PT, PTR, and PT%BW aligned or deviated from established norms in presumably healthy participants.

Table 2.2 presents normative isokinetic dynamometry data for PT values associated with ankle dorsi flexion and plantar flexion at an angular velocity of 60 degrees per second, stratified by age and gender. Table 2.2 delineates PT values for both male and female participants across various age groups, revealing a clear trend of decreasing PT with advancing age for both genders. For males, the mean PT for dorsi flexion ranges from 25.83 foot-pounds in the under 30 years group to 19.91 foot-pounds in the over 70 years group, while the mean PT for plantar flexion declines from 94.41 foot-pounds to 61.22 foot-pounds in the same age groups.

Similarly, for females, dorsi flexion PT values range from a mean of 16.26 foot-pounds in the under 30 years group to 12.53 foot-pounds in the over 70 years group, with plantar flexion values decreasing from 65.65 foot-pounds to 38.34 foot-pounds in the same age groups. Table 2.2 highlights the potential impact of age-related muscular decline on performance and for understanding the effects of age and gender on isokinetic dynamometry performance in the ankle joint.

**Table 2.2:** Normative isokinetic data for ankle dorsi flexion and plantar flexion peak torque at an angular velocity of 60 degrees per second by age and gender

| Action | Age (years) | | | | | |
|---|---|---|---|---|---|---|
| | **<30** | **30-39** | **40-49** | **50-59** | **60-69** | **>70** |
| **Male** | | | | | | |
| **DF** | 25.83 (± 4.43) | 24.34 (± 3.70) | 25.83 (± 6.64) | 25.83 (± 5.16) | 22.87 (± 3.70) | 19.91 (± 2.96) |
| **PF** | 94.41 (± 17.71) | 87.03 (± 16.22) | 82.61 (± 16.96) | 88.51 (± 14.03) | 77.44 (± 16.22) | 61.22 (± 17.71) |
| **Female** | | | | | | |
| **DF** | 16.26 (± 0.15) | 18.44 (± 0.30) | 14.75 (± 0.22) | 16.26 (± 0.37) | 13.31 (± 0.37) | 12.53 (± 0.22) |
| **PF** | 65.65 (± 20.62) | 65.65 (± 15.57) | 54.55 (± 9.58) | 56.73 (± 14.03) | 49.43 (± 12.58) | 38.34 (± 7.39) |

**PT:** Peak torque (foot-pounds) Mean (± SD)
**SD:** Standard deviation
**DF:** Dorsi flexion
**PF:** Plantar flexion

**Male sample size:** n = 77
**Mean ± SD of (age; height; body mass) in each age group of males:**
(24 ± 5; 179 ± 6; 74 ± 8) (34 ± 4; 180 ± 5; 82 ± 12) (45 ± 3; 179 ± 4; 82 ± 9) (55 ± 3; 181 ± 5; 82 ± 13)
(64 ± 2;179 ± 5; 81 ± 11) (74 ± 4; 174 ± 4; 78 ± 8)

**Female sample size:** n = 77
**Mean ± SD of (age; height; body mass) in each age group of females:**
(25 ± 4; 168 ± 9; 59 ± 10) (35 ± 3; 169 ± 7; 64 ± 6) (44 ± 3; 167 ± 6; 61 ± 7) (56 ± 2; 167 ± 7; 64 ± 11)
(63 ± 3; 163 ± 5; 63 ± 12) (73 ± 2; 164 ± 4; 62 ± 7)

**Age:** Years
**Height:** Centimeters
**Body mass:** Kilograms

Table 2.3 presents normative isokinetic dynamometry PT%BW values for ankle dorsi flexion and plantar flexion at an angular velocity of 60 degrees per second, stratified by age and gender, with high and low values. Table 2.3 serves as a critical reference for understanding the muscular performance of different populations, providing insights into how age and gender influence PT%BW capabilities in the ankle joint.

The data is organised by age groups, ranging from under 30 years to over 70 years, for both male and female participants. For males, the table indicates that PT%BW values for dorsi flexion and plantar flexion decrease with age. For instance, males in the under 30 years group exhibit a higher PT%BW for plantar flexion at 69%, while males in the over 70 years group show a decrease to 46%. Similarly, for dorsi flexion, the values drop from 19% for males in the under 30 years group to 13% for males in the over 70 years group.

In the female population, a similar pattern is observed, with PT%BW values for plantar flexion at 90% for females in the under 30 years group and decreasing to 45% for females in the over 70 years group. Dorsi flexion values also show a decline, from 14% for females in the under 30 years group to 11% for females in the over 70 years group. Table 2.3 indicates that PT%BW values for both dorsi flexion and plantar flexion decrease with age for both males and females, suggesting a decline in muscular strength and performance as participants age.

**Table 2.3:** Normative isokinetic data: Percentage of body weight for ankle dorsi flexion and plantar flexion at an angular velocity of 60 degrees per second by age and gender

| | Action | Age (years) | | | | | |
|---|---|---|---|---|---|---|---|
| | | <30 | 30-39 | 40-49 | 50-59 | 60-69 | >70 |
| **Male** | | | | | | | |
| **High** | **DF** | 19% | 16% | 18% | 17% | 15% | 13% |
| | **PF** | 69% | 57% | 55% | 57% | 53% | 46% |
| **Low** | **DF** | 13% | 15% | 14% | 15% | 14% | 12% |
| | **PF** | 47% | 39% | 37% | 41% | 34% | 25% |
| **Female** | | | | | | | |
| **High** | **DF** | 14% | 15% | 13% | 14% | 12% | 11% |
| | **PF** | 90% | 61% | 48% | 68% | 61% | 45% |
| **Low** | **DF** | 11% | 11% | 9% | 9% | 7% | 8% |
| | **PF** | 47% | 48% | 45% | 41% | 36% | 31% |

**DF:** Dorsi flexion
**PF:** Plantar flexion

**Male sample size:** n = 77
**Mean ± SD of (age; height; body mass) in each age group of males:**
(24 ± 5; 179 ± 6; 74 ± 8) (34 ± 4; 180 ± 5; 82 ± 12) (45 ± 3; 179 ± 4; 82 ± 9) (55 ± 3; 181 ± 5; 82 ± 13)
(64 ± 2;179 ± 5; 81 ± 11) (74 ± 4; 174 ± 4; 78 ± 8)

**Female sample size:** n = 77
**Mean ± SD of (age; height; body mass) in each age group of females:**
(25 ± 4; 168 ± 9; 59 ± 10) (35 ± 3; 169 ± 7; 64 ± 6) (44 ± 3; 167 ± 6; 61 ± 7) (56 ± 2; 167 ± 7; 64 ± 11)
(63 ± 3; 163 ± 5; 63 ± 12) (73 ± 2; 164 ± 4; 62 ± 7)

**SD:** Standard deviation
**Age:** Years
**Height:** Centimeters
**Body mass:** Kilograms

Table 2.4 presents normative isokinetic dynamometry PTR for ankle dorsi flexion and plantar flexion at an angular velocity of 60 degrees per second, high, low and average values, stratified by age and gender. Table 2.4 is crucial for understanding the PTR of the ankle muscles in different populations, providing insights into how age and gender influence muscular performance.

The data is organised into age groups, ranging from under 30 years to over 70 years, and includes both male and female participants. For males, Table 2.4 indicates both high and low PTR for dorsi flexion and plantar flexion across the specified age ranges. For example, the high PTR remains relatively stable at 27% for males in the under 30 years-- and the 30-39 years groups but shows a slight increase to 29% for males in the over 70 years group. This increase suggests a decrease in plantar flexion PT relative to the dorsi flexion with age. In contrast, the average low PTR is 28% for males in the under 30 years group and increases to 39% for males in the over 70 years group. This trend suggests a potential decline in muscular balance and strength as male participants age.

In the female population, the PTR also reflects age-related changes in muscular performance. The high PTR is 15% for females in the under 30 years group and increases to 24% for females in the over 70 years group, This trend suggests a potential decline in muscular balance and strength as female participants age. Conversely, the low PTR remains relatively consistent, ranging from 24% for females in the under 30 years group to 25% for females in the over 70 years group, suggesting less variability in this measure. Table 2.4 indicates that both high and low PTR values demonstrate trends that suggest a decline in muscular balance and strength with age for both males and females.

**Table 2.4:** Normative isokinetic peak torque ratios for ankle dorsi flexion and plantar flexion at an angular velocity of 60 degree per second by age and gender

| | Age (years) | | | | | |
|---|---|---|---|---|---|---|
| | **<30** | **30-39** | **40-49** | **50-59** | **60-69** | **>70** |
| **Male** | | | | | | |
| **High** | 27% | 27% | 33% | 30% | 28% | 29% |
| **Low** | 28% | 29% | 29% | 28% | 31% | 39% |
| **Average** | 27% | 28% | 31% | 29% | 30% | 34% |
| **Female** | | | | | | |
| **High** | 15% | 20% | 20% | 21% | 20% | 24% |
| **Low** | 24% | 23% | 21% | 22% | 19% | 25% |
| **Average** | 20% | 21% | 20% | 21% | 20% | 24% |

**Male sample size:** n = 77

**Mean ± SD of (age; height; body mass) in each age group of males:**

(24 ± 5; 179 ± 6; 74 ± 8) (34 ± 4; 180 ± 5; 82 ± 12) (45 ± 3; 179 ± 4; 82 ± 9) (55 ± 3; 181 ± 5; 82 ± 13) (64 ± 2;179 ± 5; 81 ± 11) (74 ± 4; 174 ± 4; 78 ± 8)

**Female sample size:** n = 77

**Mean ± SD of (age; height; body mass) in each age group of females:**

(25 ± 4; 168 ± 9; 59 ± 10) (35 ± 3; 169 ± 7; 64 ± 6) (44 ± 3; 167 ± 6; 61 ± 7) (56 ± 2; 167 ± 7; 64 ± 11) (63 ± 3; 163 ± 5; 63 ± 12) (73 ± 2; 164 ± 4; 62 ± 7)

**SD:** Standard deviation
**Age:** Years
**Height:** Centimeters
**Body mass:** Kilograms

Tables 2.0 to 2.4 collectively provide a comprehensive overview of isokinetic dynamometry parameters of PT, PT%BW and PTR, highlighting differences across age, gender, activity level and angular velocities in presumably healthy populations. These tables facilitate benchmarking our results against normative values, essential for understanding isokinetic dynamometry muscle performance variations in different populations, thus enhancing data interpretation and research into AT.

### 2.2.2. Data analysis

Each isokinetic system follows a unique format for collecting and presenting data, utilising graphical and numerical computerised layouts. The capacity to detect imbalances in bilateral or reciprocal muscle groups positions isokinetic dynamometry as a valuable screening tool before the initiation of physical activity (74).

The HUMAC Norm Cybex isokinetic dynamometer generates an automated report that includes a comprehensive data analysis. The HUMAC software produces various reports, including the "Long Torque vs. Position" report, which provides a multi-page analysis featuring torque versus position plots and complete numeric results for each set in the protocol. This report helps in understanding the participant's performance over the entire testing session.

For data analysis, the HUMAC system calculates important metrics such as PT, work, power, coefficient of variance (COV) and various ratios. Specifically, it computes the highest value from all repetitions, ensuring that the peak performance data is captured accurately (75). This includes parameters like PT to body weight, PT slope to body weight, and agonist/antagonist ratios. Additionally, the system calculates bilateral differences to aid in the assessment of muscle balance and asymmetry.

The HUMAC Norm Cybex isokinetic dynamometer user's guide defines the COV as a statistical measurement used to assess the accuracy of collected data (75). This metric is calculated by dividing the standard deviation by the mean, thereby enabling the reproducibility and accuracy of a set of repetitions to be quantitatively evaluated. For small muscle groups and joints such as the ankle, an acceptable COV is less than 20% (76). A high COV can indicate underlying issues such as pain, lack of maximal effort, apprehension due to unfamiliarity with the movements, or inadequate instructions provided by the tester (61). Maintaining a low COV is essential to ensure the reliability and validity of isokinetic dynamometry test results.

### 2.2.3. Data interpretation

Data interpretation stands as a foundational element for assessing, testing, designing, or modifying rehabilitative protocols. The information derived from isokinetic testing, including parameters of torque, position and time, provides valuable insights into an individual's muscular performance and functional capabilities. During an isokinetic dynamometry evaluation, data is graphically and numerically represented, including PT, torque-angle

curves, work, power, and time-based indexes, enabling comparisons between agonist/antagonist muscles and contralateral extremities.

The validity and reproducibility of data of muscular performance test results are contingent upon the subject delivering a complete maximum voluntary effort. One of the most intriguing aspects of isokinetic dynamometry testing lies in its capacity to objectively assess muscular performance and set specific criteria before resuming activities (59). The following are examples of data interpretation and their application in isokinetic dynamometry evaluations:

#### *2.2.3.1. Bilateral comparison*

The contralateral extremity is the most frequently used reference for interpretation in data analysis and assessing muscular function in an extremity, serving as a standard, particularly when the pathology or injury being evaluated is unilateral (49) (71). In the context of an isokinetic evaluation report, the term “deficit” refers to an index of proportionality representing the difference between the joints bilaterally (59). A discrepancy of 10 to 15% in PT values is typically considered indicative of significant asymmetry, with a greater deficit suggesting a muscle imbalance that might predispose the individual to potential muscle-related injuries, such as strains and tendinitis (61) (71) (77).

To ensure a safe return to sport, specific criteria must be met. A publicised criterion for an athlete's return to sport stipulates that the symptomatic extremity should achieve torque values equal to or exceeding 90% of the asymptomatic extremity (72).

Muscle performance can be categorised as either normal or abnormal, or deemed normal but insufficient for a particular task. Sapega A. (1990) established criteria for classifying abnormality in PT between two corresponding muscle groups in normal subjects: deficits up to 10% are considered normal; deficits between 10 to 20% as possibly abnormal; and deficits greater than 20% as probably abnormal (49) . In cases where a previous injury is anticipated to result in weaker performance in one extremity, the following criteria are employed: deficits up to 10% are normal; deficits between 10 to 20% as probably abnormal; and deficits greater than 20% as almost certainly abnormal (49). A systematic review by Mcgrath T. et al. (2016) reports that there was no statistically significant effect of extremity dominance on isokinetic dynamometry, despite the potential impact on functional performance (78).

Prior research indicates that differences in absolute PT between sides can potentially serve as a predictor for future injuries, suggesting that athletes are more prone to injuries when

there exists a disparity of 10% or greater in strength bilaterally (79) (80). According to Computer Sports Medicine, Inc., (CSMi), Humac Norms users guide the non-dominant lower-extremity is commonly approximately 5% weaker (peak slow-speed torque) than the dominant side (60). However, this parameter should not be used in isolation for interpretation as it has limitations.

#### *2.2.3.2. Unilateral ratios (agonist/antagonist ratios)*

Ratios of agonist/antagonist musculature have been meticulously established through thorough testing of normal subjects, empowering clinicians to identify potential muscular imbalances that may adversely impact an individual's return to functional activities (81). By comparing the relationship of PT between agonist/antagonist muscles, weaknesses in specific muscle groups can be identified, addressing the crucial aspect of muscle balance or imbalance and joint integrity (71). When evaluating long-term outcomes, the most ideal agonist/antagonist ratio of the symptomatic extremity appears to align with the agonist/antagonist ratio of the asymptomatic extremity (69). Analysing data on ratios of reciprocal muscle groups (agonist and antagonist) using quantitative interpretation is justifiable, aligning with the percentage guidelines provided earlier by Sapega A. (1990) (49).

An earlier study suggests that imbalances in agonist/antagonist ratios may indicate a pathological condition, and this could potentially be applied in predicting lower extremity injuries (79). To effectively identify the risk of injury and adjust rehabilitation protocols, clinicians should possess knowledge about agonist/antagonist ratios. Normalising agonist/antagonist strength ratios through appropriate interventions could potentially decrease the likelihood of injury, as it serves as an indicator used to judge the level of athletic performance (82) (80).

#### *2.2.3.3. Peak torque to body weight (normalised data)*

Subjects may display bilateral symmetry (< 10% discrepancy between extremities) and normal unilateral ratios (relationship between agonist/antagonist muscles) but may have an altered torque-to-body weight ratio (61). Peak torque to body weight is expressed as a percentage of the maximum torque production in relation to the subject’s body weight, serving as a valuable indicator of general joint integrity (59) (71). This introduces an additional dimension to the interpretation of isokinetic dynamometry parameters, assessing muscular functional capabilities. Abnormalities may include conditions such as overuse, recurring injuries, or compromised proprioception resulting from the repetitive execution of constrained movements within the joint's range of mobility (80).

Normalising PT to body weight is essential for clinical applications and research, as it allows data to be individualised (61) (83). This normalisation helps differentiate between normal force values and those required based on an individual's weight, which is crucial for comparing athletes or populations. Objective and quantifiable data, such as PT to body weight collected during testing, can serve as a baseline during preseason screening or as comparative data to evaluate the efficacy of various training regimens. Isokinetic testing during preseason screening can identify specific muscle weaknesses that may predispose athletes to injuries (61).

Comparing PT to body weight against established normative data for different age groups and activity levels facilitates the development of tailored strength and conditioning programs. These programs aim to restore normal muscle balance, strength, and endurance, thereby reducing the risk of injuries and enhancing athletic performance (61).

#### *2.2.3.4. Comparisons to descriptive normative data*

Profiling musculoskeletal performance involves gathering normative data on muscular strength within a precisely defined group of individuals, presenting a potential application of isokinetic dynamometry to establish this normative data (79). Normative data are derived from testing a large sample of healthy individuals with similar characteristics and standardised testing procedures. The inclusion of normative data is crucial for effectively differentiating between normal and abnormal conditions with a meaningful level of sensitivity, potentially predicting risk of injury (79). If applied correctly, normative data specific to populations can be used for isokinetic dynamometry interpretation; however, its use remains controversial as the data needs to be tailored to the specific population (61).

Several factors influence the measurements and interpretation of data obtained from isokinetic dynamometry, requiring careful consideration.

