

# Changes in tibial nerve stiffness during ankle dorsiflexion according to in-vivo analysis with shear wave elastography

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## Abstract

A more detailed assessment of pathological changes in the tibial nerve (TN) is needed to better assess how physical therapy influences TN pathologies. The cross-sectional nerve area can be used for TN assessment but may be influenced by individual differences in parameters, such as body height, body weight, and foot length. Therefore, there are no known reliable noninvasive quantitative methods for assessing TN neuropathy. Although recent ultrasonographic studies reported that TN stiffness changes could be used to assess TN neuropathies of the foot, these studies did not consider the joint position, and peripheral nerve tension can change with joint movement. Therefore, we considered that TN stiffness assessment could be improved by analyzing the relationship between ankle joint position and TN stiffness. This study aimed to investigate the relationship between TN stiffness and ankle angle changes using shear wave elastography. We hypothesized that the TN shear wave velocity significantly increases with ankle dorsiflexion and that the total ankle range or maximum dorsiflexion range correlates with the shear wave velocity.

This cross-sectional study included 20 TNs of 20 healthy adults. Ultrasonography and shear wave elastography were used to evaluate the TN. TN stiffness was measured at 5 ankle positions as follows: maximum dorsiflexion (100% df), plantar flexion in the resting position (0% df), and 3 intermediate points (25% df, 50% df, and 75% df).

TN shear wave velocity increased with an increase in ankle df angle. While total ankle range was significantly and negatively correlated with TN stiffness in all ankle positions, the maximum ankle df angle was significantly and negatively correlated only at 75% and 100% df.

TN stiffness below 50% df may be affected by gliding or decreased nerve loosening, and TN stiffness above 75% df may be influenced by nerve tensioning. When measuring TN stiffness for diagnostic purposes, TN should be assessed at an ankle joint angle below 50% df.

**Abbreviations:** df = dorsiflexion, ICC = intraclass correlation coefficient, MDC<sub>95</sub> = minimal detectable change with a confidence level of 95%, TN = tibial nerve.

**Keywords:** ankle joint, range of motion, peripheral nervous system diseases

## 1. Introduction

The foot is a common symptomatic site of peripheral nerve disorders, such as tarsal tunnel syndrome and diabetic neuropathy. Physical therapy has been shown to have positive effects on peripheral neuropathy in other musculoskeletal regions.<sup>[1-4]</sup> However, it remains unclear how physical therapy influences the pathology of the tibial nerve (TN), and a more detailed assessment of pathological TN changes is needed. Nerve conduction velocity is one of the parameters widely used to assess pathologies such as TN entrapment neuropathy or diabetic

neuropathy<sup>[5,6]</sup>; however, this method is painful and difficult for comprehensive assessment within a short timeframe. The cross-sectional area of the TN<sup>[7]</sup> is helpful for TN assessment; however, individual differences in body height, body weight, and foot length may influence the outcome. Therefore, better noninvasive quantitative methods for the assessment of TN neuropathy are needed.

Although recently, several ultrasonographic studies reported that stiffness changes in the TN<sup>[8,9]</sup> can be used to assess TN neuropathy of the foot, these studies analyzing TN tension did not consider the influence of the joint position, and it has been

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shown that the tension of peripheral nerves can change with joint movement.<sup>[10]</sup> Therefore, we considered that TN stiffness assessments might be established by clarifying the relationship between the ankle joint position and TN stiffness.

This study aimed to investigate the relationship between TN stiffness measured using shear wave elastography and changes in ankle angle. We hypothesized that the TN shear wave velocity significantly increases with ankle dorsiflexion and that the total ankle range or maximum dorsiflexion range correlates with TN shear wave velocity.

## 2. Methods

### 2.1. Study design and data collection

This research was designed as a cross-sectional study. Data were collected in the laboratory of Morinomiya University from January to May 2021. A physical therapy student with 6 months of experience using ultrasonography collected and managed the data. Moreover, participants' data were obtained through face-to-face interviews.

Ethics approval was granted by the University Ethics Committee (Authorization No. 2019-123). Informed consent was obtained from all participants prior to testing, and this study was conducted in accordance with the Declaration of Helsinki.

