Tension of the Ulnar, Median, and Radial Nerves During Ulnar Nerve Neurodynamic Testing: Observational Cadaveric Study

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Background. The ulnar nerve upper limb neurodynamic test (ULNT3) uses upper limb positioning to investigate symptoms arising from the ulnar nerve. It is proposed to selectively increase tension of the nerve; however, this property of the test is not well established.

Objective. The aim of this study was to determine the upper limb position that results in: (1) the greatest tension of the ulnar nerve and (2) the greatest difference in tension between the ulnar nerve and the other 2 major nerves of the upper limb: median and radial.

Design. This was an observational cadaver study.

Methods. Tension (in newtons) of the ulnar, median, and radial nerves was measured simultaneously using 3 buckle force transducers in 5 upper limb positions in 10 embalmed human cadavers (N=20 limbs). Repeated-measures analysis of variance (ANOVA) with Bonferroni post hoc tests determined differences in tension among nerves and among limb positions.

Results. The addition of shoulder horizontal abduction (H.Abd; 12.62 N; 95% confidence interval [95% CI]=10.76, 14.47) and combined shoulder abduction and internal rotation (H.Abd+IR; 11.86 N; 95% CI=9.96, 13.77) to ULNT3 (scapular depression, shoulder abduction and external rotation, elbow flexion, forearm pronation, and wrist and finger extension) produced significantly greater ulnar nerve tension compared with the ULNT3 alone (8.71 N; 95% CI=7.25, 10.17). The ULNT3+H.Abd test demonstrated the greatest difference in tension among nerves (mean difference between ulnar and median nerves=11.87 N; 95% CI=9.80, 13.92; mean difference between ulnar and radial nerves=8.47 N; 95% CI=6.41, 10.53).

Limitations. These results pertain only to the biomechanical plausibility of the ulnar nerve neurodynamic test and do not account for other factors that may affect the clinical application of this test.

Conclusions. The ULNT3+H.Abd is a biomechanically plausible test for detecting peripheral neuropathic pain related to the ulnar nerve. In situations where the shoulder complex will not tolerate the combination of shoulder external rotation in abduction, performing upper limb neurodynamic tests with internal rotation instead of external rotation is a biomechanically plausible alternative.

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The ulnar, median, and radial nerve upper limb neurodynamic tests (ULNTs) are designed to assess the interplay between mechanics and physiology of the 3 major nerves of the arm.[1] The ulnar nerve bias ULNT (ULNT3) is purported to examine the ulnar nerve to determine its contribution to neuropathic symptoms of the upper limb or neck.[2,3] The validity of the ULNT3 is based on its ability to selectively increase tension of the ulnar nerve without increasing tension of adjacent tissue.[2,4,5] It is generally accepted that this mechanical provocation is responsible for reproduction of the patient's symptoms.[6,7] However, there is evidence from one previous human cadaveric study that the ULNT3 may not selectively increase tension of the ulnar nerve.[8]

Of clinical importance, neurodynamics is complex and involves consideration of both central and homeostatic mechanisms.[9] Therefore, the outcome of a ULNT is not solely due to the development of tension within the nervous system. The outcome may be altered by nerve excursion[10,11] and compression,[12] physiological events,[6,13,14] psychosocial factors,[15,16] or whether a patient's symptoms are centrally or peripherally mediated.[9,17] However, an understanding of the development of tensile force in the nervous system in response to upper limb movement remains important, as it provides a foundation for the plausibility of a ULNT to detect peripheral neuropathic pain.

The movements that comprise the ULNT3 are based on the anatomical course of the ulnar nerve with respect to the joint axes of the upper limb.[2,4] Originally, these movements included: scapular depression, shoulder abduction and external rotation, elbow flexion, forearm supination, and wrist and finger extension.[3] However, a modification to the

ULNT3 was later proposed, suggesting that forearm pronation replace forearm supination.[9] This modification occurred, as it was observed that forearm pronation increases the distance between the medial epicondyle of the humerus and the pisiform, theoretically increasing tension of the ulnar nerve.[9] Despite this anatomical hypothesis, there were no identified studies comparing tension of the ulnar nerve between these 2 variations of the ULNT3. Therefore, it remains unclear whether forearm pronation or supination should be included as a component of the test.