## 2.3. Factors that influence isokinetic dynamometry measurements

### 2.3.1. Subject related / biological factors

The interpretation of isokinetic dynamometry data is significantly influenced by subject-related factors affecting muscular strength and performance (84) (85). It is important to emphasise that these variables are not exclusive to isokinetic dynamometry but are inherent in various muscle testing methods. Therefore, recognising and accounting for these factors becomes crucial in the design and interpretation of muscle testing protocols across different methodologies. This awareness is fundamental for ensuring a more comprehensive and accurate assessment of musculoskeletal function and performance. Key subject-related

factors that should be considered include age, body weight, gender, athletic background, body height, presence of impairment, extremity dominance, and pain.

#### *2.3.1.1. Age*

The fourth edition of Muscle and Sensory Testing, Reese, N. (2020) highlights the robust correlation between the steady growth and development of muscle strength (52). Muscle strength typically exhibits a gradual upward trend during childhood and young adulthood, succeeded by a decline throughout the individual's lifespan. This upward trajectory persists until around the ages of 20 to 30 years, after which literature indicates a decline in torque, work, and power with advancing age (61). Research indicates that age-related decline in muscle strength results from neuromuscular changes, muscle atrophy, and altered muscle contractile properties, leading to progressive disability and loss of independence (86). Muscle power experiences an earlier and more pronounced decline with age in comparison to muscle strength. Furthermore, peak muscle power has been identified as a significant predictor of functional limitations in older adults (87). Additionally, the effects of age on isokinetic dynamometry performance are discussed in Section 2.2.2, which includes normative data for ankle joint isokinetic dynamometry in dorsi flexion and plantar flexion.

#### *2.3.1.2. Body weight*

Body weight has been identified as a factor affecting isokinetic muscle performance, with the normalisation by body weight being the most effective factor in explaining the performance enhancement (61). This refers to standardising the measurements of isokinetic muscle performance testing based on an individual’s body weight. It is found that differences in body weight can influence torque production, particularly in weight-bearing joints, highlighting the importance of considering weight-related variations in test interpretation (88). Normalising the measurements by body weight allows for a more accurate comparison of muscle performance across individuals. This enables a more meaningful interpretation of the results that account for weight-related variations.

#### *2.3.1.3. Gender*

Gender differences are evident in isokinetic dynamometry measurements, with a study highlighting that men had greater strength on average than women in all muscle groups tested initially and at follow-up (89). Specifically, females consistently exhibit significantly lower PT relative to body weight compared to males (90). A cross-sectional observational study by Kanayama A. et al. (2023) investigated age-related changes and gender differences in plantar flexion velocity, comparing these with plantar flexion strength (91). Muscle strength data were normalised to body weight. The analysis of a sample size of 521

participants (n = 192 males; n = 329 females) revealed a significant gender difference in plantar flexion PT, with males demonstrating approximately 14% greater values than females ($p < 0.01$). However, no significant gender difference was found in plantar flexion velocity ($p = 0.21$). Additionally, the effects of gender on isokinetic dynamometry performance are discussed in Section 2.2.2, which includes normative data for ankle joint isokinetic dynamometry in dorsi flexion and plantar flexion. This emphasises the importance of incorporating gender-specific normative data for precise evaluation and interpretation in isokinetic dynamometry.

#### *2.3.1.4. Athletic background*

The impact of athletic background on isokinetic test results is well-established; studies have indicated a relationship between muscle strength and the time spent in leisure-time physical activity (89). Recreational athletes with specific training adaptations may demonstrate distinct strength profiles compared to non-athletes (92). Additionally, the effects of athletic background on isokinetic dynamometry performance are discussed in Section 2.2.2, which includes normative data for ankle joint isokinetic dynamometry in dorsi flexion and plantar flexion. Special attention is required when interpreting results across individuals with diverse athletic backgrounds.

#### *2.3.1.5. Body height*

Studies, exemplified by the work of Harbo T. et al. (2012), emphasise the crucial role of considering anthropometric factors like height, as they contribute to variations in lever arms and joint moments (73).

#### *2.3.1.6. Presence of impairment*

Individuals with impairments, such as neuromuscular disorders or injuries, may demonstrate altered isokinetic test results. Research led by Knapik J. et al. (2001) emphasis the influence of impairments on muscle strength assessment, requiring tailored interpretations for this specific population (93).

#### *2.3.1.7. Extremity dominance*

In medical research, the term used to denote the preferred or dominant side is known as laterality. Laterality encompasses the preferential use of one side of the body over the other, influenced by a combination of genetics and environmental factors.

According to Computer Sports Medicine, Inc, (CSMi), Humac Norms (2020) users guide the non-dominant lower-extremity is commonly approximately 5% weaker (peak slow-speed

torque) than the dominant side (60). A difference of greater than 15% between extremities is often viewed as a significant asymmetry in healthy athletes, potentially increasing their risk of injury (77).

#### *2.3.1.8. Pain in affected area*

Isokinetic dynamometry testing is contraindicated in instances of severe pain; MMT remains the preferred method of strength assessment to grade and monitor muscle function in these instances (49) (52). In cases in which strength testing is still indicated, an understanding of the effects of pain on muscle function is necessary for the accurate interpretation of the testing results. It is important to note that pain is not diagnostic or specific in discriminating between abnormalities (49).

Researchers have observed a reduction in muscle strength among individuals experiencing acute or chronic pain (52). These studies have compared strength levels between symptomatic and control groups, while others have investigated disparities between the symptomatic and asymptomatic sides.

### 2.3.2. Movement-related / technical factors

In isokinetic dynamometry testing, movement-related factors play a pivotal role, significantly influencing the precision of measurements and the interpretation of results. These factors include the speed and ROM during contractions, as well as the coordination and technique employed by the subject. Particularly critical in isokinetic testing is the control of movement velocity, as variations can significantly impact the recorded torque and power values. Similar considerations related to movement, such as form and coordination, are relevant across various muscle testing methods. Whether using isometric, isotonic, or other protocols, maintaining control and consistency in movement dynamics is essential for obtaining reliable and comparable data. Recognising and managing these movement-related factors are integral for ensuring the validity and reproducibility of muscle testing outcomes across diverse methodologies. The following movement-related factors and research conclusions are key to interpreting isokinetic dynamometry evaluations:

#### *2.3.2.1. Joint angle and range of motion (ROM)*

Each degree within the ROM has the potential to generate varying amounts of force, emphasising the importance of adhering to testing guidelines for the predetermined joint range of motion under evaluation. Due to the interplay of the length-tension relationship and joint biomechanics, force production is specific to the joint angle (61).

#### *2.3.2.2. Muscle action*

Primary muscle actions assessed with isokinetic equipment include concentric- and eccentric muscle contraction. Existing literature consistently highlights greater force production during eccentric muscle actions compared to concentric muscle actions (61).

## 2.4. Existing literature on isokinetic dynamometry in Achilles tendinopathy

Isokinetic dynamometry devices are commonly found in various facilities, primarily in outpatient orthopaedic settings. This evaluation method is proven effective in addressing a significant proportion of orthopaedic injuries and dysfunctions, particularly those involving the Achilles tendon (81). Isokinetic dynamometry serves as a versatile tool in the comprehensive assessment of AT, targeting various biomechanical aspects. Findings indicate that isokinetic dynamometry is a reliable method of measurement for assessing the torque of the plantar flexors, and it is determined that this method would serve as a valuable and reliable outcome measure for use in clinical trials (45). This approach is particularly effective in quantifying muscle strength and identifying functional deficits associated with AT, utilising the principles of isokinetic testing.

Researchers have employed this method to reveal PT deficits of the plantar flexor muscles between symptomatic and asymptomatic extremities, shedding light on specific muscular weaknesses contributing to the condition (94). In two separate meta-analyses, Hasani F. et al. (2021) and McAuliffe S. et al. (2019), both concluded that plantar flexor strength deficits are associated with AT, whether assessed within-subject (symptomatic- vs. asymptomatic extremities) or compared with healthy controls (95) (24). O'Neil S. (2019) found that participants with AT exhibited statistically significant weakness, with large deficits in plantar flexor PT, compared to healthy controls when evaluated with isokinetic dynamometry (94). Similarly, Sancho I. et al. (2022) reported that runners with AT had lower plantar flexion PT compared to healthy controls (96). These findings emphasise the importance of incorporating isokinetic strength measurements in the evaluation and management of AT.

Silbernagel K. et al. (2022) conducted a systematic review based on the International Scientific Tendinopathy Symposium (ICON 2020), discussing nine core domains for tendinopathy (97). They noted considerable variation in the outcome measures used for AT and stressed the importance of identifying and mapping all outcome measures for assessing the clinical phenotype of AT in future studies. Notably, isokinetic strength was an outcome measure in 7% of the studies (4/54). These four studies highlight the practical applications and benefits of isokinetic dynamometry as an outcome measure applied to AT in clinical settings.

1. In a study by Hortsmann T. et al. (2013), 58 patients (male n = 32; female n = 26) diagnosed with AT underwent a 12-week intervention (98). The research measured the initial and subsequent concentric and eccentric PT of the ankle in dorsi flexion and plantar flexion. These measurements were taken using isokinetic dynamometry at an angular velocity of 20 and 60 degrees per second while the patients were in a supine position. The study revealed that in the eccentric-training group, PT increased from the initial to subsequent evaluation during both eccentric- and concentric plantar flexion. Similarly, in the vibration-training group, there was an increase in concentric plantar flexion torque, with significant differences observed between follow-up and baseline values ($p<0.05$) at 10, 15, 20, 25 and 30 degrees of ankle dorsi flexion. However, the wait-and-see group did not exhibit any increase in eccentric or concentric plantar flexion PT. Consequently, the researchers concluded that vibration training could serve as an alternative treatment for AT participants who do not respond favourably to eccentric training. The IsoMed 2000 computerised dynamometer training system by D. & R. Ferstl GmbH, Hernau, Germany, was utilised for this study.

2. Nunley J. et al. (2011) conducted a retrospective review involving 27 participants (male n = 8; female n = 19) who underwent surgery using the central incision technique (99). They proposed that this technique would be an effective approach for treating AT with minimal to no loss in plantar flexion strength. Nineteen of these participants had their concentric PT strength of plantar flexion measured against the non-operative side in the prone position using isokinetic dynamometry. The specific angular velocity for these measurements was not disclosed. The study revealed no significant disparity in isokinetic strength between the operative and non-operative sides. Consequently, it was inferred that surgical debridement and resection for insertional AT utilizing the central technique present a technically sound procedure, resulting in 96% of the participants being pain-free after seven years, with minimal to no strength loss. The Humac Norm Cybex by CSMI solutions, USA, equipped with Cybex Medical/Henley Healthcare Software, Version 2.06, was the computerised dynamometer training system used in this study. According to the Humac Norm User's guide (2020) the suggested angular velocity test speeds range from 30 to 180 degrees per second (48).

3. In a prospective study by Öhberg L. et al. (2001), 24 participants (male n = 17; female n = 7) undergoing surgery for chronic Achilles tendinosis were assessed (100). The study measured concentric plantar flexion PT using isokinetic

dynamometry at angular velocities of 90 and 225 degrees per second while the participants were seated. The findings revealed that at the one-year follow-up, concentric plantar flexion PT at both 90 and 225 degrees per second did not exhibit a significant increase on the injured side compared to baseline. Additionally, it was significantly lower on the injured side than on the non-injured side. Similarly, eccentric plantar flexion PT at 90 degrees per second did not show a significant increase on the injured side and did not differ significantly from the non-injured side at the one-year follow-up. Between the one and five-year follow-ups, there was no significant increase in concentric plantar flexion PT at either velocity on the injured side, which remained significantly lower than the non-injured side at the five-year follow-up. Eccentric plantar flexion PT decreased between the one and five-year follow-ups, although not significantly; however, it remained significantly lower on the injured side compared to the non-injured side at the five-year follow-up. Despite 92% of the participants reporting being pain-free and active in sports and recreational activities, the deficit in gastrocnemius-soleus muscle strength observed on the injured side prior to surgery persisted. Measurements were conducted using the Biodex isokinetic dynamometer from Biodex Co, New York, USA.

4. O'Neill S. et al. (2018) investigated the immediate effects of heavy isometric plantar flexion exercise on sensory and motor output in 16 participants (male n = 11; female n = 5) with unilateral AT (101). They conducted an isokinetic dynamometry evaluation of plantar flexion PT before the intervention and during re-testing. Concentric PT was measured at angular velocities of 90 and 225 degrees per second with the patients' knees extended. The results indicated a significant increase in mean maximal concentric plantar flexion torque at 90 degrees per second following the intervention. However, there was no significant change observed in either concentric PT at 225 degrees per second or eccentric PT at 90 degrees per second. The study concluded that participants with AT exhibited a varied response to heavy 45-second isometric contractions and therefore, such interventions cannot be recommended for immediate pain relief or improved motor output. The Humac Norm system from CSMI solutions, USA, was the computerised dynamometer employed for the study.

The predominant outcome measure for isokinetic strength in the literature on AT and isokinetic dynamometry for plantar flexion strength is the PT parameter.

## 2.5. Limitations and gaps in existing research

Most research on plantar flexor weakness associated with AT, as evaluated through isokinetic dynamometry, primarily focuses on a single parameter – PT. This narrow focus on PT limits the development of data interpretation for other isokinetic dynamometry parameters (102). Although PT is widely regarded as the most representative and frequently reported muscle performance parameter in isokinetic dynamometry literature, other computable parameters are often overlooked. These could potentially provide additional insights beyond the conventional PT analysis (61) (103). This gap is evident in the study of gastrocnemius-soleus dysfunction and plantar flexor weakness in AT.

Studies have consistently demonstrated lower values in PT development in the plantar flexor muscles of patients with unilateral AT. For instance, a study by Andere N. (2021) on biomechanical evaluation in runners with AT restricted their exploration of defining muscle weakness through isokinetic dynamometry parameters solely to the PT parameter of the ankle plantar flexors (104).

Though utilising PT as an evaluative metric is recommended when assessing the attainment of strength criteria for the return to sport in individuals with AT, there is a pressing need for additional exploration of muscle endurance and requires further investigation (64). Payton C. and Burden A. (2017) highlighted that focusing solely on PT data, regardless of angular position, might lead to incorrect conclusions regarding muscle function (55).

## 2.6. Proposed research and its contribution

Modern medicine is grounded in evidence-based practice, where a comprehensive understanding of research studies and methodologies is crucial. Retrospective studies are particularly valuable for investigating rare diseases, their manifestations, and outcomes, offering insights that shape the direction of future prospective studies (40).

To address the gaps in existing research, our retrospective study seeks to deepen the understanding of plantar flexor weakness and gastrocnemius-soleus dysfunction in individuals with unilateral AT. It will focus on how AT affects various isokinetic dynamometry parameters, particularly torque, position, and time. The study has two primary objectives: firstly, to determine the level of dysfunction and weakness in the gastrocnemius-soleus muscles, using these specific parameters; and secondly, to perform a comparative analysis between symptomatic and asymptomatic extremities. This approach aims to identify which parameters show the most significant differences, thereby shedding light on the intricate aspects of muscle performance in individuals with unilateral AT.

The scientific background reveals a prevailing limitation in existing research on plantar flexor weakness associated with AT. Most studies focus solely on the conventional PT-only analysis, neglecting other computable parameters in isokinetic dynamometry evaluation reports. Although PT is considered a representative parameter of muscle performance, this study recognises the need to explore additional parameters, such as position and time, to provide a more comprehensive understanding of the intricacies of muscle function in the context of AT.

## 2.7. Summary

Existing research on plantar flexor weakness associated with AT often focuses solely on PT measured through isokinetic dynamometry, limiting the exploration of other parameters (19) (24) (94) (95) (96) (98) (99) (100) (101) (104). While PT is commonly used and reported, other computable parameters are overlooked, potentially hindering a comprehensive understanding of muscle performance in AT. This gap in research is evident in studies examining gastrocnemius-soleus dysfunction and plantar flexor weakness, emphasizing the importance of exploring additional parameters beyond PT to enhance insights into muscle function and rehabilitation in AT.

With this study, we aim to fill this gap by including a broader range of parameters in the torque measurements, as well as position and time, based on the outcomes of isokinetic dynamometry evaluations. To the knowledge of the authors, at the time of the study, there is a gap in research regarding the application of these three parameters to AT, necessitating further investigation. McAuliffe S. et al. (2019) in their systematic review and meta-analysis on altered strength profiles in AT, emphasised the need for clinicians to modify Achilles tendon function assessments to improve rehabilitation outcomes (24). Sara LK. (2021) also suggested that future research should broaden the evaluation of neuromuscular function in AT, particularly in assessing various properties of gastrocnemius-soleus function (23). By incorporating these additional isokinetic dynamometry parameters, we aim to uncover new insights that could enhance clinical practices in the rehabilitation of AT.

Exploring torque, position, and time parameters provides a comprehensive understanding of muscle performance, revealing strength and fatigue characteristics associated with the condition. Analyses of joint angle and time parameters could contribute to a detailed characterisation of the dynamic aspects of muscle function.

While changes in plantar flexor force capacity with AT are well-documented, the literature on the effects of AT on additional parameters of torque, position, and time remains unexplored

(19) (24) (94) (95) (96) (98) (99) (100) (101) (104). Investigating the potential effects that AT has on these additional isokinetic dynamometry parameters could assist in quantifying the current considerations of defining plantar flexor muscle weakness and gastrocnemius-soleus dysfunction, other than PT. By describing neuromuscular function of plantar flexor muscles during an isokinetic dynamometry test, it can contribute to the field by understanding the pathology as it relates to pain and functional impairment in AT. This information may enable clinicians to identify or assist in the differential diagnosis of patients at risk for developing AT. Subsequently, the objectivity of isokinetic dynamometry measurements can be used to gauge the effectiveness and progress in managing patients with AT compared to previously assessed values.

# CHAPTER 3: RESEARCH METHODOLOGY

In this chapter, the methodology of the study is explained. It encompasses the study design, population, measuring instrument, the isokinetic dynamometry evaluation procedure, ethical considerations, and the data analysis approach.

## 3.1. Study design

A retrospective study design was employed, incorporating quantitative data to investigate the relationships and potential associations between isokinetic dynamometry parameters.

## 3.2. Study population

### 3.2.1. Source of data

Isokinetic evaluation reports from male and female participants aged 18 years or older, diagnosed with unilateral AT, were included. These reports were sourced from Jannie Klingbiel Biokineticists, encompassing both sedentary and athletic participants.