### 2.2. Participants and eligibility criteria

The sample size was determined using G\* Power 3 Software, version 3.1.9.4 (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany) and the F test for 1-way ANOVA (power 0.95, effect size 0.25). Twenty participants were deemed adequate.

The study population comprised students from the Morinomiya university of medical sciences. We included 23 right ankles of 23 healthy adults (age: 21 to 39 years) in this observational study. History of orthopedic or neurological disease of the lower limbs or the trunk was considered a criterion for exclusion. 3 patients were excluded from the study because their TN was too stiff to be measured using shear wave elastography. Therefore, 20 ankles of 20 healthy adults were included in the analysis (14 men, 6 women; mean age: 23.8 ± 5.5 years; height: 168.7 ± 10.5 cm; weight: 63.2 ± 11.7 kg).

### 2.3. Primary outcome measures

The ankle range of motion (maximum dorsiflexion and plantar flexion in the resting position) and TN stiffness at 5 ankle positions were defined as outcome measures.

**2.3.1. Measurement of the ankle range of motion** The maximum dorsiflexion (100% df) was measured passively on a Biodex 3 isokinetic dynamometer (Biodex Medical System Inc, NY). The plantar flexion in the resting position (0% df) was measured using a goniometer in the prone position with both feet dropped from the bed edge and relaxed.

**2.3.2. Measurement of TN stiffness** The stiffness of the TN was assessed using a Canon Aplio300 10-MHz linear probe (PLT-1005BT; Canon Co., Ltd., Tokyo, Japan). The TN was identified using the posterior tibial artery as a landmark during a transverse scan 1 cm superior to the medial malleolus in B mode. A similar methodology was previously used by Carroll et al<sup>[8,11]</sup> (Fig. 1A). When the TN was at the center of the screen, the probe was rotated by 90° to capture the long-axis image of the TN (Fig. 1B). The probe position was marked with an oily marking pen to capture the TN at the same site. Next, the ultrasound setting was changed to shear wave velocity mode, and the shear velocity (m/s) was measured at 3 randomly

selected TN regions of interest from which the average value was calculated (Fig. 1C, D). Stiffness was measured at 5 ankle positions as follows (Table 1): maximum dorsiflexion (100% df), plantar flexion in the resting position (0% df), and 3 points (25% df, 50% df, and 75% df), which divided the range of motion from 0% df to 100% df. The measurement positions were set at the intermediate position of the trunk and neck during 90° hip flexion and 30° knee flexion using the Biodex 3 isokinetic dynamometer device.

The intraclass correlation coefficient (ICC) and the minimal detectable change with a confidence level of 95% (MDC<sub>95</sub>) (Eq. 1) were calculated for each condition.

$$MDC_{95} = \text{Standard error of the mean} \times 1.96 \times \sqrt{2}$$

### 2.4. Statistical analysis

All statistical analyses were performed using IBM SPSS Statistics for Windows, version 24.0 (IBM Corp., Armonk, NY). The Shapiro–Wilk test was used to assess the normality of the variables. As none of the variables were normally distributed, non-parametric tests were used. TN stiffness at each joint angle was compared using the Friedman test. For significance, the pairwise post hoc Wilcoxon test with Bonferroni–Holm correction was performed. The relationship between the stiffness of the TN at each angle of the ankle and that at the 100% df angle was examined using Spearman rank correlation coefficient. The relationship between the stiffness of the TN at each angle of the ankle and the total ankle range (0%–100% df) was also examined using Spearman rank correlation coefficient. Statistical significance was set at  $P < .05$ . In addition, the reliability of stiffness measurements was assessed using ICCs. A score above 0.75 was considered to indicate an excellent agreement,<sup>[12]</sup> and all ICCs were  $\geq 0.85$  (0.85–0.99). Data are presented as mean ± standard deviation.

