# Comparison of the Diagnostic Performance of Strain Elastography and Shear Wave Elastography for the Diagnosis of Carpal Tunnel Syndrome

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*Declarations of interest: none.*

*Funding: This work was supported by the 2019 Inje University research grant.*

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**Abbreviations**

*AUC, area under the ROC curve; CSA, cross-sectional area; CTS, carpal tunnel syndrome; GSU, grayscale ultrasound; NCS, nerve conduction study; ROC, receiver operating characteristic; ROI, region of interest; SE, strain elastography; SNCV, sensory nerve conduction velocity; SWE, shear wave elastography*

doi:10.1002/jum.15478

***Objectives***—To compare the diagnostic performance between strain elastography and shear wave elastography (SWE) for the diagnosis of carpal tunnel syndrome (CTS).

***Methods***—Between July 2018 and June 2019, 66 consecutive patients with 95 imaged wrists underwent wrist ultrasound, including grayscale ultrasound, strain elastography, and SWE, because of the suspicion of CTS. During wrist ultrasound, the cross-sectional area (CSA), strain ratio, elasticity, and shear wave velocity of each median nerve were measured at the proximal carpal bone level (scaphoid to pisiform). The variables were compared between the normal and CTS groups by using the independent *t* test, and subgroup analyses were performed using one-way analysis of variance. Receiver operating characteristic (ROC) curves were used to evaluate the diagnostic performance of each variable.

***Results***—CSA, elasticity, and shear wave velocity showed significant intergroup differences ($P < 0.001$, $P < 0.001$, and $P = 0.002$, respectively). However, the strain ratio showed no statistically significant intergroup difference ($P = 0.639$). In the subgroup analyses, elasticity showed significantly higher values in the severe group than in the mild and moderate groups ($P < 0.001$ and $P = 0.001$, respectively). Other parameters showed no significant differences among the different subgroups. The areas under the ROC curve were 0.823 for CSA, 0.772 for elasticity, and 0.779 for shear wave velocity. The differences in the areas under the ROC curve among CSA, elasticity, and shear wave velocity were not statistically significant (all $P > 0.05$).

***Conclusions***—SWE has a good diagnostic value in CTS. In particular, elasticity can discriminate the severe group from the other groups.

***Key Words***—Carpal tunnel syndrome; median nerve; strain elastography; shear wave elastography

## Introduction

Carpal tunnel syndrome (CTS) is one of the most common entrapment neuropathies caused by the compression of the median nerve at the level of the carpal tunnel.[1] It accounts for 90% of all compressive neuropathies and affects 3.8% of the

general population.[2] The diagnosis of CTS is mainly based on clinical information such as symptoms and signs as well as physical examinations, among which the nerve conduction study (NCS) is the gold standard. Prolonged motor and sensory latencies of the median nerve, with reduced sensory and motor conduction velocities, are considered meaningful variables for diagnosing CTS.[1] Although the NCS has high sensitivity (85%) and specificity (95%) for the diagnosis of CTS,[3] it can cause pain or discomfort to patients, owing to its invasiveness. Over the last two decades, ultrasound imaging has been proven to offer good diagnostic values for CTS.[4–11] Among the suggested variables, the cross-sectional area (CSA) of the median nerve in the carpal tunnel has proven to be the most accurate.[8] However, even CSA shows wide variations in sensitivity (62%–99%) and specificity (57%–100%). Previous studies concluded the wide range of these diagnostic values was mainly due to individual anatomical differences among patients.[12]

Ultrasound elastography is a noninvasive method that provides additional information on tissue elasticity or stiffness at the examination site.[13] It is broadly divided into strain elastography (SE) and shear wave elastography (SWE). SE evaluates the extent of tissue deformity during the manual compression-release force applied to the tissue.[14] Thus, it is a semiquantitative method because the force applied for compression cannot be accurately measured. To overcome this drawback, the strain ratio is measured, which is the ratio of the values between the reference tissue and target area. In SWE, push pulse is generated by the ultrasound probe, which travels through the tissue, making shear waves in the direction perpendicular to the push pulse. Then, the velocity of the shear wave is evaluated to determine the tissue stiffness. In point quantification SWE, a single measurement of a small FOV is obtained; meanwhile, 2-demensional SWE covers a large FOV and presents the data as a color map.[14] The velocity of the shear wave can be measured, and thus SWE is more reproducible and quantitative than SE.[13] Previous studies proved that both SE and SWE have high sensitivity and specificity in discriminating malignant breast masses from benign ones. In addition, both methods have been proven to have clinical significance in the diagnosis of hepatic masses, categorization of thyroid nodules, and evaluation of prostate cancer.[14] A recent article suggested that elastography of antenatal cervix can aid in the prediction of preterm birth.[15] However, despite the difference between the 2 methods, their diagnostic capabilities showed no significant difference between malignant and benign breast masses or thyroid nodules.[16,17]

Both methods have also been shown to have a high diagnostic performance in CTS. To our best knowledge, no study has compared SE and SWE to determine their superiority in the diagnosis of CTS. We hypothesized there was a difference between their diagnostic abilities. Therefore, the purpose of this study was to compare the performance between SE and SWE for the diagnosis of CTS.