### 3.2.2. Sample selection

A convenience sample was utilised for the retrospective analysis of data. All datasets that fulfilled the inclusion criteria on record from Jannie Klingbiel Biokineticists from 2015 to 2022 were included. A related study by O'Neil S. et al. (2019) noted significant findings with a sample size of n=16 (101).

#### *3.2.2.1. Sample recruitment*

Permission was granted by the data gatekeeper to use isokinetic dynamometry evaluation reports from patients with diagnosed unilateral AT, as documented in Appendix 2.

#### *3.2.2.2. Site of study*

Jannie Klingbiel Biokineticists, located at The Centre for Sports Medicine and Orthopaedics, 9 Sturdee Avenue, Rosebank, City of Johannesburg, South Africa, 2196.

#### *3.2.2.4. Inclusion criteria*

- Data from male and female participants aged 18 years and above.
- Diagnosis of unilateral AT confirmed by an experienced physiotherapist, sports physician, or other healthcare providers through clinical history, physical examination, and/or diagnostic investigations.

- Isokinetic dynamometry evaluation reports conducted between 2015 and 2022 for the participant's initial evaluation for the diagnosis of unilateral AT.

According to the Biodex data manual, "Isokinetic Testing and Data Interpretation: Data Analysis," the COV indicates the level of variation between repetitions (76). The manual advised maintaining a COV of less or equal to 15% for large muscle groups and less or equal to 20% for small muscle groups, such as the ankle joint. However, this study allowed for a higher variance. This exception was made because participants might experience pain, a symptom of AT, which could prevent them from consistently achieving maximal repetitions within the recommended variation limits. According to Computer Sports Medicine, Inc. (CSMi), pain is considered a relative contraindication, unlike severe pain, which is an absolute contraindication for isokinetic dynamometry testing (75). Therefore, testing could still be conducted on participants with relative contraindications (75).

#### *3.2.2.5. Exclusion criteria*

- Reports from isokinetic dynamometry evaluations that did not have an angular velocity test speed of 60 degrees per second were excluded.
- Subsequent or re-evaluation isokinetic dynamometry reports for the same diagnosis.

The CSMi Test Speeds Chart for the HUMAC Norm isokinetic dynamometer recommended conducting slow-speed torque curve tests for the ankle joint at 30 or 60 degrees per second for dorsi flexion and plantar flexion (75). The slow-speed test is particularly valuable as it provides a good indication of the participant's ability to withstand compressive forces and yields the most accurate interpretation of the torque curve shape. Clinicians and researchers can then examine the curve shape for potential indications of pain, weakness, and other abnormalities. Additionally, this testing speed offers the best information for PT%BW and PTR parameters (60). Based on these clinical considerations and the recommendations from CSMi, the researcher decided to exclude other testing velocities and focus solely on an angular velocity of 60 degrees per second for the purpose of this study.

## 3.3. Measuring instrument

Registered biokineticists at Jannie Klingbiel Biokineticists conducted the isokinetic dynamometry test evaluation, adhering to standardised protocols described below in section 3.3.1.

### 3.3.1. Isokinetic dynamometry

The testing protocol, including dynamometer settings and participant securing, followed the Humac Norm Cybex Testing and Rehabilitation System, CSMI Solutions User's Guide, Model 770 (Pages 5-12 and 5-13), as depicted in Figure 3.0. The testing range spanned from -10 degrees dorsi flexion to +30 degrees plantar flexion, with participants in a prone position and knees fully extended. This setup, which involved the extended knee position, allowed for collective recruitment of the gastrocnemius and soleus muscles (94). The interrupted stroke protocol was used, and the axis of rotation was set as described in the Humac Norm test manual (see Figure 3.1). The dynamometer was calibrated for 30 minutes before each evaluation, following which participants warmed up on a stationary bike for five minutes. Bilateral tests were standardised, with the uninvolved extremity being evaluated first. All tests were conducted while participants wore flat-heeled shoes, properly stabilised in the footplate with the footplate belts tightly secured (see Figure 3.0 and Figure 3.1). A brief explanation of the test protocol and a warm-up session involving five repetitions preceded the measurements. The isokinetic protocol then consisted of five maximal repetitions at an angular velocity of 60 degrees per second (see Table 3.0). Verbal encouragement was provided to maximise effort.




**Figure 3.0:** Isokinetic dynamometry testing position (65)

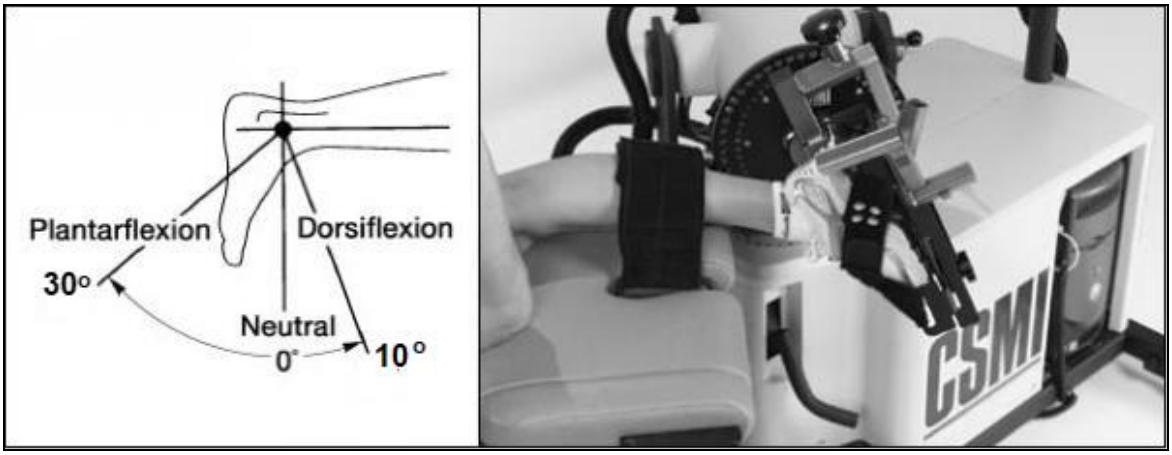



**Figure 3.1:** Isokinetic dynamometry testing range (35).

| Table 3.0: Isokinetic dynamometry testing procedure | | | |
|---|---|---|---|
| **Phase** | **Repetitions** | **Intensity** | **Angular velocity** |
| Warm-up | 3 | Submaximal | 60° per second |
| Warm-up | 2 | Maximal | 60° per second |
| Rest | - | 60 seconds | - |
| Testing | 5 | Maximal | 60° per second |

### 3.3.2. Baseline characteristics

For descriptive purposes, baseline characteristic measurements were conducted according to the protocol of the International Society for the Advancement of Kinanthropometry (ISAK) (Norton & Olds, 1996). Height was measured to the nearest 0.01 centimetre (cm) using a standard wall-mounted stadiometer (Seca Stadiometer, 216, Seca, USA) with the participants wearing minimal clothing and no shoes. Weight (kg) was measured in kilogrames on a calibrated scale (Trojan, BSA16056v, Duteck Industrial co. ltd, Taiwan). Body mass index (BMI) was calculated by dividing body mass by stature squared (weight/height$^2$) and expressed as kilogrames per square meter (kg/m$^2$) (Plowman & Smith, 2011). For evaluation purposes, measurements were converted from cm and kg to inches and pounds.

The participants symptomatic extremity (diagnosed with AT), preferred extremity (dominant extremity) height (inches) and body mass (pounds) will be collected from the isokinetic dynamometry evaluation report generated by Humac Norm Cybex software.

### 3.3.3. Demographic data

Demographic data, including chronological age and biological sex classification, were sourced from the isokinetic dynamometry evaluation report.

## 3.4. Isokinetic dynamometry parameters

A detailed analysis and report of between-extremity values for all listed plantar flexion parameters was conducted. The parameters include torque, position, and time measures as recorded by the Humac Norm Cybex software.

### 3.4.1. Torque parameters

#### *3.4.1.1. Peak torque (foot-pounds – best repetition)*

The maximum torque production during an extension/flexion movement, indicative of maximal muscular tension capability (63).

#### *3.4.1.2. Peak torque to % body weight ratio (foot-pounds – best repetition)*

A useful metric for inter-individual comparisons and evaluating functional strength relative to body weight (65).

#### *3.4.1.3. Peak torque ratio (foot-pounds – best repetition)*

Expresses the torque of the weaker muscle group as a percentage of the stronger group, significant for overall muscle function (65).

#### *3.4.1.4. Work per repetition (foot-pounds – best repetition)*

Calculated as torque times the angle in radians, representing the work done per cycle (65).

#### *3.4.1.5. Average power per repetition (watts – best repetition)*

Defined as work per unit time (65).

### 3.4.2. Position parameters

#### *3.4.2.1. Joint angle at peak torque (degrees)*

The point in the ROM where PT first occurs (65).

### 3.4.3. Time parameters

#### *3.4.3.1. Time to peak torque (seconds)*

The time from the beginning of torque development until the point where PT is first developed (65).

#### *3.4.3.2. Time peak torque held (seconds)*

The time during which peak torque is maintained (65).

#### *3.4.3.3. Force decay time (seconds)*

The time from the end of peak torque production to the end of the motion (65).

## 3.5. Validity and reliability

### 3.5.1. Validity

#### *3.5.1.1. Content validity*

The isokinetic dynamometry evaluations were designed to comprehensively assess the strength of the plantar flexor muscles, which are crucial in the context of AT. The parameters selected for measurement were aligned with the aims of the study and based on established biomechanical principles.

#### *3.5.1.2. Construct validity*

The relationships between the measured variables and the theoretical concepts they represent were confirmed through a review of literature, discussed in Chapter 2: Literature review. The parameters used, such as PT and PTR, are widely accepted indicators of muscle function and imbalance, which are integral to understanding AT, discussed in Chapter 2: Literature review.

#### *3.5.1.3. Inter-rater validity*

Registered biokineticists at Jannie Klingbiel Biokineticists conducted the isokinetic dynamometry test evaluation, adhering to standardised protocols as per section 3.3.1.

### 3.5.2. Reliability

#### *3.5.2.1. Instrument reliability*

The Humac Norm Cybex dynamometer was calibrated before each testing session to ensure accuracy.

## 3.6. Ethical considerations

Ethical clearance was sought and obtained from the Human Research Ethics Committee (Medical), ethics protocol number: M230978, Appendix 1. Data from Jannie Klingbiel Biokineticists were used with permission, ensuring the anonymity and confidentiality of participants' personal information, Appendix 2.

## 3.7. Data collection and measurement procedures

Following the approval of ethical clearance, data were collected from Jannie Klingbiel Biokineticists and recorded in Microsoft Excel under the headings listed in section 3.6 isokinetic dynamometry parameters. The data are stored in a secure folder on the primary investigators laptop that is password protected, accessible only to the researcher.

### 3.8. Data analysis

Data are reported in tables as means and standard deviations (SD) from the isokinetic dynamometry evaluation report for the following variables: torque parameters, position parameters, time parameters, age, gender, height, body weight and BMI.

The involved symptomatic extremity (AT) was compared with the uninvolved asymptomatic extremity (without AT) using the isokinetic dynamometry evaluation report generated by the Humac Norm Cybex software. Between-extremity values for all listed plantar flexion parameters were examined. The comparison between the involved symptomatic extremity and the uninvolved asymptomatic extremity was conducted using a paired t-Test for data with a normal distribution or the Wilcoxon test for data that were not normally distributed. Relationships between the extremities were determined using Pearson's product-moment correlation or Spearman's RHO test if the data were not evenly distributed. Significance was set at $p<0.05$. StataCorp Stata 18.0 BE—Basic Edition was the statistical analysis software package utilised for analysing the study results.

# CHAPTER 4: RESULTS

This chapter presents the results of this retrospective study analysing isokinetic dynamometry parameters in participants diagnosed with unilateral AT. The study was conducted following the principles set forth in the research methodology described in Chapter 3. It aimed to explore the potential differences in muscle function between the symptomatic and asymptomatic extremities in individuals with unilateral AT. Utilising data sourced from Jannie Klingbiel Biokineticists, this investigation covers a sample of (n=21) participants. Data analysis focused on torque, position, and time parameters to gain a comprehensive understanding of the impact of AT on muscular performance. The demographic characteristics of the study population, including age, gender, height, body mass, and BMI, are detailed, providing context to the findings.

The specific time frame from the initial diagnosis of AT to the commencement of biokinetic treatment was not available. Due to confidentiality agreements, the researcher did not have access to participants' personal files, which included detailed medical histories and dates of diagnosis. Consequently, the types of treatments participants underwent prior to their initial biokinetic assessment are unknown, as the isokinetic dynamometry evaluation reports did not include these details.

The initial treatments for participants and the duration since their injuries remain unspecified because access was restricted to the isokinetic evaluation reports, excluding comprehensive medical records. All participants included in the study had a primary diagnosis of unilateral AT confirmed by either by an experienced physiotherapist, sports physician, or other healthcare providers through clinical history, physical examination, and/or diagnostic investigations. No information about secondary injuries was available from the data provided, ensuring that the focus remained solely on AT as the primary diagnosis.

## 4.1. Study population

In this study, a total of 54 participants (males n=42; females n=12) initially met the inclusion criteria outlined in section 3.2.2.4, with each participant having undergone one isokinetic dynamometry evaluation during their initial assessment in both plantar flexion and dorsi flexion bilaterally. The criteria specified that the participants should be male or female patients aged 18 years or older, diagnosed with unilateral AT. Out of these 54 participants, (n=25) had unilateral AT diagnosed on their dominant extremity, and (n=29) on their non-dominant extremity. The diagnosis had to be confirmed by an experienced physiotherapist, sports physician, or other healthcare providers through clinical history, physical examination,

and/or diagnostic investigations. Additionally, the evaluations were required to be conducted between 2015 and 2022.

To ensure the accuracy of the study, we specifically included only the initial isokinetic evaluation reports for the diagnosis of unilateral AT and excluded any subsequent or re-evaluation reports for the same diagnosis. This approach ensures that each report corresponds to a unique initial evaluation and eliminates the possibility of including multiple reports from the same participant for the same diagnosis. The inclusion and exclusion criteria in section 3.2.2.4 and section 3.2.2.5 were designed to address this concern.

Upon further analysis of these isokinetic evaluations, a variation in the angular velocity of the tests was observed. Of the 54 reports, 21 were conducted at an angular velocity of 60 degrees per second, 17 at 45 degrees per second, and 16 at 30 degrees per second.

However, considering the exclusion criteria detailed in section 3.2.2.5, which stipulates that any isokinetic dynamometry evaluation reports not performed at an angular velocity of 60 degrees per second are to be excluded, the number of reports suitable for analysis was reduced. Therefore, only the 21 isokinetic evaluations conducted on 21 participants initial assessment at the required angular velocity of 60 degrees per second were included in the study (n=21). This adherence to strict criteria ensures the consistency and reliability of the research findings.

## 4.2. Demographic characteristics of the sample

In this study involving 21 participants, the demographic data revealed a diverse range of ages, heights, body masses, and BMI values, Table 4.0.

**Table 4.0: Demographic data (n=21)**

| Demographic | Mean | (SD) | [Range] |
|---|---|---|---|
| Age (years) | 53.10 | (± 12.86) | [29 - 84] |
| Height (centimetres) | 175.26 | (± 10.16) | [140 - 188] |
| Body Mass (kilograms) | 81.17 | (± 16.98) | [59 - 135] |
| BMI (kg/m$^2$) | 26.43 | (± 6.00) | [19 - 45] |

The study comprised 21 participants (n=21), with a gender distribution of 14.29% females (n=3) and 85.71% males (n=18), indicating a predominantly male sample. The mean age of

the female participants was 47.33 years (SD: ±16.26), whereas the male participants had a mean age of 54.06 years (SD: ±12.51). Overall, the participants' ages ranged from 29 to 84 years, with a mean age of 53.1 years (SD: ±12.86) and a median age of 53 years.

Height distribution among participants varied from 140 to 188 centimetres, with a mean height of 175.26 centimetres (SD: ±10.16). The body mass of participants ranged from 59 to 135 kilograms, averaging 81.17 kilograms (SD: ±16.98). Regarding Body Mass Index (BMI), values ranged from 19 to 45 kg/m², with a mean BMI of 26.43 kg/m² (SD: ±6.00).

## 4.3. Involved (symptomatic) extremity

**Table 4.1: Distribution of symptomatic extremity among participants (n=21)**

| Symptomatic extremity | Frequency | Percent |
|---|---|---|
| Left (L) | 13 | 61.90% |
| Right (R) | 8 | 38.10% |
| Total | 21 | 100.00% |

The distribution of the symptomatic extremity amongst participants showed that 61.90% of participants (n=13) had the left side as the symptomatic extremity, and 38.10% of participants (n=8) had the right as the symptomatic extremity, Table 4.1. This is particularly notable considering that all participants (100%, n = 21, Section 4.4) identified their right side as the dominant extremity.

## 4.4. Preferred (dominant) extremity

All participants (100%, n = 21) identified their right side as the dominant extremity.