The ability of the ULNT3 to selectively increase tension of the ulnar nerve is currently unclear. One previous human cadaveric study[8] measured tension of the ulnar, median, and radial nerves simultaneously in the axilla and showed that the ULNT3 with forearm supination failed to increase tension of the ulnar nerve significantly more than the median or radial nerve. Therefore, the ULNT3 may not effectively differentiate among neuropathic symptoms arising from the 3 major nerves of the arm.[8] Supporting this conclusion, previous human cadaveric studies have shown that shoulder external rotation, a standard component of the ULNT3, does not increase tension of the cords of the brachial plexus[18-20] or peripheral nerves when measured in the axilla.[19] Additionally, the application of shoulder external rotation in abduction has been shown to stress the nonneural structures of the anterior shoulder.[2,21,22] This stress may affect the clinical utility of ULNT3, as patients with certain shoulder pathologies or those with pain that is highly irritable may not tolerate this position. Despite several studies investigating tension of the ulnar nerve during different upper limb positions,[8,19,23-28] the most effective upper limb position for ULNT3 remains undefined.
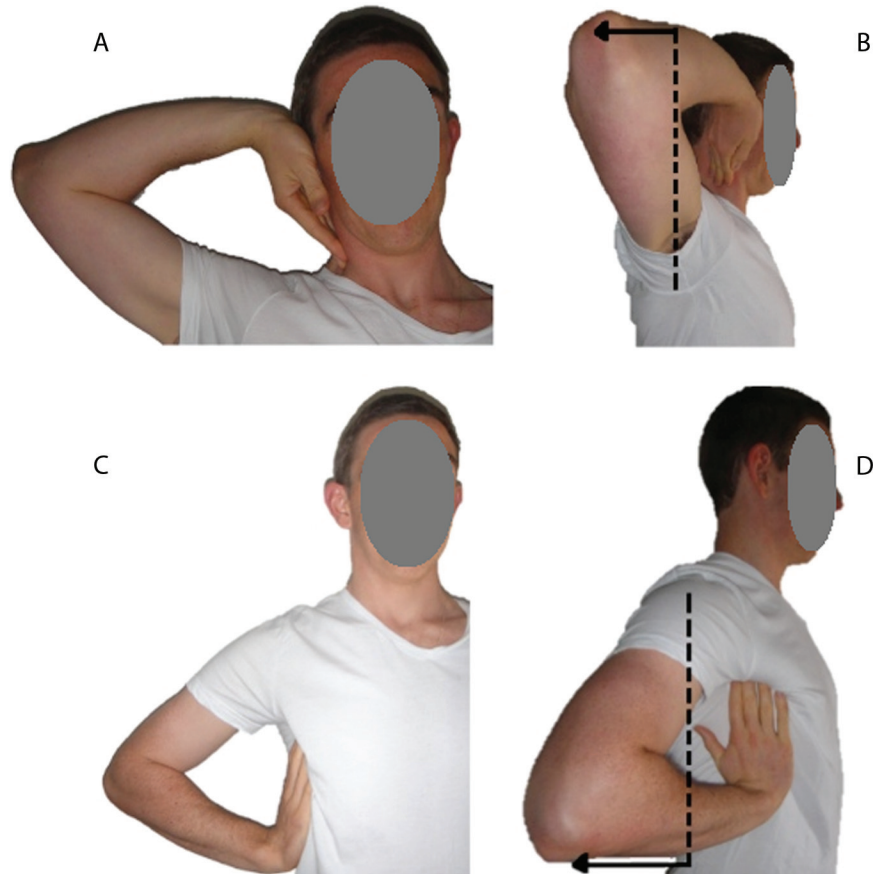
The purpose of this study was to determine the upper limb position that results in: (1) the greatest tension of the ulnar nerve and (2) the greatest difference in tension between the ulnar nerve and the other 2 major nerves of the upper limb: median and radial. This position will constitute a biomechanically plausible ULNT for the ulnar nerve based on the development of tensile force within the nervous system. As such, it may contribute to more accurate clinical interpretation of symptom reproduction during testing, which may improve the clinical detection of neuropathic pain related to the ulnar nerve.