## 3. Results

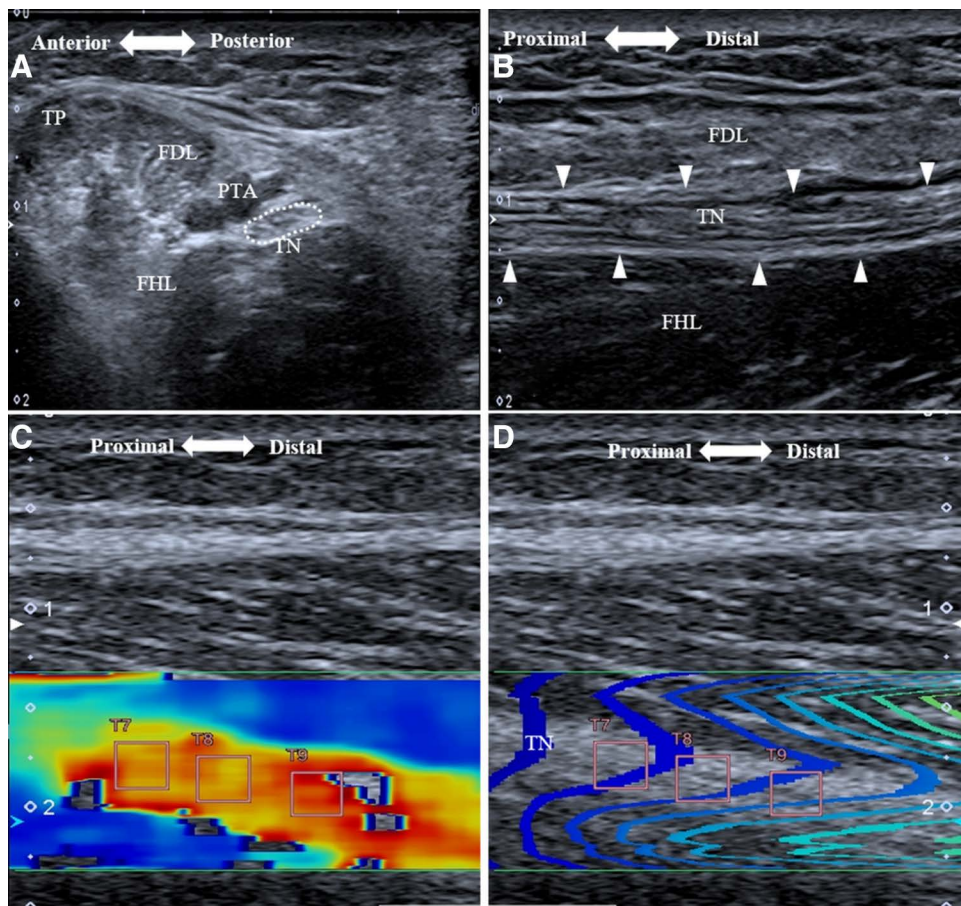
Loosening of the TN was observed at 0% df (Fig. 2A,B). It decreased with dorsiflexion of the ankle. The TN was gliding with dorsiflexion of the ankle, and tension was observed in above 75% of dorsiflexion (Fig. 2A,C).

TN shear wave velocity increased with dorsiflexion (0% df: 4.5 ± 1.7 m/s [MDC<sub>95</sub>: 1.0 m/s]; 25% df: 5.2 ± 1.6 m/s [MDC<sub>95</sub>: 1.6 m/s]; 50% df: 6.2 ± 1.5 m/s [MDC<sub>95</sub>: 1.5 m/s]; 75% df: 7.0 ± 1.1 m/s [MDC<sub>95</sub>: 1.1 m/s]; and 100% df: 7.5 ± 0.7 m/s [MDC<sub>95</sub>: 0.7 m/s]). There were significant differences in shear wave velocity above the MDC<sub>95</sub> when comparing 0% and 75% df, 0% and 100% df, and 25% and 100% df (Fig. 3).

There was a significant negative correlation between the maximum ankle dorsiflexion and stiffness of the TN at 100% df ( $P = .01$ ) and 75% df ( $P = .002$ ) (Table 2). The shear wave velocity of the TN at 75% df and 100% df was higher in participants with lower maximal ankle dorsiflexion. In addition, there was a significant negative correlation between the total ankle range of motion and stiffness of the TN at each joint angle (Table 2). The shear wave velocity of the TN at each joint angle was high among the study participants with a reduced total ankle range.