**Table 4.2: Comparison of isokinetic dynamometry parameters between symptomatic (SYM) and asymptomatic (ASYM) extremities (n=21)**

| Parameter | Mean (SYM) | (SD) (SYM) | Mean (ASYM) | (SD) (ASYM) | Mean | (SD) | p-value |
|---|---|---|---|---|---|---|---|
| **Torque** | | | | | | | |
| PT | 38.81 | (±10.97) | 40.91 | (±11.48) | | | 0.24 |
| PT-D | | | | | 4.52 | (±17.16) | |
| PT%BW | 22.43 | (±7.00) | 23.57 | (±7.17) | | | 0.25 |
| PTR | 49.76 | (±13.16) | 48.52 | (±13.10) | | | 0.67 |
| WPR | 17.57 | (±5.48) | 18.91 | (±5.90) | | | 0.16 |
| WPR-D | | | | | 6.14 | (±19.63) | |
| APR | 35.48 | (±11.71) | 39.05 | (±13.14) | | | 0.06 |
| APR-D | | | | | 8.00 | (±18.83) | |
| **Position** | | | | | | | |
| JAPT | 1.81 | (±5.11) | 2.24 | (±3.89) | | | 0.0001 |
| **Time** | | | | | | | |
| TPT | 0.20 | (±0.13) | 0.21 | (±0.11) | | | 0.50 |
| TPTH | 0.36 | (±0.33) | 0.34 | (±0.39) | | | 0.49 |
| FDT | 0.25 | (±0.09) | 0.28 | (±0.15) | | | 0.37 |

| | | |
|---|---|---|
| **PT:** | Peak torque | (foot-pounds - best repetition) |
| **PT-D:** | Peak torque deficit | (%) |
| **PT%BW:** | Peak torque as a percentage of body weight | (%) |
| **PTR:** | Peak torque ratio | (%) |
| **WPR:** | Work per repetition | (foot-pounds - best repetition) |
| **WPR-D:** | Work per repetition deficit | (%) |
| **APR:** | Average power per repetition | (watts - best repetition) |
| **APR-D:** | Average power per repetition deficit | (%) |
| **JAPT:** | Joint angle at peak torque | (degrees) |
| **TPT:** | Time to peak torque | (seconds) |
| **TPTH:** | Time peak torque held | (seconds) |
| **FDT:** | Force decay time | (seconds) |
| **SYM:** | Symptomatic extremity | |
| **ASYM:** | Asymptomatic extremity | |
| **SD:** | Standard deviation | |

## 4.5. Torque parameters

The study's findings on torque parameters are summarised in Table 4.2.

### 4.5.1. Peak torque (foot-pounds – best repetition) (PT)

The symptomatic extremity had a mean PT of 38.81 foot-pounds (SD: ±10.97), marginally lower than the asymptomatic extremity 40.91 foot-pounds (SD: ±11.48). However, a paired t-Test (p-value: 0.24) indicated no statistical significant difference.

### 4.5.2. Peak torque deficit (%) (PT-D)

The boxplot in Figure 4.0 illustrates the PT-D expressed as a percentage, representing the discrepancy in PT between the symptomatic and asymptomatic extremities of the participants (n=21). The mean PT-D observed was 4.52% (SD: ±17.16), indicating a marginal reduction in PT on the symptomatic extremity within this cohort. Notably, the distribution of PT-D values is depicted through various percentiles, with the largest deficit value being -31% and the largest surplus at 38%. The interquartile range (IQR), which represents the middle 50% of the data, spans from -6 to 15%, highlighting the central tendency of the dataset.

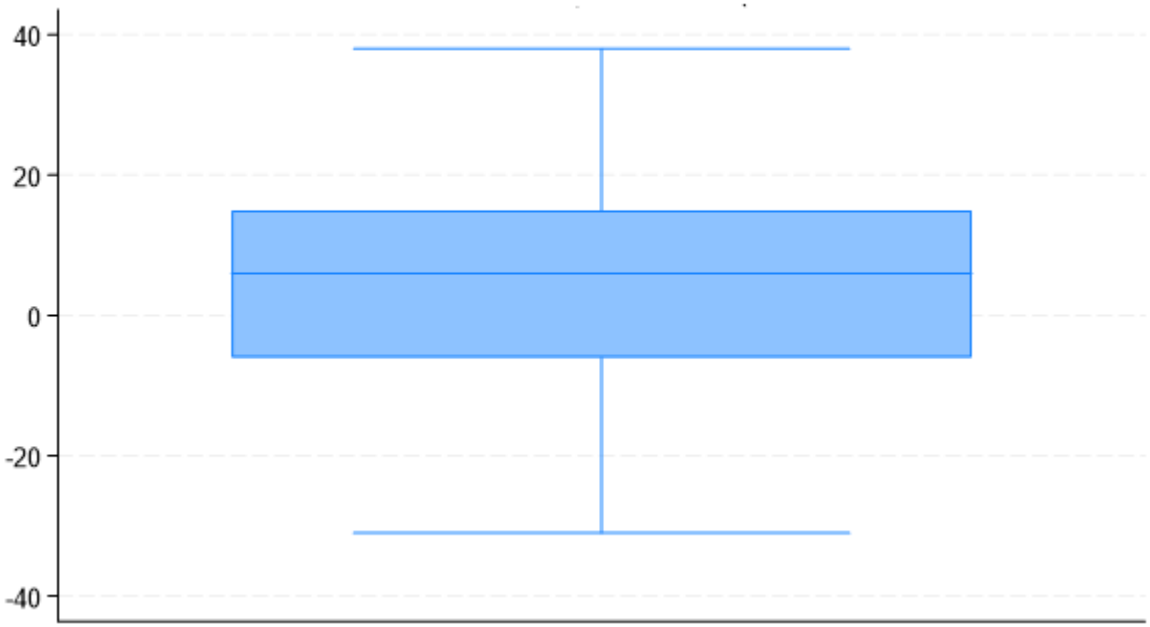



**Figure 4.0: Boxplot showing the distribution of peak torque deficit percentages in subjects with unilateral Achilles tendinopathy (n=21)**

**Y-axis:** Peak torque deficit (%)

#### 4.5.3. Peak torque to % body weight (PT%BW)

Symptomatic extremities showed a mean PT%BW of 22.43% (SD: ±7.00), slightly lower than asymptomatic extremities 23.57% (SD: ±7.17). The paired t-Test (p-value: 0.25) indicated no statistical significance in this sample.

#### 4.5.4. Peak torque ratio (%) (agonist / antagonist ratio) (PTR)

The PTR, representing the agonist/antagonist ratio, showed that the mean PTR was 49.76% (SD: ±13.16) for symptomatic extremities and 48.52% (SD: ±13.10) for asymptomatic extremities. The paired t-Test (p-value: 0.67) revealed no statistical significance in this sample.

#### 4.5.5. Work per repetition (foot-pounds – best repetition) (WPR)

Symptomatic extremities showed a mean WPR of 17.57 foot-pounds (SD: ±5.48), lower than the 18.91 foot-pounds (SD: ±5.90) of asymptomatic extremities. The paired t-Test (p-value: 0.16) indicated no statistical significant difference in this sample.

#### 4.5.6. Work per repetition deficit (%) (WPR-D)

The boxplot in Figure 4.1 illustrates the distribution of the deficit in work performed per repetition among the sample of participants (n=21). The boxplot indicates a mean WPR-D of 6.14% (SD: ±19.63), suggesting a slight reduction in work performed during each repetition on the symptomatic extremities of participants. The IQR, which measures the middle 50% of data points, extends from -6 to 19%, showing the spread of the central half of the dataset. Notably, the 50th percentile (median) is at 0%, demonstrating that half of the observations are at or above the no-deficit mark, while the other half are below it.




**Figure 4.1: Boxplot showing work per repetition deficit percentages in subjects with unilateral Achilles tendinopathy (n=21)**

**Y-axis:** Peak torque deficit (%)

### 4.5.7. Average power per repetition (watts - best repetition) (APR)

The mean APR was 35.48 watts (SD: ±11.71) on the symptomatic extremity, lower than the 39.05 watts (SD: ±13.14) of the asymptomatic extremity. The paired t-Test (p-value: 0.06) showed a trend towards statistical significance but was not conclusively significant in this sample.

### 4.5.8. Average power per repetition deficit (%) (APR-D)

The data revealed a variance in muscle performance on the symptomatic extremity among subjects with unilateral AT (n=21). In Figure 4.2, the analysis reveals a mean deficit of 8.00% (SD: ±18.83), signifying a notable variance in the sample's power generation during repetitive tasks on the symptomatic extremity. The data range extends from a substantial deficit of -36% to a surplus of 46%, with the IQR demonstrating the middle 50% of observations between a 2% deficit to an 18% surplus. The median value is at 9%, denoting that half of the participants displayed a deficit below this figure, while the other half exhibited equal or greater deficits.

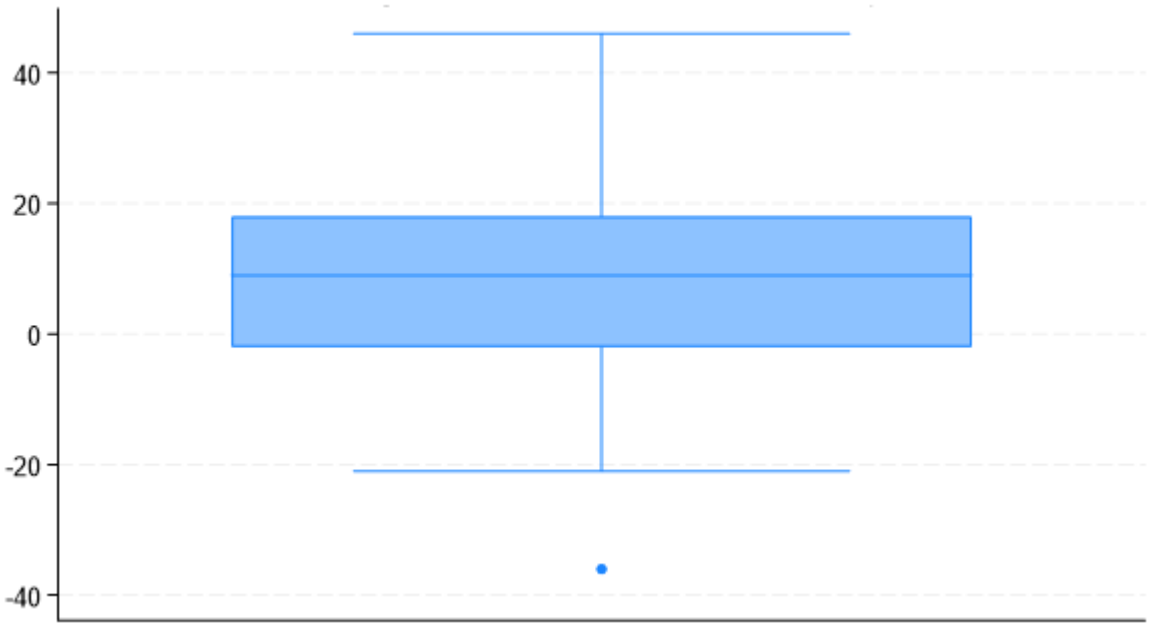



**Figure 4.2: Boxplot showing average power per repetition deficit percentages in participants with unilateral Achilles tendinopathy (n=21)**

**Y-axis:** Peak torque deficit (%)

## 4.6. Position parameters

The study's findings on position parameters are summarised in Table 4.2.

### 4.6.1. Joint angle at peak torque (degrees) (JAPT)

The examination of the JAPT via a boxplot analysis revealed a statistically significant difference between the symptomatic and asymptomatic extremities of patients with unilateral AT. The boxplot in Figure 4.3 visualises the distribution of JAPT for symptomatic and asymptomatic extremities. The symptomatic extremity shows a broader IQR from negative two to six degrees, with a median of two degrees, indicating that half of the sample recorded their PT at a joint angle within this range. In contrast, the asymptomatic extremity has a narrower IQR from one to four degrees and a slightly higher median of three degrees, suggesting a more consistent and higher angle at PT across the sample (n=21).

Outliers are present on both extremities, with values at negative five degrees for the symptomatic extremity and negative six degrees for the asymptomatic extremity, indicating instances where PT occurred at greater joint flexion. The symptomatic extremities mean JAPT is 1.81 degrees (SD: ±5.11), which is lower than the asymptomatic extremities mean

of 2.24 degrees (SD: ±3.89). The statistical analysis, using the Wilcoxon signed-rank test, shows a significant difference (p-value: 0.0001) between the two extremities.

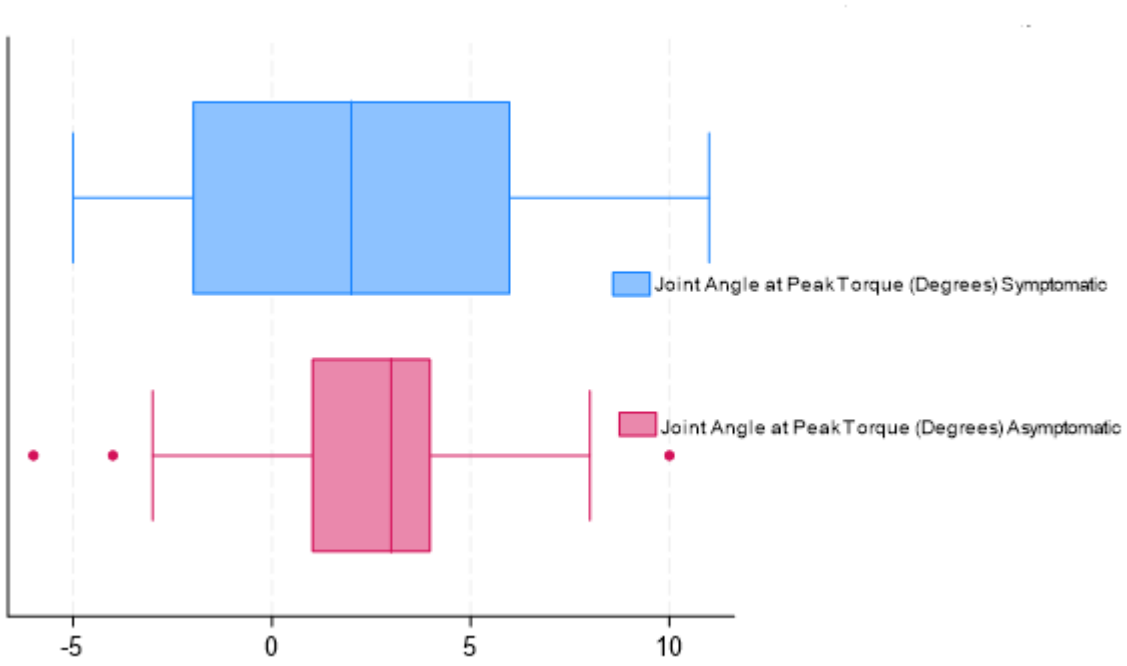



**Figure 4.3: Boxplot of joint angle at peak torque (degrees) in symptomatic vs. asymptomatic extremities of patients with unilateral Achilles tendinopathy (n=21)**

**X-axis:** Degrees

## 4.7. Time parameters

The study's findings on time parameters are summarised in Table 4.2.

### 4.7.1. Time to peak torque (seconds) (TPT)

The symptomatic and asymptomatic extremities showed similar mean TPTs, 0.20 seconds (SD: ±0.13) vs. 0.21 seconds (SD: ±0.11), with no statistical significant difference in this sample (p-value: 0.5).

### 4.7.2. Time peak torque held (seconds) (TPTH)

The mean TPTH was similar between the symptomatic and asymptomatic extremities, 0.36 seconds (SD: ±0.33) vs. 0.34 seconds (SD: ±0.39), with no statistical significant difference in this sample (p-value: 0.49).

### 4.7.3. Force decay time (seconds) (FDT)

The mean FDT was slightly lower on the symptomatic extremities 0.25 seconds (SD: ±0.09) vs. 0.28 seconds (SD: ±0.15) on the asymptomatic extremities, but the paired t-Test (p-value: 0.37) indicated no statistical significant difference in this sample.

## 4.8. Summary

Chapter 4 presents a comprehensive investigation of the isokinetic dynamometry parameters in individuals with unilateral AT. Key findings include a non-significant difference in PT between symptomatic- and asymptomatic extremities, and a statistically significant difference in the JAPT. These results provide valuable insights into the biomechanical implications of AT and its impact on muscle function. The consistency in TPT across symptomatic- and asymptomatic extremities suggests that muscle responsiveness remains relatively unaffected. The clinical implications of these findings underscore the importance of a multifaceted approach in AT rehabilitation, focusing on strength, endurance, and biomechanics.

# CHAPTER 5: DISCUSSION

This chapter presents a comprehensive discussion on the outcomes of this retrospective study conducted to evaluate isokinetic dynamometry parameters in patients diagnosed with unilateral AT. The primary objective of this research was to investigate the effects of unilateral AT on various isokinetic dynamometry parameters, namely torque, position, and time, in diagnosed individuals. These parameters were analysed to determine the magnitude of dysfunction and weakness in the gastrocnemius-soleus muscles, comparing the symptomatic- and asymptomatic extremities to understand the unilateral nature of AT.

The study's approach employed general percentage guidelines, isokinetic normative data, and a comparative analysis with established research. These methodologies enabled an understanding of muscle dysfunction and weakness in unilateral AT. The results were benchmarked against established norms and guidelines, offering valuable insights into the biomechanics and functional implications of AT. This chapter delves into the significance of these findings and implications for future research in musculoskeletal disorders.

In order to position the current study within the broader scope of AT research, Table 5.0 (Appendix 3) compares the demographic and physical characteristics across studies that employed isokinetic dynamometry. This appendix presents a comparative analysis of sample size, gender distribution, age, height, body weight, and BMI between our study and the selected research. Comparing the characteristics of our study population to these relevant investigations is crucial for positioning our findings within the existing body of evidence, highlighting both similarities and differences across study samples.

The studies included in this comparison were selected based on their relevance to our research objectives, which focused on evaluating isokinetic strength measures in participants diagnosed with AT. By aligning our findings with these comparable studies, we can better interpret our results and assess their generalizability to the broader population of patients with this condition. This comparative analysis provides important context for understanding the significance and implications of our findings, as well as their potential impact on future research and clinical practice in the field of musculoskeletal disorders.

## 5.1. Study population

Our research, as represented in Table 5.0, examined 21 bilateral isokinetic dynamometry evaluation reports (n=21), examining plantar flexion of the ankle. These assessments were conducted on both symptomatic- and asymptomatic extremities, at an angular velocity of 60 degrees per second (concentric). The cohort of our study incorporated individuals aged 18 years and above, drawn from both active and sedentary lifestyles, all diagnosed with unilateral AT. The AT diagnosis was validated by an experienced healthcare professional, including physiotherapists and/or sports physicians, utilising a comprehensive approach that integrated clinical history, physical examination, and/or diagnostic investigations. The evaluations spanned from 2015 to 2022, allowing for a diverse- and longitudinal perspective on AT.

In contrast, the study conducted by O'Neill S. et al. (2019), Table 5.0, involved 16 participants (n=16) (101). This study shared commonalities with ours in terms of unilateral AT and age criteria. However, it diverged in its approach to angular velocity, analysing torque at 90- and 225 degrees per second (concentric) and 90 degrees per second (eccentric). This variation in angular velocities could significantly impact muscle response to isokinetic exercise, hence influencing the study's outcomes in distinct ways.