## Materials and Methods

### *Patient selection*

This retrospective study was performed with approval from our institutional review board, and written informed consent was obtained from all patients. Between July 2018 and June 2019, we initially included 81 patients (120 wrists) referred to radiologists for wrist ultrasound imaging because of the suspicion of CTS. Of them, 15 patients (25 wrists) were excluded according to the following criteria: (i) history of previous trauma or surgery at the examined wrist or hand (3 patients [4 wrists]); (ii) anatomical variances such as a bifid median nerve (2 patients [3 wrists]); (iii) other systemic or neuropathic conditions involving the median nerve (5 patients [10 wrists]); (iv) incomplete wrist ultrasounds (2 patients [4 wrists]); and (v) no available NCS results (3 patients [4 wrists]). Finally, 66 consecutive patients (13 men and 53 women; age range, 27–87 years; mean age, 56.5 years) with 95 imaged wrists (48 left wrists and 47 right wrists; both wrists in 35 patients) were included in this study. The confirmative diagnosis in each case was based on clinical findings and NCSs. The calculated power of our study was determined to be 0.38 using the post-hoc power analysis.[18]

### *Ultrasound examination*

The ultrasound examinations were performed by 2 experienced musculoskeletal radiologists with 6 and 5 years of clinical experience (SH and JY). The radiologists were blinded to the patients' electrodiagnostic test results. They only had access to the patients'

demographic information, such as name, age, and sex. All patients were examined using the same ultrasound machine (LOGIQ E9, GE Healthcare, Milwaukee, WI) with an ML 6–15 linear array transducer (GE Healthcare, Wauwatosa, WI) for grayscale ultrasound (GSU) and SE, and with an L9 linear array transducer (GE Healthcare, Wauwatosa, WI) for SWE. This ultrasound machine provides comb-push ultrasound shear elastography, which is a recently developed 2D SWE technique. It is less affected by significant shear wave attenuation in areas that are far from the push beam, making it more reliable and accurate for measurements of shear wave velocity.[19]

All patients underwent ultrasound examinations in the seated position facing the examiner. Their arms were extended, with the forearm in the supine position and the wrists resting on a soft cushion. The fingers were held in a relaxed position while they were semiflexed. During each examination, instructions were given to the patients not to change the position or apply force on the wrists to avoid increasing carpal tunnel pressure during the examination.

During GSU, transverse images were acquired from the carpal tunnel inlet at the proximal carpal bone level (scaphoid to pisiform). Thereafter, the examiners measured each CSA of the median nerve at this level by performing a continuous boundary trace of the nerve. CSA was automatically calculated by the ultrasound device. The examiners minimized manual compression to avoid any deformity of the median nerve.

After GSU, both SE and SWE were performed for each patient. SE was performed focusing on the same field of view, with a series of light vertical pressures applied at the proximal carpal bone level, followed by decompression. A visual indicator on the right upper corner of the ultrasound device screen displayed the quality of the compression degree. Red color represented softer tissues; blue color represented harder tissues; and yellow or green color represented tissues with intermediate elasticity. To minimize the direct pressure applied by the transducer, a gel pad (Aquaflex®, Parker Laboratory, NJ) was placed between the transducer and skin. The compression-decompression cycles were repeated until at least 3 images with acceptable compression quality were acquired. To minimize intraobserver and interobserver variations and to avoid transient temporal fluctuations, we acquired total SE images encompassing the entire cine loop.[20] During

