Introduction: Carpal tunnel syndrome (CTS) is a compression neuropathy of the median nerve at the wrist. Since chronic nerve compression is known to be followed by pathological changes in the nerve trunk, i.e., fibrosis and thickening of the epineurium, it may cause material property change of the nerve. Ultrasound indices of median nerve deformation are known to be useful to assess CTS. Recently, ultrasound elastography, an imaging method for measuring tissue strain using a conventional ultrasound machine, has been used for measuring the hardness of soft tissues. It is based on the principle that tissue compression produces displacement (strain) within the tissue. Since the compression is applied by examiner’s hand, an unstable compression-release cycle can cause unreliable data. To improve the reliability of strain measurement, we developed the automatic vibratory equipment for ultrasonic strain measurement. In this study, we assessed the diagnostic accuracy of the equipment by using it to measure median nerve strain. We then compared these measurements with other ultrasound indices. We hypothesized that the automatic vibratory equipment would be able to detect differences in median nerve strain in individuals with CTS, compared to healthy controls.

Methods: This study protocol was reviewed, and approved by our Institutional Review Board. Forty wrists of 20 asymptomatic volunteers (All female, age range 22-62 with a mean age of 40.9 years) and 22 wrists of 16 patients (eleven female and five male, age range 43-85 with a mean age of 64.7 years) were evaluated by ultrasound. CTS patients with a history of systemic disease associated with a higher incidence of CTS, such as thyroid disease, obesity or rheumatoid arthritis, as well as all patients with any upper extremity surgery in their medical history, were excluded. Participants were given a brief description of the purpose of the research and the testing procedures during the initial contact. Written consent was obtained from all study participants. CTS was diagnosed by both clinical findings and the nerve conduction study.

Automatic Vibratory Equipment: This equipment was developed to apply a controlled cycle and level of compression to the tissues. The equipment was characterized by two parts, i.e. a forearm table with a motor for the compression-release cycle, and a programmed controller (Figure 1-a). The forearm table consisted of a motor, a placement adjuster, a transducer holder, a protractor, and a table. The table was designed so that the transducer could be placed at the level of the subject’s wrist crease and the placement adjuster could adjust the height of the transducer. The displacements and cycles of the motor were controlled with the programmed controller. The displacement was adjustable in the range of 0.1-3.0mm. The cycle was adjustable in the range of 0.46-4.80Hz (Gyouden Co., Tsukuba, Japan). Strain Measurement of Median Nerve: Each subject was imaged sitting with the elbow flexed and the forearm supinated. The forearm of the examinee was secured to the table. An ultrasound scanner (Hivision Avius; Hitachi Aloka Medical, Ltd., Tokyo, Japan) equipped with a linear array transducer was set to a depth of 20 mm. The transducer was placed parallel to the wrist crease (proximal carpal tunnel), with the wrist in the neutral position (Figure 1-a). The transducer was maintained perpendicular to the skin surface of the wrist crease. The median nerve was identified by cross-sectional ultrasonographic imaging and the median nerve strain was measured with real time tissue elastography. The reference coupler, which has a fixed value of elasticity, was attached to the transducer. The compression-release cycles were applied with the automatic vibratory equipment. The cycle was set to 1.5Hz. The cycle of the compression-release was monitored by a numeric scale indicator in real time. The displacement was adjusted with the strain between -0.7 to 0.7 on the monitor. The strains of median nerve and reference coupler were measured using the built in software of the ultrasound system. The outline of the imaged median nerve was traced and the nerve strain was measured (Figure 1-b). In addition, the strain of the reference coupler was measured just above the median nerve. The median nerve strain and the strain ratio (=strain of the reference coupler/strain of median nerve) were measured. The strains were measured five times. The average of five times data was used for analysis. In addition to the strain measurement, median nerve morphological indices (area and perimeter) were also measured. Using Analyze 10.0 Software (Biomedical Imaging Resource, Mayo Clinic, Rochester, MN), the cross-sectional ultrasonographic images of the carpal tunnel were reviewed. Based on these images, the median nerve area and perimeter were calculated. Statistical Analysis: The results were expressed with a mean and a +/- standard deviation. To compare the values between the controls and the patients, Welch’s t-test was used. Receiver operating characteristic (ROC) curves were calculated to determine the diagnostic value of the indices. The performance of diagnostic variables were
Results: The strains of the median nerve were smaller in patients than in controls (0.45±0.12 and 0.23±0.07 for the controls and patients, respectively). The strain ratios were larger in patients than in controls (1.68±0.27 and 3.23±1.64 for the controls and patients, respectively). The median nerve areas were larger in patients than in controls (11.2±2.0mm$^2$ and 14.1±3.4mm$^2$ for the controls and patients, respectively). The median nerve perimeters were larger in patients than in controls (16.3±1.7mm and 18.2±2.6mm for the controls and patients, respectively). There were significant differences between controls and patients for all indices (P<0.05). The results of ROC curves were shown in Figure 2. The AUCs were 0.903, 0.817, 0.779, and 0.755 for the strain, strain ratio, area and perimeter, respectively. The median nerve strain showed the largest AUC value.

Discussion: This study investigated the diagnostic variables of a method for quantifying median nerve strain using automatic vibratory equipment. According to the results of AUC values, the median nerve strain proved to be the most accurate measurement for the diagnosis of CTS. It was confirmed that the median nerve strain can distinguish CTS patients from healthy controls.

Significance: Using automatic vibratory equipment to measure ultrasonic median nerve strain may be useful when attempting to identify individuals who have carpal tunnel syndrome.

Acknowledgements: N/A

References: N/A
Figure 1: Strain measurement settings
(b) An image of real time tissue elastography. A: Strain of the median nerve, B: Strain of the reference coupler.

Figure 2: ROC curves