Another study by O'Neill S. et al. in 2019, Table 5.0, focused on a group of 39 runners (n=39) diagnosed with unilateral AT, ranging in age from 18 to 70 years (94). This research also employed isokinetic dynamometry, but differed in its application of angular velocities, using 90 and 225 degrees per second (concentric) and 90 degrees per second (eccentric). The specific focus on runners provides a targeted lens through which the impacts of AT in this particular demographic can be understood, offering potentially unique insights into the condition's effects within this athletic group. Griffen C. et al. (2021) reported the prevalence of AT could reach up to 52% among specific athletic groups, while in the general population, this figure is 2% (12) (35).

Furthermore, Horstmann T. et al.'s (2013) study, Table 5.0, encompassed a larger sample of 58 recreational runners (n=58) diagnosed with AT (98). This study was unique in its methodology, randomly assigning participants into three distinct groups: vibration training (n=23, Table 5.0, Group 1), eccentric training (n=19, Table 5.0, Group 2), and a control group (n=16, Table 5.0, Group 3) that followed a wait-and-see policy. The study employed bilateral isokinetic dynamometry to assess force, both at the outset and in follow-up evaluations. The participants executed concentric plantar flexion and dorsi flexion at maximum effort in three consecutive cycles at an angular velocity of 60 degrees per second.

Our study's emphasis on maintaining a consistent angular velocity of 60 degrees per second enabled a standardised evaluation approach for the ankle joint in AT patients. This consistent velocity offered a contrasting perspective to the varied velocities used in O'Neill S. et al.'s studies, which could lead to an understanding of muscle performance under different dynamic conditions.

## 5.2. Demographics

### 5.2.1. Gender (M/F)

A key aspect of understanding AT involves examining its demographic distribution, particularly in terms of gender. This discussion incorporates data from our study and compares it with other significant research in this area. The comparative analysis is presented in Table 5.0.

The data from our study aligns with the broader observation that AT predominantly affects males. In our cohort, males comprised a significant majority (85.71%, n=18), a pattern echoed in the studies by O'Neill S. et al. (2019) and Horstmann et al. (2013), where males consistently outnumbered females. This trend is not isolated, but reflects the general prevalence of AT, which is notably higher in middle-aged men (11).

The gender disparity in AT incidence could be attributed to several factors, including biomechanical, hormonal, and lifestyle differences between males and females. It's widely reported that middle-aged men, particularly those engaged in sports or physical activities, are at a higher risk of developing AT. This risk factor is crucial in understanding the condition's aetiology and formulating gender-specific preventative and rehabilitative approaches.

However, a systematic review and meta-analysis by Murphy M. et al. (2019) on the efficacy of heavy eccentric calf training for treating mid-portion AT, provide further insight into this gender distribution (105). Their analysis, covering seven studies including 241 participants, of which five trials included the gender spread, reported a near-even gender distribution with 45% males and 54% females.

The gender distribution in AT studies, including ours, underlines the importance of considering gender as a significant variable in AT research and management. This understanding can lead to more effective, tailored treatment plans and potentially contribute to improved outcomes in both male- and female participants suffering from AT.

Understanding the gender distribution is essential for clinicians when applying study findings to diverse patient populations. It prompts consideration of potential gender-specific biomechanical differences in AT.

### 5.2.2. Age (years)

In our study, an analysis of the age distribution among participants was conducted, as outlined in Table 5.0. The findings revealed a mean age of 53.1 years (SD: ±12.86) and a median age of 53 years. The systematic review and meta-analysis by Murphy M. et al. (2019) included seven studies with participants aged from 36.6 (SD: ±7.2) to 49.2 years (SD: ±11.3), signifying the prevalence of this condition in the middle-aged demographic (105). In a subgroup analysis of their systematic review and meta-analysis on the prevalence of AT in physical activity, it was noted that the prevalence of AT increases with age, being highest among groups aged 45 years and over, and lowest among those aged 18 years (13).

In comparison, the studies conducted by O'Neill S. et al. in (2019) depict similar age groups (94) (101). In their studies, average participant age was 48.6 years (SD: ±8.9), and 47 years (SD: ±11.8). These studies primarily involved physically active individuals, possibly explaining the slightly lower mean ages. The specific inclusion of runners in the journal of Physical Therapy in Sport study suggests a group potentially more prone to AT at a younger age, likely attributable to the strenuous nature of their activities. Lyght M. et al. (2016) highlight the Achilles tendon's vulnerability to overuse injuries due to the constant high stresses it endures during locomotion (5).

Horstmann T. et al.'s study from (2013) presents a demographic, with mean ages ranging from 44.4 (SD: ±7.7) to 46.0 years (SD: ±6.9) across its groups (98). This could reflect the recreational nature of the runners involved, where varying levels of athletic intensity might influence the onset of AT. Kingma, J. et al. (2007) and Wang Y. et al. (2022) emphasise that AT is a frequent diagnosis in active individuals, particularly in the 35 to 45 year age group, and is more prevalent in sports involving running or jumping (11) (13). Wang Y. et al. (2022) also notes that runners face a substantially higher risk of AT compared to their inactive counterparts, with elite male runners experiencing a lifetime incidence of over 50% (13).

The age profiles across these studies highlights the complex nature of AT. This condition is not limited to elite athletes or middle-aged individuals but affects both active and sedentary populations. Our study emphasises the importance of developing targeted preventive and treatment strategies adaptable to various age groups and activity levels. This understanding

is vital for clinicians and researchers in formulating age-specific rehabilitation protocols and in recognising potential risk factors such as age and activity levels.

### 5.2.3. Height (cm)

In our research, we examined the height of participants involved in isokinetic dynamometry studies on AT, as presented in Table 5.0. In our study, the average height of the 21 participants was 175 centimetres (SD: ±10.2), spanning a range from 140 to 188 centimetres. This data provides valuable insights into the physical stature of individuals affected by AT and its potential implications on the condition's presentation and management.

Comparatively, the study by O'Neill S. et al. (2019) reports an average height of 173.4 centimetres (SD: ±9.1), showing a slightly lower average height compared to our study (101). The absence of a range in their data limits the scope for understanding the full spectrum of height variations within their participant group.

In O'Neill S. et al.'s (2019) other study, the mean height was slightly higher at 177 centimetres (SD: ±6.8) (94). This higher average could be attributed to the specific athletic population of runners they studied. However, without the range of heights, it is challenging to draw definitive conclusions about the height distribution in their sample.

Horstmann T. et al.'s (2013) study presented similar average heights across their three groups, with Group 1 averaging 175.1 centimetres (SD: ±9.0), Group 2 at 173.3 centimetres (SD: ±8.9), and Group 3 at 175.8 centimetres (SD: ±7.4) (98). The inclusion of height ranges in their study provides a better understanding of the variability among participants.

Clinicians should consider how height and related biomechanical factors might influence the presentation and progression of AT in different individuals.

### 5.2.4. Body mass (kg)

In AT research, body mass is a variable that can influence both the incidence and the progression of the condition. Our study observed a mean body mass of 81.2 kilograms (SD: ±17) among 21 participants (n=21), with a range from 59 to 135 kilograms (Table 5.0). This broad range indicates a significant diversity in body composition among participants, which is essential for understanding the physical demands placed on the Achilles tendon in different individuals.

Comparatively, O'Neill S. et al.'s (2019) study reported a similar mean body mass of 81.6 kilograms (SD: ±14.3), in a sample size of 16 participants (n=16) (101). The similarity in body mass between the two studies suggests a possible trend in the physical profiles of individuals with AT.

On the other hand, the study by O'Neill S. et al. (2019), focusing on runners, reported a slightly lower mean body mass of 77 kilograms (SD: ±12.1) (94). This difference could be attributed to the specific athletic demands and body composition associated with long-distance running, where a lighter body mass is often advantageous.

The Horstmann T. et al.'s (2013) study presented varying body masses across its three groups, with Group 1 averaging 79.2 kilograms (SD: ±16.5), Group 2 at 74.5 kilograms (SD: ±10.3), and Group 3 at 79.6 kilograms (SD: ±15.9).

The significance of body mass in the context of AT cannot be understated as AT is believed to result from overuse which impairs the Achilles tendon's ability to endure stress and tension (8). Heavier body mass can potentially increase the load on the Achilles tendon during physical activities, theoretically contributing to the development or exacerbation of tendinopathy.

In clinical practice, these findings highlight the importance of personalised treatment approaches. Rehabilitation programmes for AT should be tailored to the individual's body mass, ensuring that exercises and load management strategies are appropriate for their specific physical profile.

**5.2.5. BMI (kg/m²)**

In the discussion of AT, BMI is an integral metric that intertwines body weight with height, offering insights into the general health and physical condition of individuals. Our study exhibited a mean BMI of 26.43 kg/m² (SD: ±6.00) among 21 participants (n=21), with a range extending from 19 to 45 kg/m² (Table 5.0). This range encapsulates a diverse BMI spectrum, from normal range to very severely obese, indicative of the varied physical profiles of individuals afflicted with AT (106).

Contrastingly, O'Neill S. et al.'s (2019) study reported a mean BMI of 27 kg/m² (SD: ±2.7), slightly higher than our study (101). This marginal increase could reflect the specific physical stature of their study cohort, potentially suggesting a trend towards a higher BMI in individuals with AT.

Horstmann T. et al.'s (2013) study displayed varied BMI values across its groups (98). Group 1 had a mean BMI of 25.6 kg/m² (SD: ±3.7), Group 2 was at 24.8 kg/m² (SD: ±2.7), and Group 3 recorded 25.7 kg/m² (SD: ±4.3). These figures align closely with the general population averages in BMI ranges, indicating that AT is not exclusively a condition of higher BMI individuals.

The O'Neill S. et al. (2019) study did not report BMI, which limits comparative analysis (94). However, the inclusion of this parameter in other studies underlines its significance in understanding the physical composition of individuals with AT.

From a clinical perspective, BMI serves as an important indicator for assessing the overall physical health status of patients with AT. The ranges of BMI values classify normal range between 18.5 to 24.9 kg/m² and overweight (pre-obese) between 25.0 to 29.9 kg/m² (106). In the range of BMI values observed in these studies, Table 5.0, all but Group 2 from the study of Horstmann T. et al.'s (2013) is classified as overweight (pre-obese). Higher BMIs may suggest a greater mechanical load on the Achilles tendon, potentially necessitating modified or gradual loading programs in rehabilitation to mitigate the risk of exacerbating the condition.

The presence of individuals with a wide BMI range in these studies also emphasises the importance of holistic health management in AT care. Lifestyle modifications, nutritional counselling, and targeted exercise regimens might be beneficial adjuncts to traditional physical therapy interventions, especially for individuals with a BMI classification not in the normal range.

### 5.3. Involved (symptomatic) extremity

The analysis of the involved- or symptomatic extremity in unilateral AT within our study cohort reveals intriguing patterns that could have significant implications for understanding the aetiology and management of this condition. According to our data, there was a noticeable asymmetry in the distribution of the symptomatic extremity among the participants.

In our study, the left side was identified as the symptomatic extremity in 13 out of 21 participants (n=21), accounting for 61.90% of the cases. This prevalence suggests a notable inclination toward left-side unilateral AT within our study group (Table 4.1). The reasons behind this left-sided dominance in symptomatology could be multi-faceted, involving biomechanical- and physiological factors that warrant further investigation.

On the other hand, the right side was affected in eight participants, making up 38.10% of the total study population. While this represents a smaller proportion compared to the left side, it is nonetheless significant and points to the need for a balanced consideration of both sides in clinical assessment and research.

### 5.4. Preferred (dominant) extremity and symptomatic extremity in Achilles tendinopathy

Our study's observation that all participants (100%, n=21) identified their right side as the dominant extremity introduces an intriguing dimension to the understanding of unilateral AT. The prevalence of left-side symptoms in a predominantly right-side dominant group raises critical questions about the relationship between extremity dominance and the development of AT. It suggests the possibility that the non-dominant side, in this case, the left, might be subjected to different or unaccustomed stresses and strains, potentially leading to a higher incidence of tendinopathy.

This finding between the symptomatic extremity and the non-preferred extremity in our study participants suggests a complex relationship between extremity dominance and the vulnerability to AT. The finding that symptoms predominantly occurred in the non-dominant extremity has direct implications for clinical practice. These insights not only enhance our understanding of the condition's clinical presentation but also have the potential to inform more effective, side-specific therapeutic interventions.

### 5.5. Objectives and methodology

Our study aimed to elucidate two critical aspects of unilateral AT in participants diagnosed with this condition. The objectives were to:

1. Determine the magnitude of dysfunction and weakness in the gastrocnemius-soleus muscles in participants diagnosed with unilateral AT across various parameters (torque, position, and time).

2. Compare these parameters between the symptomatic and asymptomatic extremities in these individuals to identify specific differences that may contribute to our understanding of the unilateral nature of AT.

Addressing objective one:

To achieve our first objective, we employed a multi-faceted approach:

1. Utilisation of general percentage guidelines:

We referred to the general percentage guidelines from "Muscle performance evaluation in orthopaedic practice," published in the Journal of Bone and Joint Surgery by Sapega A. (1990) (49). These guidelines served as a framework to differentiate between normal and abnormal muscle function, thereby identifying dysfunction and weakness. Sapega's guidelines categorise bilateral strength deficits for the purpose of orthopaedic practice into three distinct ranges: less than 10% as normal, 10 to 20% as possibly abnormal, and greater than 20% as probably abnormal in a presumably healthy population (49) (107). In cases where a previous injury is anticipated to result in weaker performance in one extremity, the following criteria are employed: deficits up to 10% are normal; deficits between 10 to 20% as probably abnormal; and deficits greater than 20% as almost certainly abnormal. These categorisations continue to be referenced in literature, demonstrating their enduring relevance and utility.

For instance, Camargo P. et al. (2009) referenced Sapega's criteria, asserting that bilateral differences in PT of less than 10% are considered normal, while differences between 10 to 20% indicate a probable abnormality (108). This application highlights the guidelines' effectiveness in assessing muscle function and identifying potential dysfunctions. Similarly, Johnson C. et al. (2019) reiterated Sapega's categories, confirming their applicability in evaluations of muscle strength discrepancies (109). They referenced that side-to-side differences of less than 10% are normal, 10 to 20% are possibly abnormal, and those exceeding 20% are probably abnormal. Both studies utilised isokinetic dynamometry in their assessments, highlighting the integration of these guidelines into current research.

Moreover, a study by Eagle S. et al. (2018) also referenced Sapega’s guidelines (107). This study employed a retrospective cohort design to analyse whether bilateral strength symmetry of lower-extremity musculature is related to previous knee injury history. Eagle S. et al. sought to investigate differences in bilateral knee strength of the quadriceps and hamstrings based on previous knee injury occurrence, as well as the odds of reporting previous knee injury based on the magnitude of isokinetic knee strength asymmetry (i.e., less than 10%, 10 to 20%, and greater than 20%).

The study included 150 male participants who completed a one-day testing protocol, incorporating a self-reported injury history and isokinetic dynamometry strength testing. Results indicated that participants with isokinetic knee extension average PT differences of less than 10% had 77% lower odds of reporting previous knee injury

compared to those with greater than 20%. Similarly, participants with isokinetic knee extension strength differences of greater than 10 to 20% demonstrated 76% lower odds of reporting knee injuries compared to those with differences greater than 20%. However, no significant odds ratios were found based on isokinetic knee flexion bilateral strength differences in average PT. This study highlighted that more symmetrical isokinetic dynamometry knee extension strength was associated with reduced odds of reporting previous knee injuries, thereby establishing a relationship between greater isokinetic dynamometry knee extension asymmetry and knee injuries in their military population sample.

2. Reference to isokinetic normative data:
   We consulted "A compendium of isokinetics in clinical usage and rehabilitation techniques" (4th Edition) by Davies G. (1992), for normative data on isokinetic parameters (72). This enabled us to establish benchmarks for assessing dysfunction and weakness in parameters like PT, PTR, and PT%BW.

3. Comparison with established research:
   We compared our data with the findings from "Maximal isokinetic and isometric muscle strength of major muscle groups related to age, body mass, height, and sex in 178 healthy subjects" by Harbo T. et al. (2012), in the European Journal of Applied Physiology (73). This comparison was crucial in understanding how our results on PT, PTR and PT%BW aligned or deviated from established norms in healthy subjects.

Addressing objective two:
To achieve the second objective, we adopted a comparative approach:

1. Comparative analysis of extremities:
   We analysed the involved symptomatic extremity (with AT) and the uninvolved asymptomatic extremity (without AT) using data from the isokinetic dynamometry evaluation report generated by the Humac Norm Cybex software. This comparison encompassed all listed plantar flexion parameters.

2. Statistical testing:
   A paired t-Test was employed for data with normal distribution, while the Wilcoxon test was used for non-normally distributed data. This statistical approach ensured accurate comparisons between the symptomatic and asymptomatic extremities.

3. Correlation analysis:

   To explore relationships between the extremities, Pearson's product-moment correlation was utilised for evenly distributed data, and Spearman's RHO test for unevenly distributed data. Our statistical significance was set at $p<0.05$.

4. Identification of correlations:

   This comprehensive analysis aimed to identify correlations between the involved symptomatic- and uninvolved asymptomatic extremities that are not commonly reported or researched in the literature. This approach was crucial in unravelling unilateral AT's and its impact on muscle functionality.

The methodology adopted in this study provided a comprehensive approach to understanding the nuances of muscle dysfunction and weakness in unilateral AT. By employing a robust analytical framework and comparing our findings with established norms and guidelines, we were able to draw meaningful insights into the unilateral nature of AT. These insights are invaluable not only for clinical understanding and management of AT but also for guiding future research in this domain.

## 5.6. Torque parameters

The study's findings on torque parameters are summarised in Table 4.2.