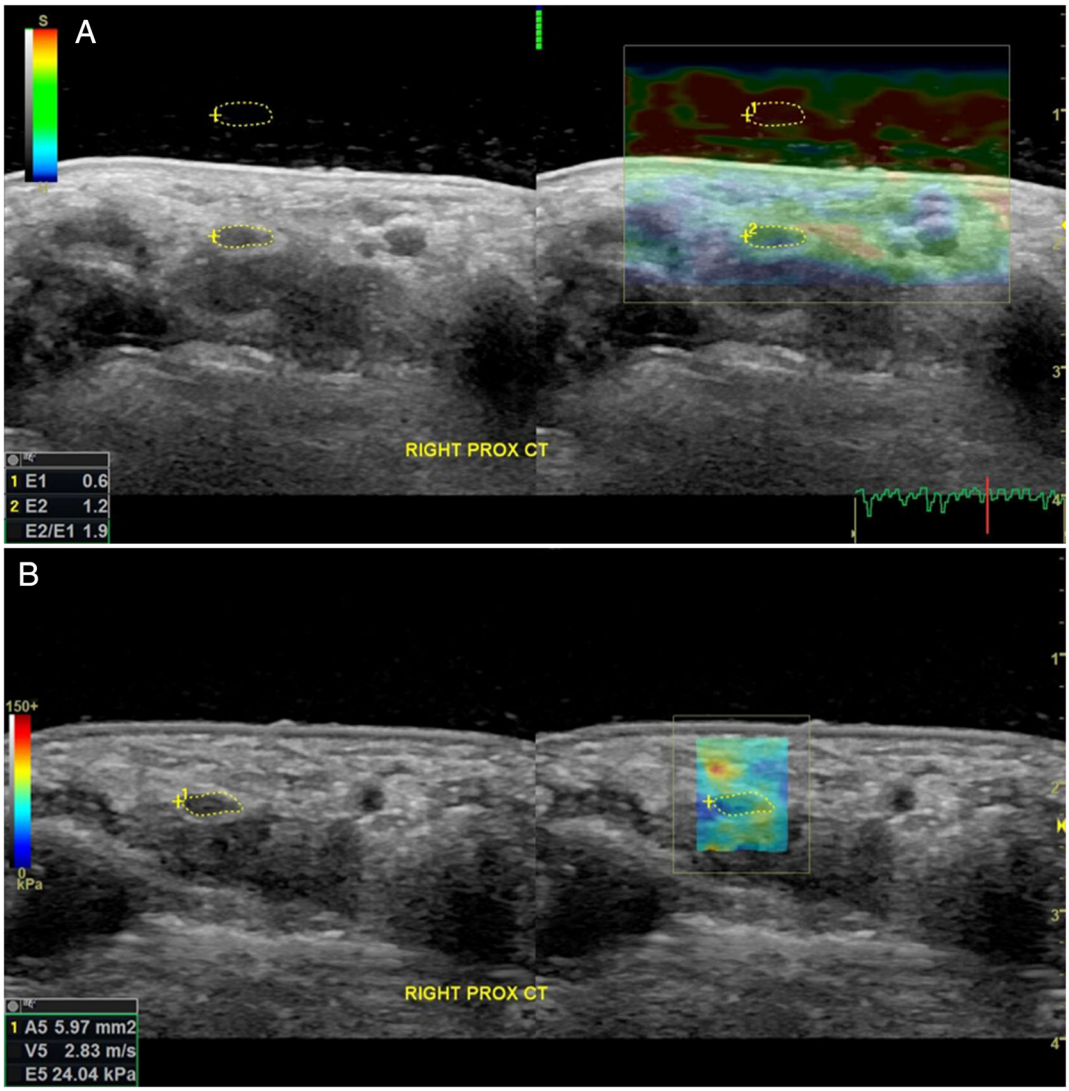
**Table 1.** The mean values of the measurement parameters in median nerve in normal group and patients with carpal tunnel syndrome

| | Normal (13 wrists) | CTS group (Total 82 wrists) | | | *P*-value |
|---|---|---|---|---|---|
| Cross-sectional area ($cm^2$) | 0.878 ± 0.370 | 1.343 ± 0.440 | | | < 0.001 |
| | | Mild (24 wrists) | Moderate (35 wrists) | Severe (23 wrists) | |
| | | 1.209 ± 0.526 | 1.333 ± 0.388 | 1.498 ± 0.384 | |
| Strain ratio | 5.074 ± 2.725 | 4.760 ± 2.154 | | | 0.639 |
| | | Mild (24 wrists) | Moderate (35 wrists) | Severe (23 wrists) | |
| | | 4.646 ± 1.725 | 4.478 ± 2.334 | 5.307 ± 2.258 | |
| Elasticity (kPa) | 24.221 ± 10.857 | 39.044 ± 19.129 | | | < 0.001 |
| | | Mild (24 wrists) | Moderate (35 wrists) | Severe (23 wrists) | |
| | | 30.609 ± 10.949 | 34.396 ± 12.695 | 54.920 ± 24.440 | |
| Shear wave velocity (m/sec) | 2.760 ± 0.635 | 3.713 ± 2.066 | | | 0.002 |
| | | Mild (24 wrists) | Moderate (35 wrists) | Severe (23 wrists) | |
| | | 3.117 ± 0.565 | 3.831 ± 3.011 | 4.155 ± 0.867 | |

Note: Data are presented as mean ± standard deviation.

the examination, B-mode images and color-coded SE images were displayed together, thus assisting the placement of regions of interest (ROIs) at the location of the median nerve. After SE examination, 3 best-fit B-mode–elastogram representative image pairs with good compression degree were selected.[20] All ROIs were drawn on the GSU images. The target ROI was drawn to include the entire CSA of the median nerve in each selected image. The reference ROI was also drawn at the overlying gel pad, with approximately the same size as the median nerve area. We endeavored to draw the reference ROI such that its size was equal to the size of the target ROI. After the ROI was drawn on the GSU images, an identical ROI was drawn on the SE images automatically and immediately. The strain ratio (mean strain of the reference ROI/mean strain of the target ROI) was calculated. Their mean values were determined as the representative value.