## 4. Discussion

This study investigated the relationship between TN stiffness and changes in ankle angle using shear wave elastography. We hypothesized that TN stiffness would significantly increase with ankle angle changes, and the total ankle range or maximum dorsiflexion range would correlate with the shear wave velocity results. Based on the results of the shear wave elastography, TN stiffness above the MDC<sub>95</sub> significantly increased at >75% df. Moreover, the total ankle range had a significant

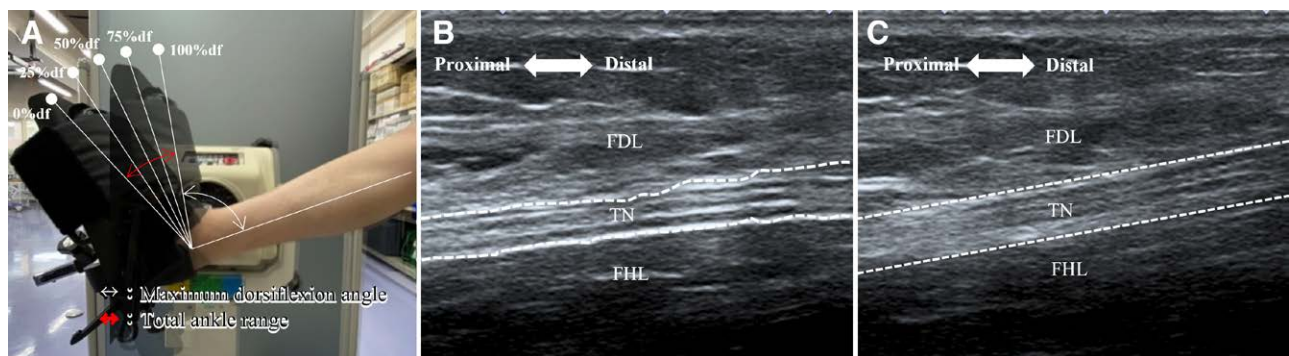


**Figure 1.** B-mode ultrasound images and shear wave elastography of the tibial nerve. The shear velocity was measured at 3 randomly selected tibial nerve regions of interest. (A) Short-axis images of the tibial nerve in plantar dorsiflexion (0°). (B) Long-axis images of the tibial nerve in plantar dorsiflexion (0°). (C) Color mapping of shear wave velocity results. (D) Propagation of shear wave velocity results. FDL = flexor digitorum longus muscle, FHL = flexor hallucis longus muscle, PTA = posterior tibial artery, TN = tibial nerve, TP = tibialis posterior muscle.

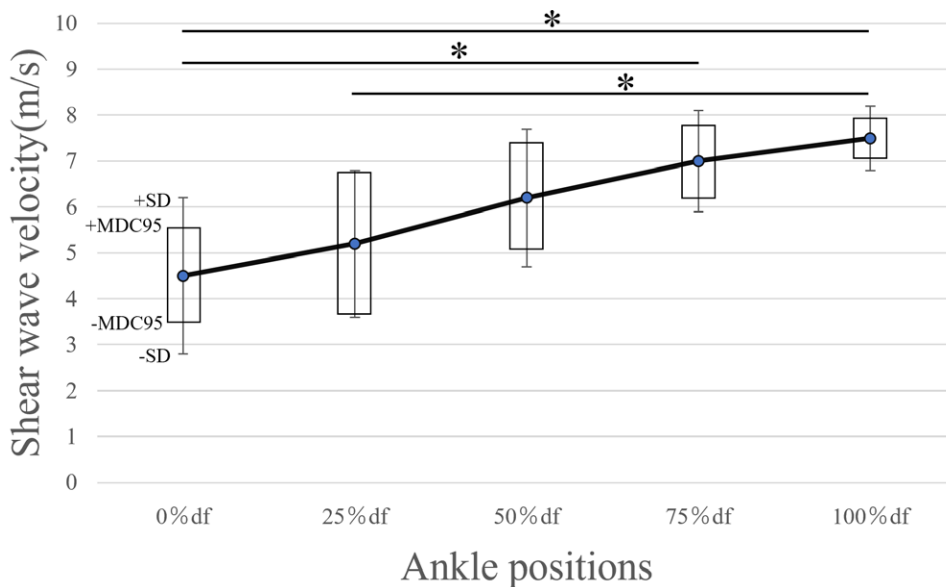
**Table 1**  
**Angles of 5 ankle positions in measuring tibial nerve stiffness.**

Total ankle range	Ankle df (0% df)	25% df	50% df	75% df	Maximum ankle df (100% df)
34.3° ± 6.8°	-17.8° ± 3.3°	-9.2° ± 3.2°	-0.6° ± 3.9°	7.9° ± 5.1°	16.5° ± 6.5°

Plantar flexion is indicated by a minus sign (-), and dorsiflexion is indicated by a plus sign (+).  
 Abbreviation: df, dorsiflexion.