### 5.6.1. Peak torque (foot-pounds – best repetition) (PT)

The evaluation of PT is critical in understanding muscle strength and dysfunction in AT patients. According to Davies G. (1992), the average isokinetic PT values for ankle plantar flexion tested at an angular velocity at 60 degrees per second are 83 foot-pounds for females and 107 foot-pounds for males (n=25; Table 2.0) (72). Normative isokinetic data from Harbo T. et al. (2012) for ankle plantar flexion and dorsi flexion PT at 60 degrees per second by age and gender (n=77 females; n=77 males; Table 2.2) are 56.73 foot-pounds (SD: ±9.58) for females and 88.51 foot-pounds (SD: ±14.03) for males in the age group 50-59 years (73).

In our sample population (n=21), which had a mean age of 53.1 years (SD: ±12.86; Table 4.0 and Table 5.0) and a median age of 53 years, the mean PT for the symptomatic extremity was 38.81 foot-pounds (SD: ±10.97; Table 4.2), while the mean PT for the asymptomatic extremity was 40.91 foot-pounds (SD: ±10.97; Table 4.2) (Table 4.2). Both values are considerably lower than the normative values from Davies G. (1992) and Harbo

T. et al. (2012) compared to healthy controls, indicating bilateral dysfunction and weakness in the gastrocnemius-soleus muscles within our sample population.

Despite a marginal difference in PT between symptomatic- and asymptomatic extremities, the paired t-Test showed no statistically significant difference (p-value: 0.24; Table 4.2), suggesting that the observed numerical difference might not be consistent across the AT population. This lack of significant difference challenges the common perception that AT leads to a substantial reduction in strength in the affected extremity. The findings imply potential compensatory mechanisms or uniform muscle adaptation in response to AT.

Our study's methodology and data analysis have provided valuable insights into the impact of unilateral AT on muscle functionality. By comparing our results with established guidelines and norms, we offer a significant contribution to the clinical understanding and future research directions in the realm of musculoskeletal disorders.

### 5.5.2. Peak torque deficit (%) (PT-D)

In our examination of unilateral AT, one crucial aspect we examined was the PT-D. This key parameter represents the percentage difference in PT between the symptomatic- and asymptomatic extremities, offering a window into the functional impairment attributable to the condition.

We found the mean PT-D across participants to be 4.52% (Table 4.2), indicating a lower PT in the symptomatic extremity compared to the asymptomatic extremity. The SD was calculated at (SD: ±17.16; Table 4.2), highlighting the individual variability in functional impairment.

According to Sapega A. (1990), a deficit of less than 10% is considered normal in a presumably healthy individual; in an individual where one extremity is expected to be weaker, a deficit of 10 to 20% is considered abnormal (49). The observed mean PT-D of 4.52% falls within the normal range, as per Sapega’s general percentage guidelines, in a presumably healthy population. However, when comparing our results with Davies G. (1992), both symptomatic 38.81 foot-pounds (SD: ±10.97; Table 4.2) and asymptomatic 40.91 foot-pounds (SD: ±10.97; Table 4.2) extremities showed considerably lower PT than the norms (83 foot-pounds for females, 107 foot-pounds for males) (72). This proposes that, although the PT-D of 4.52% is less than 10% and considered normal, this finding should be interpreted with caution, the individual mean PT values for both the symptomatic extremity

and asymptomatic extremity suggests bilateral dysfunction and weakness in the gastrocnemius-soleus muscles.

### 5.6.3. Peak torque to % body weight (PT%BW)

In our study of unilateral AT, we analysed the PT%BW. This parameter is instrumental in providing a perspective on muscular strength relative to the individual's body mass, thus offering a personalised evaluation of muscle capabilities.

The mean PT%BW on the symptomatic extremity was found to be 22.43% (SD: ±7.00; Table 4.2). This figure represents the relative muscular strength of the symptomatic extremities in proportion to the participants' body weight. For the asymptomatic extremity, the mean PT%BW was slightly higher at 23.57% (SD: ±7.17; Table 4.2). This suggests a marginally greater relative muscular strength in the asymptomatic extremities when adjusted for body weight.

The observed data suggests a trend where, on average, participants demonstrated marginally higher relative PT on their asymptomatic extremities. However, the notable SDs underscores the individual variances in the impact of unilateral AT on relative muscular strength.

According to Davies G. (1992), the average PT values relative to body weight in isokinetic ankle plantar flexion at an angular velocity of 60 degrees per second are 60% for females and 65% for males (n=25; Table 2.0) (72). In comparison, Harbo T. et al. (2012) reported PT%BW values ranging from 41 to 68% for females and 41 to 57% for males in individuals aged 50 to 59 years at an angular velocity of 60 degrees per second (male n=77; female n=77; Table 2.3) (73). Our participants, with a mean age of 53.1 years (SD: ±12.86; Table 4.0 and Table 5.0), showed significantly lower PT%BW values, indicating bilateral dysfunction and weakness in the gastrocnemius-soleus muscles. This deviation from the norms is noteworthy and indicative of broader muscular impairment in AT patients.

Our study’s results, while indicating a trend towards lower PT%BW in symptomatic extremities, did not reveal a statistically significant difference. The paired t-test (p-value: 0.25; Table 4.2) did not show a significant variance, suggesting that these differences may not be uniformly representative across the broader AT-affected population or might be influenced by compensatory mechanisms in the symptomatic extremity.

The analysis of PT%BW in our study provides key insights into the functional implications of unilateral AT. It underscores the importance of considering individual body weight in the evaluation of muscle strength and offers a more holistic understanding of the condition's impact. This approach is vital for developing personalised rehabilitation strategies and for advancing research into the biomechanics and rehabilitative interventions for AT.

### 5.6.4. Peak torque ratio (agonist / antagonist ratio) (PTR)

In our study, we also evaluated the PTR, which represents the agonist/antagonist ratio. This parameter is critical in assessing the functional balance between opposing muscle groups, particularly in the context of unilateral AT.

The mean PTR for the symptomatic extremities was 49.76% (SD: ±13.16; Table 4.2), while for the asymptomatic extremities, it was slightly lower at 48.52% (SD: ±13.10; Table 4.2). The similar standard deviations for both groups suggest a considerable variability in PTR values within our study population. This variation highlights individual differences in muscular balance and the physiological response to unilateral AT. A paired t-test was conducted to compare the PTR values between the symptomatic and asymptomatic extremities, yielding a (p-value: 0.67; Table 4.2). This result indicates no statistically significant difference between the two groups.

According to Davies G. (1992), the typical isokinetic PTR for ankle dorsiflexion to plantar flexion at an angular velocity of 60 degrees per second is approximately 19.27% (1:5.19; Table 2.0) for females and 18.5% (1:5.35; Table 2.0) for males (72). Among female athletes, the PTR is approximately 19.23% (1:5.2; Table 2.1), while sedentary females exhibit a higher ratio of approximately 32.26% (1:3.1; Table 2.1). In male athletes, the PTR is about 18.52% (1:5.4; Table 2.1), compared to approximately 37.03% (1:3.7; Table 2.1) in sedentary males. In contrast, Harbo T. et al. (2012) reported average ratios of 21% for females and 29% for males among individuals aged 50 to 59 years at an angular velocity of 60 degrees per second (Table 2.4) (73). In our study, participants had a mean age of 53.1 years (SD: ±12.86; Table 4.0 and Table 5.0) and exhibited significantly higher PTR values than those reported in the literature. This deviation from established norms suggests a bilateral dysfunction and weakness of the plantar flexors relative to the dorsi flexors in individuals with AT.

Sapega A. (1990) stated that it is reasonable to interpret data on agonist/antagonist muscle groups quantitatively in accordance with the general percentage guidelines (49). The commonly cited criterion of 80 to 90% of the measured capability in the uninvolved extremity

can be used as a minimum standard for the involved extremity before the patient returns to sports or strenuous work after injury. Our findings show that the mean PTR on the symptomatic extremity is approximately 97.5% of that on the asymptomatic extremity. This bilateral difference is less than 10%, which falls within the normal range according to the general percentage guidelines established by Sapega A. (1990) (49).

Understanding PTR is essential for clinicians and researchers. It informs the design of targeted rehabilitation strategies by providing insights into the relative strength and functional balance of opposing muscle groups. Moreover, PTR aids in monitoring recovery progress in AT patients. From a research perspective, PTR offers valuable information on the biomechanical consequences of AT and potential compensatory mechanisms.

Our study's analysis of the PTR in the context of unilateral AT reveals significant insights into the condition's impact on the balance between agonist- and antagonist muscle groups. By revealing the subtle but important details about muscle group balance and function, it offers vital insights for both clinical management and research into this condition. The findings highlight the need for comprehensive rehabilitation approaches that consider not just the strength but also the functional balance of the affected extremities.

**5.6.5. Work per repetition (foot-pounds – best repetition) (WPR)**

In our examination of unilateral AT, we investigated the WPR, quantified in foot-pounds for the best repetition. This metric is crucial for understanding the energy output by muscles in each cycle of activity, highlighting aspects of muscular endurance and performance.

The mean WPR for symptomatic extremities was 17.57 foot-pounds (SD: ±5.48; Table 4.2), slightly less than the 18.91 foot-pounds (SD: ±5.90; Table 4.2) for the asymptomatic extremities. Our paired t-Test yielded a (p-value: 0.16; Table 4.2), indicating no statistically significant disparity in WPR between the symptomatic and asymptomatic extremities. The observed WPR suggests a marginal yet consistent energy output deficit in the symptomatic extremities compared to the asymptomatic ones. However, given the lack of statistical significance, this finding may not consistently apply to all individuals with unilateral AT.

Understanding WPR is critical for clinicians. It illuminates the functional capacity and muscular endurance in extremities affected by AT, guiding the development of tailored rehabilitation programs focused on restoring and boosting muscular performance. For researchers, WPR serves as an important parameter to understand the biomechanical impacts of AT and the efficiency of muscle function in affected individuals. This insight is key

for a comprehensive evaluation of AT's effects and the success of different treatment methods.

Sapega A. (1990) notes that 80 to 90% of the measured capability in the uninvolved extremity is a standard for the involved extremity before returning to high-impact activities post-injury (49). Applying this to our findings, the mean WPR on the symptomatic extremities represents approximately 92.9% of the mean on the asymptomatic extremities. This bilateral difference is less than 10%, which falls within the normal range according to the general percentage guidelines established by Sapega A. (1990) (49). Although Davies G. (1992) and Harbo T. et al. (2012) do not provide normative data on WPR, our study's findings suggest a pattern of bilateral dysfunction and weakness in the gastrocnemius-soleus muscles, particularly when cross-referenced with PT, PT%BW and PTR findings.

Our exploration of WPR in unilateral AT patients reveals insights into the condition's impact on muscular performance. While the observed differences in WPR were not statistically significant, they indicate a trend towards decreased energy output in symptomatic extremities. These findings underscore the need for personalised rehabilitation strategies and further research into the biomechanical and rehabilitative aspects of unilateral AT.

**5.6.6. Work per repetition deficit (%) (WPR-D)**

In our study of unilateral AT, we assessed the WPR-D, a critical metric for understanding the functional impact of AT on muscle performance during repeated activities.

The mean WPR-D across our participant cohort was 6.14% (SD: ±19.63; Table 4.2). This figure suggests a reduction in WPR on the symptomatic extremity compared to the asymptomatic extremity. The substantial SD reflects a wide range of WPR-D among participants, highlighting significant individual differences in the degree to which unilateral AT affects muscular performance and endurance.

Understanding WPR-D is crucial. It quantifies the extent of functional impairment due to AT, aiding in setting realistic rehabilitation goals and monitoring recovery. This metric guides clinicians in customising treatment plans to address specific deficits in muscle performance. WPR-D provides valuable insights into the biomechanical- and functional consequences of AT. It contributes to on-going efforts to enhance diagnostic accuracy and rehabilitative strategies for managing this condition.

According to Sapega A. (1990), a deficit of less than 10% is generally normal for healthy individuals. In cases where one extremity is expected to be weaker, a deficit of 10 to 20% is indicative of probable abnormality (49). The observed mean WPR-D of 6.14% falls within the normal range, as per Sapega A.'s general percentage guidelines, in a presumably healthy population. However, given the known presence of unilateral AT, this finding should be interpreted with caution as our study's findings suggest a pattern of bilateral dysfunction and weakness in the gastrocnemius-soleus muscles, particularly when cross-referenced with the PT, PT%BW and PTR findings.

**5.6.7. Average power per repetition (watts - best repetition) (APR)**

In our study into unilateral AT, we assessed the APR, measured in watts during the best repetition. This parameter is pivotal in assessing the rate at which work is performed by the muscles, highlighting their efficiency and capability, especially in the context of AT.

The mean APR on the symptomatic extremity was 35.48 watts (SD: ±11.71; Table 4.2), which was slightly lower than the 39.05 watts (SD: ±13.14; Table 4.2) observed on the asymptomatic extremity. The paired t-Test yielded a (p-value: 0.06; Table 4.2). Although this does not reach the conventional threshold of statistical significance ($p < 0.05$), it suggests a marginal trend toward a difference in average power between the two extremities.

Understanding APR in the context of AT is crucial for assessing dynamic muscle function. This knowledge assists in developing targeted rehabilitation programs aimed at restoring muscular power, crucial for returning to high-impact activities. The APR provides insights into the biomechanical effects of AT, contributing to a deeper understanding of the condition's impact on muscle efficiency and performance.

According to Sapega A. (1990), the commonly cited criterion of 80 to 90% of the measured capability in the uninvolved extremity can be used as a minimum standard for the involved extremity before the patient returns to sports or strenuous work after injury (49). Our findings show that the mean APR on the symptomatic extremity is approximately 90.9% of that on the asymptomatic extremity. This bilateral difference is less than 10%, which falls within the normal range according to the general percentage guidelines established by Sapega A. (1990) (49).

While Davies G. (1992) and Harbo T. et al. (2012) do not provide specific norms for APR, our results, particularly when considered alongside the PT, PT%BW and PTR findings,

suggest a pattern of bilateral dysfunction and weakness in the gastrocnemius-soleus muscles.

### 5.6.8. Average power per repetition deficit (%) (APR-D)

Our study into unilateral AT also included a detailed analysis of the APR-D. This metric reflects the percentage difference in the rate of work performed per cycle between the symptomatic- and asymptomatic extremities, and is instrumental in assessing the dynamic functional impact of AT on muscular performance.

Our study found a mean APR-D of 8.00% (SD: ±18.83; Table 4.2). This value indicates a moderate reduction in power on the symptomatic extremity, suggesting that AT affects the rate at which work is done in the affected muscles. The wide SD underscores significant individual variability, pointing to the unique nature of AT's impact across different individuals.

For clinicians, the APR-D is a valuable tool in quantifying dynamic functional impairment in patients with AT. It assists in setting realistic rehabilitation goals and in tailoring treatment plans based on individual deficits. This metric enriches our understanding of AT's biomechanical and functional repercussions for researchers, shedding light on the varying degrees of muscular efficiency and performance impairment caused by the condition.

According to Sapega A. (1990), a deficit of less than 10% in presumably healthy individuals is considered within the normal range; differences of 10 to 20%, as possibly abnormal; and those greater than 20%, as probably abnormal (49). In cases where one extremity is expected to be weaker, a deficit of 10 to 20% is indicative of probably abnormal; and those of more than 20%, as almost certainly abnormal. Given the context of unilateral AT, this seemingly 'normal' range requires careful interpretation. The observed mean WPR-D of 8.00% falls within the normal range, as per Sapega’s criteria, in a presumably healthy population. However, given the known presence of unilateral AT, this finding should be interpreted with caution as the APR-D should be viewed alongside other study findings (PT, PT%BW, PTR), which have indicated patterns of bilateral dysfunction and weakness in the gastrocnemius-soleus muscles in AT patients. Davies G. (1992) and Harbo T. et al. (2012) do not provide specific norms for WPR-D.

## 5.7. Position parameters

The study's findings on position parameters are summarised in Table 4.2.

### 5.7.1. Joint angle at peak torque (degrees) (JAPT)

Our study's focus on the JAPT in unilateral AT patients provides critical insights into the biomechanical aspects of muscle performance in this condition. JAPT signifies the joint angle at which the muscle exhibits its maximum torque (PT), reflecting the optimal functional stance of the muscle.

The symptomatic extremity showed a mean JAPT of 1.81 degrees (SD: ±5.11; Table 4.2), which was notably lower than the asymptomatic extremities mean of 2.24 degrees (SD: ±3.89; Table 4.2). The Wilcoxon signed-rank test revealed a statistically significant difference (p-value: 0.0001; Table 4.2), indicating notable biomechanical alterations in the symptomatic extremity.

According to Sapega A. (1990), the commonly cited criterion of 80 to 90% of the measured capability in the uninvolved extremity can be used as a minimum standard for the involved extremity before the patient returns to sports or strenuous work after injury (49). Our findings show that the mean JAPT on the symptomatic extremity is approximately 80.8% of that on the asymptomatic side. This bilateral difference is 19.2%, which falls within the possibly abnormal range (10 to 20%) for a presumably healthy population and the probably abnormal range (10 to 20%) in cases where a previous injury is expected to result in weaker performance in one extremity. This classification is based on the general percentage guidelines established by Sapega A. (1990) (49). Davies G. (1992) and Harbo T. et al. (2012) do not provide specific norms for JAPT.

For clinicians, the alteration in JAPT in symptomatic extremities suggests a need for a tailored approach in rehabilitation strategies. This could involve specific adjustments in ROM exercises and strengthening programs to accommodate and correct the biomechanical changes. For researchers, the significant variance in JAPT between symptomatic and asymptomatic extremities underscores the complexity of AT's impact, extending beyond strength and power deficits to include fundamental changes in muscle biomechanics.

The reduced JAPT on the symptomatic extremity could be indicative of adaptive or compensatory mechanisms in response to dysfunction or muscle weakness. These biomechanical shifts could manifest in altered gait patterns or an increased risk of further injuries, emphasising the importance of addressing not just muscle strengthening but also the restoration of normal joint kinematics.

These findings emphasise the importance of a multi-faceted treatment approach in AT, considering both the strength- and biomechanical aspects of rehabilitation. The significant difference in JAPT adds a new dimension to our understanding of AT's implications and reinforces the need for targeted rehabilitative interventions.

## 5.8. Time parameters

In our investigation of unilateral AT, the analysis of time parameters provides essential insights into the temporal aspects of muscle function. These insights are pivotal in understanding the responsiveness and dynamic capabilities of the affected muscles. The study's findings on time parameters are summarised in Table 4.2.