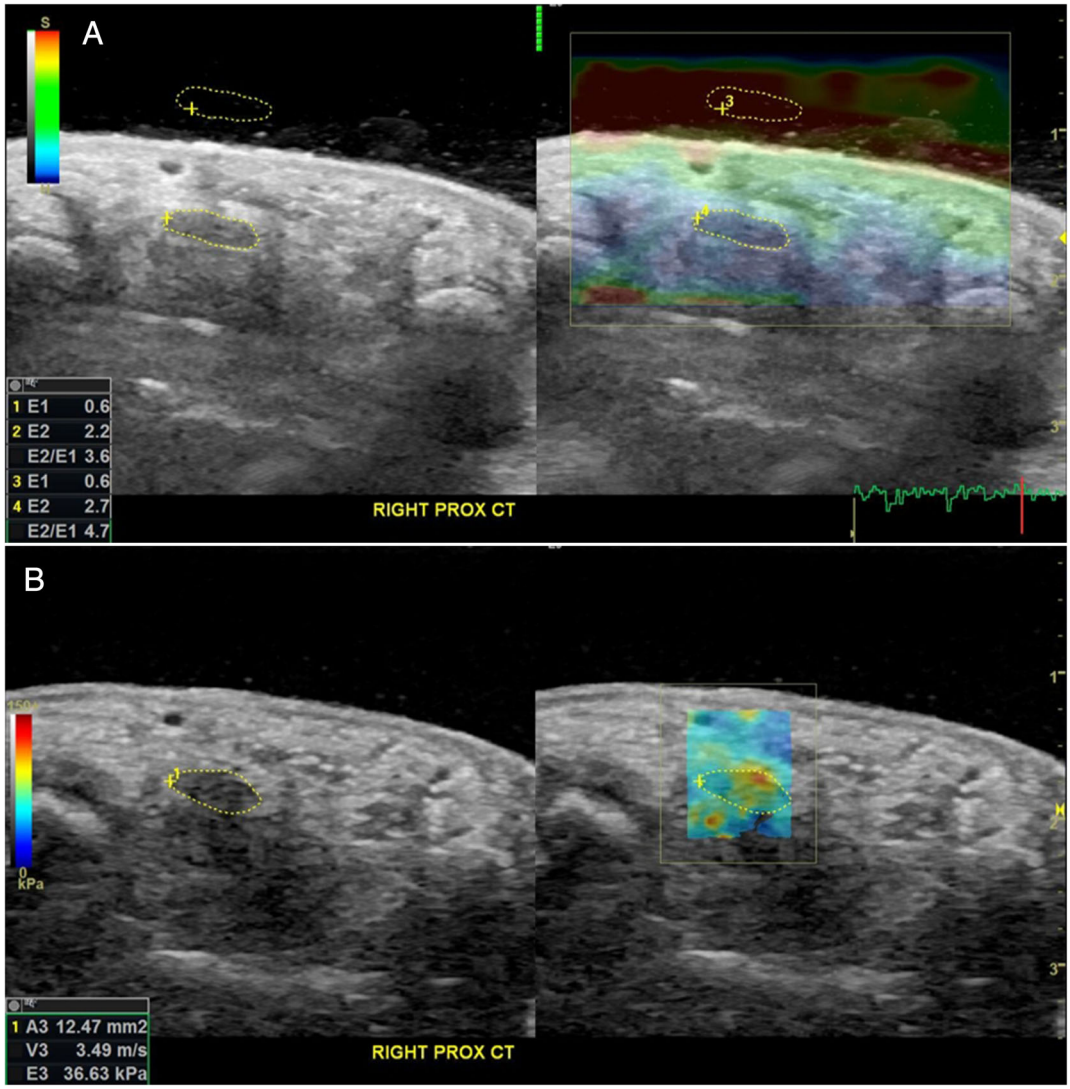
**Figure 1.** A 52-year-old woman in the normal group. The cross-sectional area of the median nerve at the proximal carpal bone level is 0.640 $cm^2$. From strain elastography **(A)**, the strain ratio is 1.9. From shear wave elastography **(B)**, elasticity is 24.04 kPa and shear wave velocity is 2.83 m/s.



SWE was performed at the proximal carpal bone level. During the examination, the gel pad was also used on the wrist to maintain an examination environment identical to the SE examination. Care was taken to ensure the median nerve was not compressed by the transducer, because this could alter the measurements of shear wave velocity.[21] Six separate transverse images were acquired using a rectangular color-coded box placed at the median nerve at the proximal carpal bone level. The color codes represented the shear modules, ranging from blue (low) to red (high). The ROI (mean, 11.2 $mm^2$; range, 3.7–24.8 $mm^2$) was drawn on each image to include the entire CSA of the median nerve, and the software displayed the area of the ROI, mean velocity in meters per second (m/s), and stiffness in kilopascal (kPa) of the ROI. To minimize intraobserver variability, the average of 6 values was considered as the representative value.