**Figure 2.** Dynamics of the tibial nerve at different angle positions. (A) The 5 positions during stiffness measurements. (B) Loosening of the tibial nerve at 0% df. (C) The tension of the tibial nerve at 100% df. df = dorsiflexion, FDL = flexor digitorum longus muscle, FHL = flexor hallucis longus muscle, TN = tibial nerve.



**Figure 3.** Differences in tibial nerve stiffness at 5 ankle positions. Tibial nerve stiffness and  $MDC_{95}$  at the 5 ankle joint positions are shown. Significant differences were observed only when the value was greater than the  $MDC_{95}$ . \* $P < .01$ . df = dorsiflexion,  $MDC_{95}$  = minimal detectable change with a confidence level of 95%, SD = standard deviation.

**Table 2**

**Spearman rank correlation coefficient of ankle positions with maximum ankle dorsiflexion and total ankle range.**

Ankle positions	Maximum ankle df		Total ankle range	
	R	P-value	R	P value
0% df	-.41	.074	-.60	.005†
25% df	-.43	.059	-.59	.007†
50% df	-.42	.067	-.53	.016*
75% df	-.66	.002†	-.80	<.001‡
100% df	-.54	.014*	-.66	.002†

The correlations between the shear wave velocity of the tibial nerve at 5 ankle positions and the ankle range of motion are shown.

\* $P < .05$ .

† $P < .01$ .

‡ $P < .001$ .

Abbreviation: df, dorsiflexion.

negative correlation with TN stiffness at all ankle positions. However, the maximum ankle dorsiflexion angle was significantly and negatively correlated only at 75% and 100% df. In other words, TN stiffness increased in an angle-dependent manner; however, the degree of stiffness varied below 50% df and above 75% df.

The study also examined the relationship between nerve stiffness and ankle range of motion. Andrade et al reported that sciatic nerve stiffness increases during ankle dorsiflexion.<sup>[1]</sup> Considering that the TN is a branch of the sciatic nerve, our findings complement their results. In addition, by analyzing the TN closer to the ankle joint rather than at its bifurcation from the sciatic nerve, this may be the first study to clarify the characteristics of nerve stiffness at specific angles.

The outer portion of each peripheral nerve is surrounded by the epineurium, and epineurium bundles form nerve fascicles surrounded by the perineurium.<sup>[13]</sup> Peripheral nerves at the resting position are loose. During joint movement, nerve movement transitions from loosening to gliding and then tensioning.<sup>[10,14–16]</sup> Therefore, our findings suggest that the characteristics of TN stiffness below 50% df may be affected by a decrease in nerve loosening or gliding and those above 75% df by nerve tensioning.

The present study provides relevant clinical information, as peripheral nerve stiffness is used to diagnose peripheral neuropathy. For example, it has been shown that TN stiffness increases significantly in patients with diabetes mellitus.<sup>[19,17]</sup> Thus, assessing the nerve at an ankle joint angle lower than 50% df will avoid the influence of angle-dependent stiffness and allow for a more accurate diagnosis and detection of pathological stiffness. However, the study participants were healthy adults, and the changes in TN stiffness associated with diseases, such as tarsal tunnel syndrome, are not clear. In the future, it will be necessary to compare healthy participants with those affected by peripheral nerve diseases.

### 5. Conclusions

A significant increase in TN stiffness above  $MDC_{95}$  occurred at over 75% df, and the maximum ankle dorsiflexion angle was significantly and negatively correlated with only ankle positions above 75% df. The stiffness of the TN was affected by the ankle position, suggesting that ankle position should be considered in the measurement of TN stiffness.

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