### 5.8.1. Time to peak torque (seconds) (TPT)

Time to PT, a significant parameter measuring the duration it takes for a muscle to reach its maximum PT. This metric is pivotal in assessing the responsiveness and functional condition of the muscles, particularly under the influence of unilateral AT.

Both the symptomatic- and asymptomatic extremities demonstrated similar TPT: 0.20 seconds (SD: ±0.13; Table 4.2) for the symptomatic extremity and 0.21 seconds (SD: ±0.11; Table 4.2) for the asymptomatic extremity. The paired t-Test indicated no statistically significant difference (p-value: 0.50; Table 4.2), suggesting similar muscle responsiveness on both extremities. Time to PT values on both extremities indicate that despite the presence of AT, the symptomatic muscle’s ability to generate force quickly remains relatively unaffected.

According to Sapega A. (1990), the commonly cited criterion of 80 to 90% of the measured capability in the uninvolved extremity can be used as a minimum standard for the involved extremity before the patient returns to sports or strenuous work after injury (49). Our findings show that the mean TPT on the symptomatic extremity is approximately 105% of that on the asymptomatic extremity. This bilateral difference is less than 10%, which falls within the normal range according to the general percentage guidelines established by Sapega A. (1990) (49).

While Davies GJ (1992) and Harbo T. et al. (2012) do not provide specific norms for TPT, our results, particularly when considered alongside the PT, PT%BW and PTR findings, suggest a pattern of bilateral dysfunction and weakness in the gastrocnemius-soleus muscles.

For clinicians, the similarity in TPT between symptomatic and asymptomatic sides indicates that unilateral AT does not significantly impact the speed of muscle contraction. This is critical in designing rehabilitation strategies focused on strength and endurance rather than solely on improving contraction speed. For researchers, these findings contribute to the understanding of neuromuscular control in AT, suggesting that the condition's impact might be more related to muscle strength and endurance rather than the quickness of force generation. The analysis of TPT in unilateral AT reinforces the understanding that while AT impacts muscle function, its effect on the speed of force generation is less pronounced.

### 5.8.2. Time peak torque held (seconds) (TPTH)

Time PT held is a parameter that measures the duration for which the muscle can maintain its PT. This metric provides insights into muscular endurance and stability, especially in the context of unilateral AT.

Both symptomatic- and asymptomatic extremities showed comparable durations for maintaining PT: 0.36 seconds (SD: ±0.33; Table 4.2) and 0.34 seconds (SD: ±0.39; Table 4.2), respectively. No statistically significant difference was found (p-value: 0.49; Table 4.2), suggesting similar muscular endurance and stability on both sides. The similarity in TPTH across symptomatic- and asymptomatic extremities can indicate that despite the presence of AT, the affected muscles retain their endurance capabilities.

According to Sapega A. (1990), the commonly cited criterion of 80 to 90% of the measured capability in the uninvolved extremity can be used as a minimum standard for the involved extremity before the patient returns to sports or strenuous work after injury (49). Our findings show that the mean TPTH on the symptomatic extremity is approximately 94.1% of that on the asymptomatic extremity. This bilateral difference is less than 10%, which falls within the normal range according to the general percentage guidelines established by Sapega A. (1990) (49).

While Davies G. (1992) and Harbo T. et al. (2012) do not provide specific norms for TPTH, our results, particularly when considered alongside the PT, PT%BW and PTR findings, suggest a pattern of bilateral dysfunction and weakness in the gastrocnemius-soleus muscles.

For clinicians, the findings imply that unilateral AT does not significantly impact the muscle’s ability to sustain PT, a crucial factor for rehabilitation focusing on muscular endurance and stability. For researchers, this result adds to the body of knowledge on AT, emphasising the

need to consider factors beyond muscle strength and power, like endurance in force maintenance.

The study's findings on TPTH in unilateral AT patients provide crucial insights into the muscles' ability to sustain PT. The similar TPTH on both symptomatic- and asymptomatic extremities suggests that AT's impact does not extend significantly to altering the muscles' endurance or the time they can maintain maximum force. The study underscores the importance of considering various aspects of muscle performance in managing and researching AT, focusing not only on strength and endurance -deficits but also on the ability to maintain PT.

### 5.8.3. Force decay time (seconds) (FDT)

Force decay time, a parameter that measures the duration it takes for the force to decrease from its peak to a designated lower threshold. This metric is vital for understanding the rate at which muscles can relax after exertion and is particularly relevant in the context of unilateral AT. Force decay time is an important measure for understanding the ability of muscles to sustain force over time, reflecting aspects of muscle endurance and fatigue resistance.

The symptomatic extremities showed a slightly quicker force decay 0.25 seconds (SD: ±0.09; Table 4.2) compared to the asymptomatic extremities 0.28 seconds (SD: ±0.15; Table 4.2). No significant difference was observed (p-value: 0.37; Table 4.2), suggesting comparable muscle endurance and fatigue resistance rates between both sides.

According to Sapega A. (1990), the commonly cited criterion of 80 to 90% of the measured capability in the uninvolved extremity can be used as a minimum standard for the involved extremity before the patient returns to sports or strenuous work after injury (49). Our findings show that the mean FDT on the symptomatic extremity is approximately 89% of that on the asymptomatic extremity. This bilateral difference is 11%, which falls within the possibly abnormal range (10 to 20%) for a presumably healthy population and the probably abnormal range (10 to 20%) in cases where a previous injury is expected to result in weaker performance in one extremity. This classification is based on the general percentage guidelines established by Sapega A. (1990) (49).

While Davies G. (1992) and Harbo T. et al. (2012) do not provide specific norms for FDT, our results, particularly when considered alongside the PT, PT%BW and PTR findings, suggest a pattern of bilateral dysfunction and weakness in the gastrocnemius-soleus muscles.

Despite the presence of AT, our findings suggest that the affected muscles retain a substantial portion of their recovery capabilities, as indicated by the similar FDT between symptomatic and asymptomatic extremities.

Understanding FDT is crucial in rehabilitating AT patients, as it offers insights into muscle endurance and fatigue resistance, aiding in designing effective rehabilitation strategies. Our study's examination of FDT adds to the growing body of knowledge on AT, emphasising the condition's multifaceted impact on muscle function. It highlights the need for comprehensive assessments and targeted rehabilitation strategies that consider all dimensions of muscle performance affected by AT.

## 5.9. Summary

Isokinetic dynamometry is a widely used assessment method in various healthcare settings, particularly in outpatient orthopaedic clinics. This technique has proven effective in evaluating a significant proportion of orthopaedic injuries and dysfunctions, including those involving the Achilles tendon and the gastrocnemius-soleus muscles (81). Literature indicates a strong association between Achilles tendon injuries and reduced plantar flexor power, with deficits often present prior to injury (26). Altered function of the gastrocnemius-soleus muscles has been identified as a primary modifiable risk factor for AT with a reported relationship between symptoms and weakness in this muscle group (19) (26).

Given this context, isokinetic dynamometry has been established as a reliable tool for measuring the torque of the plantar flexors, making it a valuable outcome measure for clinical trials (45). This approach is particularly useful for quantifying muscle strength and identifying functional deficits associated with AT, utilising the principles of isokinetic dynamometry testing. Despite the established relationship between plantar flexor strength and Achilles tendon injuries, many clinicians and researchers neglect to assess plantar flexor strength. This oversight is often due to the cumbersome, stationary, and expensive nature of an isokinetic dynamometer, which is regarded as the "Gold Standard" in strength assessment (25) (26).

Furthermore, data interpretation is a crucial element in assessing, testing, designing, or modifying rehabilitative protocols. The information derived from isokinetic dynamometry testing, including parameters of torque, position, and time, provides valuable insights into an participants muscular performance and functional capabilities.

When interpreting isokinetic dynamometry data, the contralateral extremity is commonly used as a reference for assessing muscular function, particularly in cases of unilateral pathology or injury (49) (71). In isokinetic dynamometry evaluation reports, the term "deficit" refers to an index of proportionality representing the difference between the joints bilaterally as a percentage (59). Sapega's guidelines categorise bilateral strength deficits for orthopaedic practice into three ranges: less than 10% as normal, 10 to 20% as possibly abnormal, and greater than 20% as probably abnormal in a presumably healthy population (49) (107).

In cases where a previous injury is anticipated to result in weaker performance in one extremity, deficits up to 10% are considered normal, deficits between 10 to 20% as probably abnormal, and deficits greater than 20% as almost certainly abnormal. Prior research suggests that differences in absolute PT between sides can potentially serve as predictors for future injuries, indicating that athletes are more prone to injuries when there exists a disparity of 10% or greater in strength bilaterally (79) (80). A discrepancy of 10 to 15% in PT values is typically considered indicative of significant asymmetry, with a greater deficit suggesting a muscle imbalance that might predispose the individual to potential muscle-related injuries, such as strains and tendinitis (61) (71) (77).

However, it is important to note that there are few studies that have measured additional parameters of quantifying plantar flexion strength from an isokinetic dynamometry evaluation report in paarticipants with unilateral AT. In this study, nine isokinetic dynamometry parameters were evaluated bilaterally, all of which fell within the normal range according to established percentage guidelines, indicating no significant asymmetry (less than 15%) and not reaching the conventional threshold of statistical significance (p-value: $< 0.05$). However, an exception was noted for FDT and JAPT. Force decay time exhibited a bilateral difference of 11%, but this was not statistically significant (p-value: 0.37; Table 4.2). In contrast, the JAPT demonstrated a statistically significant (p-value: 0.0001; Table 4.2) bilateral difference of 19.2%. These bilateral differences places FDT and JAPT within the possibly abnormal range (10 to 20%) for a healthy population and the probably abnormal range (10 to 20%) in cases where a prior injury is expected to weaken one extremity, according to general percentage guidelines. Consequently, the JAPT may indicate significant asymmetry (greater than or equal to 15%), suggesting a potential imbalance that could predispose participants to muscle-related injuries.

It is noteworthy that most studies examining plantar flexor strength deficits by means of isokinetic dynamometry, define muscle weakness in terms of PT only- limiting the

exploration of other parameters, such as JAPT (19) (24) (94) (95) (96) (98) (99) (100) (101) (104). Peak torque is widely recognised as the most representative and frequently reported parameter of muscle performance in the literature on isokinetic dynamometry (19) (24) (94) (95) (96) (98) (99) (100) (101) (104). Researchers have utilised isokinetic dynamometry to identify PT deficits in the plantar flexor muscles between symptomatic- and asymptomatic extremities, thereby illuminating specific muscular weaknesses associated with AT (94). Two meta-analyses conducted by Hasani F. et al. (2021) and McAuliffe S. et al. (2019) concluded that deficits in plantar flexor strength are significantly correlated with AT, whether assessed within participants (symptomatic- vs. asymptomatic extremities) or in comparison with healthy controls (95) (24).

In our study, we observed a mean PT deficit (PT-D) of 4.52% (SD: ±17.16; Table 4.2) across participants, which falls within the normal range according to established guidelines, indicating no significant asymmetry (less than 15%). This finding contrasts with the conclusions of Hasani F. et al. (2021) and McAuliffe S. et al. (2019), who reported that deficits in plantar flexor strength are associated with AT when assessed within participants (symptomatic- vs. asymptomatic extremities) (95) (24). However, our findings support the conclusion that deficits in plantar flexor strength are significant when compared to normative values from healthy controls.

According to Davies G. (1992), the average isokinetic PT values for ankle plantar flexion at an angular velocity of 60 degrees per second are 83 foot-pounds (SD: ±13) for females and 107 foot-pounds (SD: ±18) for males in a presumably healthy athletic population (n=25; Table 2.1) (72). In contrast, the average PT values for a presumably healthy sedentary population (n=30; Table 2.1) at the same angular velocity are significantly lower, measuring 47 foot-pounds (SD: ±10) for females and 71 foot-pounds (SD: ±16) for males (72).

To further validate our findings, we compared our PT data with the findings from "Maximal isokinetic and isometric muscle strength of major muscle groups related to age, body mass, height, and sex in 178 healthy subjects" by Harbo T. et al. (2012) (73). Normative isokinetic data from their study for ankle plantar flexion and dorsi flexion PT at 60 degrees per second by age and gender (n=77 females; n=77 males; Table 2.2) are 56.73 foot-pounds (SD: ±9.58) for females and 88.51 foot-pounds (SD: ±14.03) for males in the age group 50-59 years.

Our study comprised 21 participants (n=21), with a gender distribution of 14.29% females (n=3) and 85.71% males (n=18). The mean age of the female participants was 47.33 years

(SD: ±16.26), whereas the male participants had a mean age of 54.06 years (SD: ±12.51). Overall, the participants' ages ranged from 29 to 84 years, with a mean age of 53.1 years (SD: ±12.86; Table 4.0 and Table 5.0) and a median age of 53 years.

Our results showed that the mean PT for the symptomatic extremity was 38.81 foot-pounds (SD: ±10.97; Table 4.2), while the mean for the asymptomatic extremity was 40.91 foot-pounds (SD: ±10.97; Table 4.2). Both values are considerably lower than the normative values from Davies G. (1992) and Harbo T. et al. (2012) compared to healthy controls, indicating bilateral dysfunction and weakness in the gastrocnemius-soleus muscles within our sample population. The observed dysfunction and weakness in the symptomatic extremity (with AT) within our sample population aligns with existing literature on deficits in plantar flexor PT in participants with AT compared to healthy controls. O'Neil S. (2019) found that participants with AT exhibited statistically significant weakness (p-value: $< 0.001$), with substantial deficits in plantar flexor PT compared to healthy controls assessed through isokinetic dynamometry (94). Similarly, Sancho I. et al. (2022) reported that runners with AT demonstrated lower plantar flexion PT compared to their healthy counterparts (96).

These findings have significant clinical implications. The clinical relevance of our study on unilateral AT, which revealed bilateral plantar flexor PT deficits compared to healthy controls, aligns with the findings of O'Neil (2019) (94). These findings indicate that clinicians should not use the asymptomatic extremity in participants with unilateral AT as a comparator when assessing strength with isokinetic dynamometry. In clinical practice, the contralateral extremity is often used as a reference for evaluating muscular function, particularly in cases of unilateral pathology or injury (49) (71). However, our results suggest that this approach of isokinetic dynamometry interpretation may not provide an accurate assessment. Instead, normative values need to be considered in participants diagnosed with AT, and how these strength deficits relate to healthy controls as rehabilitation targets. The lack of significant difference in PT-D, 4.52% (SD: ±17.16; Table 4.2), and PT (p-value: 0.24; Table 4.2), between symptomatic- and asymptomatic extremities suggests that clinicians should not aim to rehabilitate PT to that of the asymptomatic extremity, as both extremities do not appear to have normal power when compared to normative data.

Therefore, bilateral comparison, often used as a reference for evaluation, should not be relied upon in isolation for interpreting isokinetic dynamometry results due to its limitations.

Normative data specific to populations can significantly enhance the interpretation of isokinetic dynamometry results when applied correctly. However, the use of such data

remains controversial, as it must be tailored to the specific population being studied (61). This tailoring enables researchers to establish benchmarks for assessing dysfunction and weakness in parameters such as PT, PTR, and PT normalised to body weight (PT%BW). Nonetheless, while normative data can provide valuable insights, certain limitations exist that must be acknowledged. Factors such as age, gender, activity level, and anthropometric characteristics significantly influence muscular strength, necessitating the development of population-specific norms (61). Moreover, variations in testing protocols, equipment, and data analysis methods across studies can complicate the comparison and interpretation of normative data (79). Thus, careful consideration of these factors is essential for accurate data interpretation.

In our study, we included male and female participants diagnosed with unilateral AT, aged 18 years or older, who were either physically active or sedentary. These participants were evaluated in ankle plantar flexion and dorsi flexion using isokinetic dynamometry at an angular velocity of 60 degrees per second, with the knee in an extended position bilaterally. To ensure the relevance of our findings, we aimed to compare our results with normative data from isokinetic dynamometry evaluations conducted at the same angular velocity and knee position, thereby aligning closely with our methodology.

To address population-specific factors, we included and compared our results to normative data from presumably healthy populations, considering variables such as gender, activity level, age, and both high and low values for the relevant parameters where normative data is available. This comprehensive approach enhances the robustness of our findings and their applicability to clinical practice. For instance, PT to body weight is expressed as a percentage of the PT production in relation to the subject's body weight, serving as a valuable indicator of general joint integrity (59) (71). Abnormalities may include conditions such as overuse, recurring injuries, or compromised proprioception resulting from the repetitive execution of constrained movements within the joint's range of mobility (80). Normalising PT to body weight is essential for clinical applications and research, as it allows data to be individualised (61) (83). Thus, this normalisation helps differentiate between normal force values and those required based on a participants weight, which is crucial for comparing athletes or populations. Objective and quantifiable data, such as PT%BW collected during testing, can serve as a baseline during preseason screening or as comparative data to evaluate the efficacy of various training regimens. Isokinetic dynamometry testing during preseason screening can identify specific muscle weaknesses that may predispose athletes to injuries (61).

Comparing PT%BW against established normative data for different age groups and activity levels facilitates the development of tailored strength and conditioning programs. These programs aim to restore normal muscle balance, strength, and endurance, thereby reducing the risk of injuries and enhancing athletic performance (61).

In our study, the mean PT%BW on the symptomatic extremity was 22.43% (SD: ±7.00; Table 4.2). In contrast, the mean PT%BW for the asymptomatic extremity was slightly higher at 23.57% (SD: ±7.17, Table 4.2). When compared bilaterally, this deficit is less than 5%, which falls within the normal range according to established guidelines, indicating no significant asymmetry (less than 15%). This finding highlights the limitations of interpreting isokinetic dynamometry results using the contralateral limb as a reference. Therefore, there is a need for an additional dimension of interpretation, such as the inclusion of normative data.

According to Davies G. (1992), the average PT%BWW in isokinetic dynamometry ankle plantar flexion at an angular velocity of 60 degrees per second with the knee in extension are 60% for females and 65% for males (n=25; Table 2.0) (72). Comparatively, Harbo T. et al. (2012) reported PT%BW values in isokinetic dynaometry ankle plantar flexion at an angular velocity of 60 degrees per second ranging from 41 to 68% for females and 41 to 57% for males in participants aged 50 to 59 years at the same angular velocity (Table 2.3) (73).