During all GSU, SE, and SWE examinations, we asked the patients to cooperate by minimizing

**Figure 2.** A 55-year-old woman in the mild carpal tunnel syndrome (CTS) group. The cross-sectional area of the median nerve at the proximal carpal bone level is 1.136 $cm^2$. From strain elastography **(A)**, the strain ratio is 4.7. From shear wave elastography **(B)**, elasticity is 36.63 kPa and shear wave velocity is 3.49 m/s.

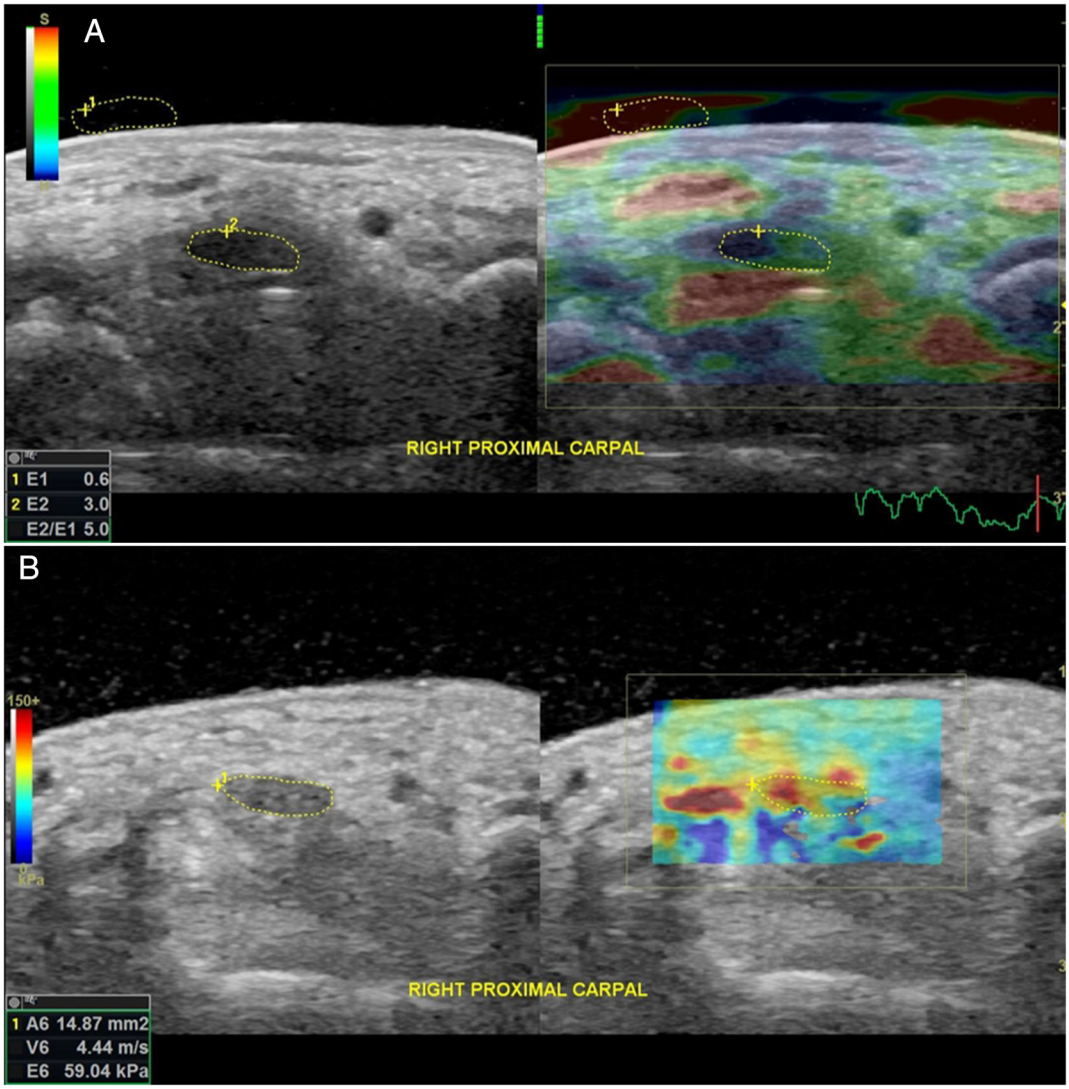


movements as much as possible.[21] We also allowed the patients 2 or 3 short breaks, during which they could move freely. This way, patient movement was minimized during the examinations. In order to eliminate selection bias and keep the measuring method constant, all quantitative measurements of elasticity were retrospectively performed by one radiologist (EJP, with 4 years of experience) who did not perform the SWE and SE examinations, in random order at the ultrasound workstation by retrieving SE and SWE images.