Our participants, with a mean age of 53.1 years (SD: ±12.86; Table 4.0 and Table 5.0), exhibited significantly lower PT%BW values compared to the normative values reported by Davies G. (1992) and Harbo T. et al. (2012) for healthy controls. This was evident in both the symptomatic- and asymptomatic extremities, indicating bilateral dysfunction and weakness in the gastrocnemius-soleus muscles. This deviation from normative values is noteworthy and indicative of broader muscular impairment in patients with unilateral AT. Such impairment increases their risk of injury and predisposes them to further complications.

Altered function of the plantar flexor muscles has been identified as a primary modifiable risk factor for AT (19). Therefore, this finding suggests that muscle strengthening may serve as an important preventative measure and is relevant to current therapeutic management strategies. A systematic review and meta-analysis further supports this notion, demonstrating that strength training has a highly significant protective effect, with a relative risk reduction (RR) of 0.315 (0.207-0.0480); potentially decreasing the incidence of overuse injuries in the lower extremities by nearly 50%, and acute injuries by 33% (110).

The standard of care for AT includes evidence-based progression in tendon loading exercises, which are fundamental to the management of this condition (111) (112) (105). Numerous exercise interventions have been reported specifically for AT, and these can be broadly categorised into six main approaches (105):

1. Heavy-load eccentric calf muscle training (HECT), also known as the Alfredson eccentric protocol (113)
2. Modified HECT, a low-volume version of the original protocol (114)
3. Concentric training (115)
4. Eccentric overload training, also referred to as the Silbernagel protocol (116)
5. Heavy slow resistance training (HSR) (117)
6. The 'Stanish protocol' (118)

These interventions vary in their specific parameters, such as the type of muscle contraction (eccentric, concentric, or a combination), the load and velocity of contractions, and the overall training volume. However, they all aim to address the underlying pathophysiology of AT (discussed in section 2.1) and promote tendon adaptation through targeted exercise and load management.

The effectiveness of these interventions has been investigated in various studies, with some protocols demonstrating clinically significant outcomes in terms of pain reduction and functional improvement (112) (105). For example, Alfredson H. et al. (1998) reported that a 12-week HECT intervention significantly decreased pain during activity (p-value: $< 0.001$) and led to significant increases in both concentric (p-value: $< 0.05$) and eccentric (p-value: $< 0.01$) plantar flexion PT in participants diagnosed with Achilles tendinosis (degenerative changes) from baseline to 12 weeks (113). Similarly, a study by Beyer R. et al. (2015) found that both traditional eccentric training and HSR training produced positive clinical outcomes for participants with AT in both the short- and long-term (117). Notably, there was a significant improvement in physical activity and pain during sporting activities (p-value: $< 0.0001$), along with a significant reduction in tendon antero-posterior thickness (p-value: $< 0.0001$) and tendon neovascularization as measured by colour Doppler (p-value: $< 0.005$) in both groups from baseline to 12 weeks.

Despite these promising findings, further research is needed to establish the optimal exercise parameters and to determine the most effective approach for individual participants based on their specific characteristics and preferences. Therefore, factors such as the

severity of tendinopathy, the patient's age, activity level, and comorbidities should be considered when selecting the most appropriate exercise intervention.

This study provides an understanding of the impact of unilateral AT on muscle functionality as evaluated by isokinetic dynamometry across various parameters of torque, position and time. Key findings reveal bilateral dysfunction and weakness in the gastrocnemius-soleus muscles in individuals with unilateral AT, affecting both the symptomatic- and asymptomatic extremities. This was evidenced through a comparative analysis of PT, PT%BW, and PTR parameters against established norms, offering a valuable reference for interpreting the results.

The data-driven approach enhances clinical decision-making by enabling more accurate baseline assessments. For clinicians, the findings highlight the importance of incorporating isokinetic dynamometry testing in the evaluation of AT to identify discrepancies in bilateral strength and compare parameters against normative data. When asymmetries, weaknesses, and dysfunctions are identified, implementing a rehabilitative program specifically designed to address these discrepancies through strength training could improve patient outcomes and reduce the risk of injury. Detailed analyses of torque, position, and time parameters help tailor rehabilitation protocols to individual needs. For instance, JAPT and differences in work and power output between extremities can guide specific exercises aimed at correcting biomechanical imbalances and enhancing functional performance. Individualising rehabilitation programs based on these parameters ensures targeted interventions.

Regular isokinetic dynamometry testing allows for continuous monitoring of a participants progress throughout the rehabilitation process. By comparing current performance with baseline measurements, clinicians can assess the effectiveness of interventions and make necessary adjustments. One critical application of isokinetic dynamometry is determining a participants readiness to return to sports or daily activities. By quantifying muscle strength and endurance, clinicians can evaluate whether the participant has regained sufficient functional capacity and muscle balance. Ratios of PTR and PT%BW are particularly useful in assessing whether the patient has achieved the necessary strength to reduce the risk of re-injury.

Educating patients about their muscle function and imbalances can motivate them to adhere to their rehabilitation program. Discussing the isokinetic dynamometry evaluation results with patients in an understandable format, highlighting their progress and areas needing improvement, can enhance their commitment to the prescribed rehabilitation program.

Furthermore, this research paves the way for future investigations to explore a broader range of isokinetic dynamometry parameters in understanding and managing AT.

# CHAPTER 6: CONCLUSION

The study on unilateral AT and its impact on isokinetic dynamometry parameters has yielded several critical insights, reinforced by both the strengths and limitations identified in the research.

The findings emphasise the essential role of isokinetic dynamometry in assessing muscle function and strength, particularly in relation to AT. While traditional methods like MMT offer limited precision, isokinetic dynamometry provides a detailed quantification of muscle performance, essential for treatment orientation. The study revealed that bilateral differences in PT and other torque and time parameters did not indicate significant asymmetry (greater than or equal to 15%)—a potential imbalance that could predispose participants to muscle-related injuries—except in the case of JAPT. Time parameters such as TPT and TPTH were similar in both extremities, indicating that AT may not significantly affect the speed of muscle contraction or endurance in maintaining PT. Although APR suggested a slight trend toward reduced energy output in symptomatic extremities, it did not reach the conventional threshold of statistical significance.

Despite the importance of identifying such discrepancies, the study notes that using the contralateral extremity as a reference for strength comparisons in unilateral AT may be misleading. The observed deficits in PT, PT%BW, and PTR in both symptomatic- and asymptomatic extremities compared to normative data highlight that strength impairments extend beyond the symptomatic extremity, indicating bilateral muscle dysfunction and weakness. This challenges the common practice of using the asymptomatic extremity as a benchmark, particularly in cases of unilateral pathology or injury, and emphasises the need to integrate normative values for more accurate assessments, interpretation and effective rehabilitation interventions.

The study's results advocate for a more nuanced approach in interpreting isokinetic dynamometry data. While normative data is valuable, the variability due to age, gender, activity levels and angular velocity testing speed must be accounted for to ensure accurate comparisons. Clinicians should be cautious when using bilateral comparisons in isolation for interpreting isokinetic dynamometry results due to their limitations and should consider population-specific norms to tailor rehabilitation interventions effectively. The evidence points to the necessity of incorporating detailed isokinetic dynaometry testing in the clinical evaluation and management of AT, focusing on correcting identified muscle imbalances through targeted strength training. Regular monitoring and a personalised approach to

rehabilitation, supported by isokinetic dynamometry data, could improve patient outcomes and potentially reduce the risk of re-injury.

This study presents several notable strengths in its methodology and approach that have contributed to these findings. A key strength lies in the focused research objective, which effectively addresses a specific gap in the existing literature by expanding the analysis of isokinetic dynamometry parameters beyond PT. By incorporating additional relevant metrics, such as positional parameters and time measures, the study provides a more comprehensive understanding of muscle performance in participants with unilateral AT.

Moreover, the use of standardised protocols for isokinetic dynamometry significantly enhances the reliability and validity of the results. The adoption of a recognised testing system, the Humac Norm Cybex Testing and Rehabilitation System, further lends credibility to the findings. The application of appropriate statistical analyses, including paired t-Tests and Wilcoxon tests, enabled a robust examination of the differences between symptomatic- and asymptomatic extremities, offering valuable insights into the bilateral impact of unilateral AT. The inclusion of both male and female participants contributes to a broader understanding of the gender-specific effects of AT, despite the male predominance within the sample.

However, certain limitations must be acknowledged when interpreting the study’s results, which impact the generalisability and applicability of the findings. The relatively small sample size (n=21) may restrict the generalisability of the findings; a larger cohort could yield more robust data and potentially uncover additional insights. Additionally, the study’s strict exclusion criteria, which required evaluations at an angular velocity of 60 degrees per second, may have resulted in the omission of relevant data from participants tested at other velocities. This restriction could limit the applicability of the findings, as it does not consider potential variations in muscle performance that might occur at different angular velocities.

Furthermore, the significant skew towards male participants (n=18 males; n=3 females) may limit the applicability of the findings to the female population. Although this gender distribution aligns with the typical incidence of AT, which is more prevalent in males, the small number of female participants restricts the ability to make direct comparisons between genders. Additionally, the retrospective design of the study introduces potential biases related to data quality and completeness, which could impact the study's conclusions.

An additional limitation arises from the unavailability of detailed medical histories and the specific time frame from the initial diagnosis of AT to the initial isokinetic dynamometry evaluation. Due to confidentiality agreements, the researcher did not have access to participants medical files, which included comprehensive medical records and dates of diagnosis. Consequently, the types of treatments participants underwent before their initial biokinetic assessment are unknown, as the isokinetic dynamometry evaluation reports did not include these details. This lack of information regarding initial treatments and the duration since injury introduces an element of uncertainty regarding the context in which the participants muscle performance was evaluated. While all participants had a primary diagnosis of unilateral AT confirmed by an experienced physiotherapist, sports physician, or other healthcare providers through clinical history, physical examination, and/or diagnostic investigations, the absence of data on secondary injuries further limits the ability to fully understand the broader clinical scenario.

An important aspect of the research methodology was the flexibility applied to the COV during isokinetic dynamometry data collection. While the Biodex data manual recommends a COV of less than or equal to 15% for large muscle groups and less than or equal to 20% for smaller muscle groups such as the ankle joint, this study permitted a higher variance. This decision recognises that participants with AT might experience pain that prevents them from consistently achieving maximal repetitions within the recommended variation limits. By allowing for a higher COV, the study acknowledges the challenges faced by participants with AT and clinicians, thereby enhancing the applicability of its findings to real-world clinical scenarios where optimal performance may not always be achievable due to the condition.

However, the decision to permit a higher COV also introduces limitations that could affect the precision of the study's conclusions. While accommodating pain-related inconsistencies is crucial, accepting a higher variance may compromise the reliability of the data, as performance variations could obscure meaningful differences between symptomatic- and asymptomatic extremities. Additionally, relying on previously established guidelines without strict adherence could raise questions regarding the validity of the findings. The potential for increased variability in the data might also limit the generalisability of the results, as it may not accurately reflect typical performance metrics for the studied population.

Given these strengths and limitations, future research should aim to validate these findings with larger, more diverse cohorts and explore a broader range of isokinetic dynamometry parameters in AT. Comparative studies investigating isokinetic dynamometry parameters across different populations with AT could provide valuable insights into the condition's

varied impacts. Additionally, there is a need for evaluating various treatment approaches for AT, using isokinetic dynamometry as an objective measure to assess outcomes. Such research could significantly contribute to optimising rehabilitation protocols and improving patient outcomes in AT.

Despite these limitations, this research report makes a valuable contribution to understanding unilateral AT through various isokinetic dynamometry parameters. By critically examining both its strengths and limitations, the study provides a foundation for informing future research and clinical practices aimed at improving outcomes for participants diagnosed with AT. Continued research with a larger cohort is necessary to further understand isokinetic dynamometry parameters in AT and to validate these conclusions.

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# APPENDICES

## Appendix 1: Ethical clearance

| UNIVERSITY OF THE WITWATERSRAND JOHANNESBURG | HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL) |
|---|---|

**Office of the Deputy Vice-Chancellor (Research and Innovation)**

**TO:** Mr R Lloyd
School of Therapeutic Sciences
Department of Exercise Science & Sports Medicine
Medical School
University

E-mail: rohanlloyd88@gmail.com

**CC:** Supervisor: Professors D Constantinou and P Gradidge
<Demitri.Constantinou@wits.ac.za>
and <HREC-Medical Research Office@wits.ac.za>

**FROM:** Mr Iain Burns
Human Research Ethics Committee (Medical)
Tel: 011 717 1252

E-mail: Iain.Burns@wits.ac.za

**DATE:** 2023/10/25

**REF:** R14/49

**PROTOCOL NO:** **M230978** (This is your ethics application reference number. Please quote it in all enquiries, oral or written, relating to this study.)

**PROJECT TITLE:** *A retrospective study of isokinetic dynamometry parameters in patients diagnosed with unilateral Achilles tendinopathy*

Please find attached the Clearance Certificate for the above project. I hope it goes well and that an article in a recognized publication comes out of it. This will reflect well on your professional standing and contribute to Government funding of the University.

MSWorks2000/Iain0007/Clearscan.wps

UNIVERSITY OF THE WITWATERSRAND JOHANNESBURG

R49 Mr R Lloyd

# HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)
## CLEARANCE CERTIFICATE NO. M230978

**NAME:** Mr R Lloyd **DEGREE:** MSc
**(Principal and Co-Investigators)**

**DEPARTMENT:** School of Therapeutic Sciences
Department of Exercise Science & Sports Medicine
Medical School
University

**PROJECT TITLE:** *A retrospective study of isokinetic dynamometry parameters in patients diagnosed with unilateral Achilles tendinopathy*

**DATE CONSIDERED:** Ad hoc

**DECISION:** Approved unconditionally

**CONDITIONS:**

**NOTE:** If contact information regarding student study participants is required, please contact the Registrar's office - <Nicoleen.Potgieter@wits.ac.za>

**SUPERVISOR:** Professors D Constantinou and P Gradidge

**APPROVED BY:** Professor P Ruff, Chairperson, HREC (Medical)

**DATE OF APPROVAL:** 2023/10/25 **EXPIRY DATE:** 2028/10/24

**This Clearance Certificate is valid for 5 years from the date of approval. An extension may be applied for.**

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**DECLARATION OF INVESTIGATORS**

To be completed in duplicate and **ONE COPY** returned to the Research Office secretariat on the 3rd floor, Phillip Tobias Building, Parktown, University of the Witwatersrand, Johannesburg.

I/we fully understand the conditions under which I am/we are authorized to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated from the research protocol as approved, I/we undertake to submit details to the Committee. **I agree to submit a yearly progress report**. When a funder requires annual re-certification, the application date will be one year after the date when the study was initially reviewed. In this case, the study was initially reviewed in **September** and therefore reports and re-certification will be due in the month of **September** each year. Unreported changes to the study may invalidate the clearance given by the HREC (Medical).

Signature of Principal Investigator Date

## Appendix 2: Permission from Jannie Klingbiel

I, Jan Frederik Gerhardt Klingbiel am the gatekeeper of the data required for LLOYD, Rohan Mr, Student number: 482942, research report titled:

**A RETROSPECTIVE STUDY OF ISOKINETIC DYNAMOMETRY PARAMETERS IN PATIENTS DIAGNOSED WITH UNILATERAL ACHILLES TENDINOPATHY**

I grant permission to use the isokinetic dynamometry reports (ankle plantar- and dorsi flexion) from Jannie Klingbiel Biokineticists for research purposes. The information will be treated ethically with respect to confidentiality and no details that can identify patients will be used (e.g. names). Data will be collected from 2015.01.01 until 2022.12.31.

Date: 06/07/2023

Signature:

**Appendix 3: Table 5.0: Comparative demographic and physical characteristics in isokinetic dynamometry studies on Achilles tendinopathy**

**Table 5.0: Comparative demographic and physical characteristics in isokinetic dynamometry studies on Achilles tendinopathy**

| Study Reference | Sample Size (n) | Gender (M/F) | Age (years) | Height (cm) | Weight (kg) | BMI (kg/m²) |
|---|---|---|---|---|---|---|
| Lloyd R. et al., (2024) | 21 | 18 / 3 | 53.1 ± 12.86 [29-84] | 175 ± 10.2 [140-188] | 81.2 ± 17 [59-135] | 26.43 ± 6.00 [19-45] |
| O'Neill S. et al., (2019) (101) | 16 | 11 / 5 | 48.6 ± 8.9 [-] | 173.4 ± 9.1 [-] | 81.6 ± 14.3 [-] | 27 ± 2.7 [-] |
| O'Neill S. et al., (2019) (94) | 39 | 34 / 5 | 47 ± 11.8 [-] | 177 ± 6.8 [-] | 77 ± 12.1 [-] | N/R |
| Horstmann T. et al., (2013) (98) - Group 1 | 23 | 13 / 10 | 46.0 ± 6.9 [32-55] | 175.1 ± 9.0 [162-195] | 79.2 ± 16.5 [50-111] | 25.6 ± 3.7 [18.6-32.1] |
| Horstmann T. et al., (2013) (98) - Group 2 | 19 | 10 / 9 | 45.7 ± 8.5 [25-55] | 173.3 ± 8.9 [160-191] | 74.5 ± 10.3 [62-107] | 24.8 ± 2.7 [20.8-29.4] |
| Horstmann T. et al., (2013) (98) - Group 3 | 16 | 9 / 7 | 44.4 ± 7.7 [27-53] | 175.8 ± 7.4 [162-184] | 79.6 ± 15.9 [58-110] | 25.7 ± 4.3 [20.3-33.8] |

**M:** Male
**F:** Female
**SD:** Standard deviation
**Mean ± SD [Range]**

**Appendix 4: Turnitin report**

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A RETROSPECTIVE STUDY OF ISOKINETIC DYNAMOMETRY PARAMETERS IN PATIENTS DIAGNOSED WITH UNILATERAL ACHILLES TENDINOPATHY

Rohan Lloyd
Student number: 482942

A research report submitted to the Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of MSc (Med) in the field of Biokinetics

Supervisor: Professor Philippe Gradidge and Professor Dervin Constantinou

Johannesburg, 2024

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