### *Electrodiagnostic test*

NCSs were performed in all included patients. The examinations included the following items: sensory and motor conduction velocity, distal and proximal motor latency, distal sensory latency, and motor and sensory action potential amplitudes of the median nerve. According to the NCS results, the severity of CTS was classified into normal, mild, moderate, and severe, according to the classification suggested by Padua et al.[22] The normal group was defined as having negative NCS results. The mild CTS group

**Figure 3.** A 57-year-old woman in the moderate carpal tunnel syndrome (CTS) group. The cross-sectional area of the median nerve at the proximal carpal bone level is 1.439 $cm^2$. From strain elastography **(A)**, the strain ratio is 5.0. From shear wave elastography **(B)**, elasticity is 59.04 kPa and shear wave velocity is 4.44 m/s.

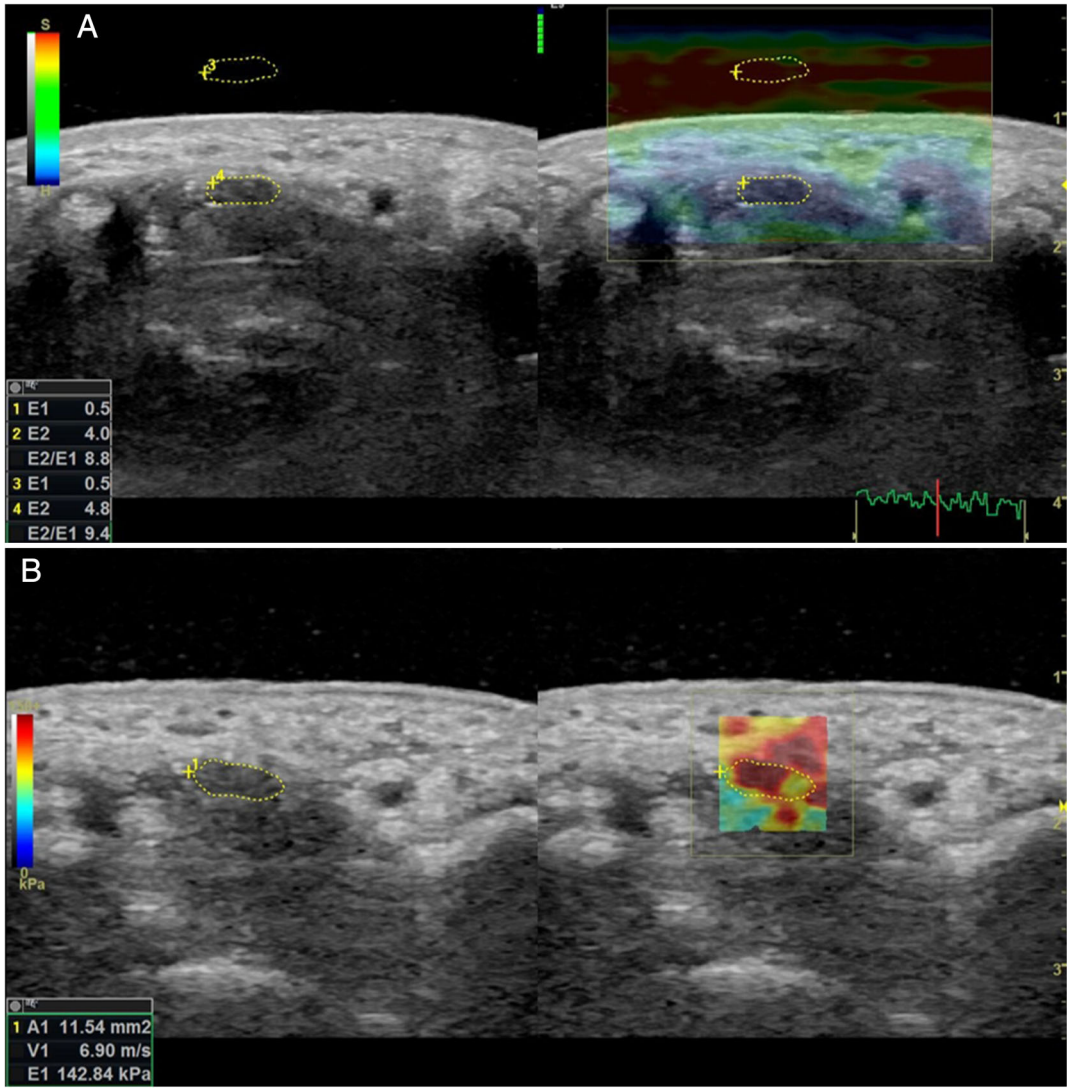


showed slowing of median sensory nerve conduction velocity (SNCV) but with normal distal motor latency. The moderate CTS group showed slowing of SNCV with abnormal distal motor latency. The severe CTS group showed the absence of SNCV or motor response.

### *Statistical analysis*

All statistical analyses were performed using MedCalc Statistical Software version 17.6 (MedCalc Software bvba, Ostend, Belgium) and IBM SPSS Statistics for Windows/Macintosh, Version 21.0 (IBM Corporation, Armonk, NY). The correlations between each parameter and CTS severity grade were evaluated using the Pearson correlation coefficient. The mean values were compared between the normal and other CTS groups by using the independent *t* test. The differences between the means of the values were compared using one-way analysis of variance for comparison of the CTS subgroups. Receiver operating

**Figure 4.** A 66-year-old man in the severe carpal tunnel syndrome (CTS) group. The cross-sectional area of the median nerve at the proximal carpal bone level is 1.490 $cm^2$. From strain elastography **(A)**, the strain ratio is 9.4. From shear wave elastography **(B)**, elasticity is 142.84 kPa and shear wave velocity is 6.90 m/s.



characteristic (ROC) curves were used to evaluate the diagnostic performance of each parameter. The performances were quantified by calculating the area under the ROC curves (AUC).

## Results

Among the 95 wrists, 13 were included in the normal group, 24 in the mild group, 35 in the moderate group, and 23 in the severe group. The mean values of CSA, strain ratio, elasticity, and shear wave velocity in each group are summarized in Table 1. Figures 1 to 4 show SE and SWE measurement in normal, mild, moderate and severe CTS groups.

Except for the strain ratio, the other 3 parameters showed a positive correlation with CTS severity. Elasticity showed the highest correlation value (r = 0.513; 95% confidence interval [CI], 0.348–0.648), followed by CSA (r = 0.403; 95% CI, 0.220–0.559) and shear wave velocity (r = 0.252; 95% CI, 0.053–0.432). The strain ratio showed no significant correlation with CTS severity (r = 0.040; 95% CI, −0.161–0.240).

CSA was significantly larger in the CTS groups than in the normal group ($P < 0.001$). Elasticity and shear wave velocity showed statistically significant differences between the normal and CTS groups ($P < 0.001$ and $P = 0.002$, respectively). The strain ratio showed no statistically significant difference between the two groups ($P = 0.639$).

In subgroup analyses, elasticity showed significantly higher values in the severe group than in the mild and moderate groups ($P < 0.001$ and $P = 0.001$, respectively; Table 2). Other parameters showed no significant differences among the different subgroups (all $P > 0.05$; Table 2).

The AUCs for each parameter for diagnosing CTS are shown in Table 3 and Figure 5. The AUC of CSA showed the maximum value of 0.823 (95% CI,

**Table 2.** The comparison of the measurement parameters in median nerve between subgroups of carpal tunnel syndrome

| | | *P*-value |
|---|---|---|
| Cross-sectional area ($cm^2$) | Mild vs. Moderate | 0.303 |
| | Mild vs. Severe | 0.051 |
| | Moderate vs. Severe | 0.118 |
| Strain ratio | Mild vs. Moderate | 0.765 |
| | Mild vs. Severe | 0.264 |
| | Moderate vs. Severe | 0.186 |
| Elasticity (kPa) | Mild vs. Moderate | 0.239 |
| | Mild vs. Severe | 0.001* |
| | Moderate vs. Severe | 0.001* |
| Shear wave velocity (m/sec) | Mild vs. Moderate | 0.179 |
| | Mild vs. Severe | 0.064 |
| | Moderate vs. Severe | 0.551 |

*Statistically significant.

**Figure 5.** Receiver operating characteristic (ROC) curves of cross-sectional area, elasticity, and shear wave velocity.

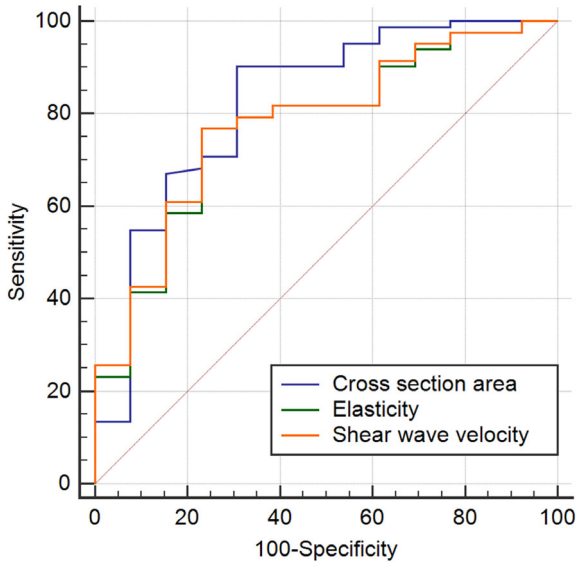



**Table 3.** The areas under the ROC curve (AUC) and the best cut-off values of median nerve measurements in patients with carpal tunnel syndrome

| | AUC | Best cut-off values | Sensitivity (%) | Specificity (%) |
|---|---|---|---|---|
| Cross-sectional area ($cm^2$) | 0.823 (0.731–0.894) | 0.871 | 90.24 | 69.23 |
| Elasticity (kPa) | 0.772 (0.675–0.852) | 26.755 | 76.83 | 76.92 |
| Shear wave velocity (m/sec) | 0.779 (0.682–0.857) | 2.980 | 76.83 | 76.92 |

Note: Data in parentheses are 95% confidence interval.

0.731–0.894). The AUCs of elasticity, shear wave velocity, and strain ratio were 0.772 (95% CI, 0.675–0.852), 0.779 (95% CI, 0.682–0.857), and 0.514 (95% CI, 0.409–0.618), respectively. Although the AUCs showed significant differences between CSA and strain ratio ($P = 0.0146$), the differences among CSA, elasticity, and shear wave velocity were not statistically significant (all $P > 0.05$).

## Discussion

When constant pressure is applied to the median nerve, it inevitably undergoes a series of changes. Increased pressure in the carpal tunnel causes stagnation or blockage of venous outflow and provokes venous congestion and hyperemia, followed by nerve edema.[23] The swelling of the median nerve can be visualized as an increase in CSA and bowing of the overlying flexor retinaculum on images, including ultrasound and magnetic resonance images.[24,25] As this vicious cycle continues, blood flow to the vasa nervorum is blocked, leading to an ischemic change of the nerve itself. Chronic ischemic change causes damage to the myelin sheath and axon, which in turn causes sensory and motor latency in the NCS.[23]

In our study, median nerve elasticity in the CTS groups was higher than that in the normal group, with significantly higher values in the severe CTS group than in the other groups. Shear wave velocity and CSA showed significant differences between the normal and CTS groups but showed no significant difference among the CTS subgroups. Furthermore, unexpectedly, the strain ratio showed no diagnostic values in distinguishing any of the groups.

Many studies using various ultrasound techniques for CTS evaluation have been reported. In the clinical setting, the simplest and most commonly used method is CSA measurement using GSU, which is known to have good diagnostic performance. In our study, CSA showed sufficient strength in discriminating the normal group from the CTS groups. However, it showed no statistical significance among the different CTS severity subgroups. Median nerve CSA can be affected by many factors, including age, sex, and ethnic group, which could be the reason for its lack of sensitivity for distinguishing among the subgroups.[26]

From a clinical perspective, identifying patients with severe CTS is important because these patients are less likely to respond to conservative treatment (ie, steroid treatment) and are more likely to eventually undergo surgical management.[27,28] This makes our finding noteworthy.

Several studies have revealed correlations between either SE or SWE and CTS grades. The study by Kantarci et al. reported a similar result to our study, showing that shear wave elasticity was significantly higher in the patient group than in the control group.[29] Furthermore, in the subgroup analysis, the severe or extremely severe CTS group showed higher elasticity than did the mild or moderate group. Cingoz et al. also showed that shear wave elasticity values in the median nerve were higher in the CTS group (53.0 kPa; interquartile range, 40.8–77.0 kPa) than in the control group (36.8 kPa; interquartile range, 31.0–39.9 kPa).[23] The increase in elasticity can be explained by recurrent ischemic injury and fibrotic changes, which cause increased stiffness of the median nerve in patients with CTS. Furthermore, increased pressure in the carpal tunnel itself may cause an increase in the propagation velocity of the shear wave, causing higher stiffness values.[30]

As for SE, our study showed no statistically significant differences between the CTS and normal groups, as well as among the different CTS subgroups. This result is inconsistent with those of previous studies, which suggested the strain ratio shows reliable diagnostic performance.[31,32] This could be attributed to some differences between the previous studies and ours. In our study, 2 operators performed elastography without the implementation of interobserver agreement. Since SE requires manual compression, not only temporal variation but also interobserver variation can be a drawback.[33,34] Although adequate compression range is displayed by the color coded bar, lack of standard figure remains the major shortcoming.[34] Second, in our study, the reference ROI was placed in the overlying gel pad. Unlike the reference couplers used in other studies, the gel pads are consumable items, and this could affect the reference ROI. To overcome this drawback, we replaced the gel pads as often as possible, but the disadvantage cannot be completely eliminated. Lastly, in our study, the SE images used for measurement were selected arbitrarily by the third reader, who did not participate in the ultrasound and

elastography. This factor may affect the low performance of the SE.[35]

This study has several limitations. First, our study had a retrospective design and a small sample size, and there might have been a selection bias. Nonetheless, this was resolved by including consecutive patients who underwent wrist ultrasound during the determined period. Second, we did not implement interobserver agreement. However, we standardized the wrist ultrasound examination at our institution to minimize differences among operators. Third, we measured elastography on axial images, at one point. Considering the anatomic structure of the median nerve as a long, cylindrical shape, the measurement may be different in other planes. However, most studies on CTS use measurements along the axial planes, and hence, we selected axial images to maintain consistency with the other parameters.

In conclusion, SWE has a good diagnostic value in CTS. In particular, elasticity can help discriminate the severe CTS group from the remaining groups.

## Acknowledgments

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

## Funding

This work was supported by the 2019 Inje University research grant.

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