Method

Prior to the commencement of data collection, 10 cadaver specimens ethically approved for anatomical dissection at the University of Newcastle and not used for the collection of ulnar nerve tension data were examined to generate hypotheses about the upper limb positions most likely to induce the greatest tension of the ulnar nerve. This hypothesis generation was necessary because measuring tension in all of the possible upper limb positions (ie, all possible combinations of movements at the neck, shoulder, elbow, wrist, and fingers) was not feasible. These anatomical observations revealed that the distance between the medial humeral epicondyle and the bifurcation of the medial cord of the brachial plexus was greater with shoulder internal rotation compared with external rotation in 90 degrees of shoulder abduction, suggesting the ulnar nerve would have to traverse farther during internal rotation, theoretically increasing its tension. We also observed that with the shoulder in the position for ULNT3 (110° abduction and 90° external rotation), the ulnar nerve runs anterior to the glenohumeral joint axis. We, therefore, hypothesized that the addition of shoulder

horizontal abduction (defined as movement of the humerus posteriorly in the transverse plane with the shoulder abducted to approximately 90°) to ULNT3 also would increase tension of the ulnar nerve.

From these observations, the upper limb positions to be tested were determined. The 5 test positions were: (1) ULNT3 (scapular depression, shoulder abduction and external rotation, elbow flexion, forearm pronation, and wrist and finger extension); (2) ULNT3 with shoulder internal rotation instead of external rotation (ULNT3+IR); (3) ULNT3 with forearm supination instead of pronation (ULNT3+Sup); (4) ULNT3 with the addition of shoulder horizontal abduction (ULNT3+H.Abd, Fig. 1 [A and B]); and (5) ULNT3 with shoulder internal rotation instead of external rotation and with the addition of horizontal abduction (ULNT3+H.Abd+IR, Fig. 1 [C and D]) (Tab. 1).

Data were collected from 10 whole-body human cadavers (mean age at time of death=81 years, range=65–94). All test procedures were applied to both upper limbs (N=20 limbs). The cadavers were embalmed less than 48 hours after death with Arterial Anatomical NF embalming fluid (Genelyn Pty Ltd, Marden, South

Figure 1.
Anterior and lateral views of 2 variations of the current neurodynamic test for the ulnar nerve (ULNT3: scapular depression, shoulder abduction and external rotation, elbow flexion, forearm pronation, and wrist and finger extension). (A) and (B): the current test with addition of horizontal abduction (ULNT3+H.Abd); (C) and (D) the current test with the addition of horizontal abduction and internal rotation (ULNT3+H.Abd+IR). Arrows illustrate the direction of the additional horizontal abduction away from the mid-transverse plane.

Table 1.
Five Upper Limb Positions Used to Compare Tension in the Nerves of the Upper Limb[a]

Position	Scapular	Shoulder	Elbow	Forearm	Wrist
ULNT3	Depression	110° abduction, external rotation	140° flexion	Pronation	Extension
ULNT3+IR	Depression	**80° abduction, internal rotation**	140° flexion	Pronation	Extension
ULNT3+Sup	Depression	110° abduction, external rotation	140° flexion	**Supination**	Extension
ULNT3+H.Abd	Depression	110° abduction, external rotation, **horizontal abduction**	140° flexion	Pronation	Extension
ULNT3+H.Abd+IR	Depression	**80° abduction, internal rotation, horizontal abduction**	140° flexion	Pronation	Extension

[a] ULNT3=ulnar nerve upper limb neurodynamic test (scapular depression, abduction and external rotation, elbow flexion, forearm pronation, and wrist and finger extension) as described by Butler[10]; ULNT3+IR=ULNT3 with internal rotation; ULNT3+Sup=ULNT3 with forearm supination; ULNT3+H.Abd=ULNT3 with horizontal abduction; ULNT3+H.Abd+IR=ULNT3 with horizontal abduction and internal rotation. Movements in bold font have been added to the end position of ULNT3.

Australia, Australia). Kleinrensink et al[29] demonstrated a strong positive correlation in tensile force data between embalmed and nonembalmed specimens, suggesting the use of embalmed specimens would provide acceptable data for comparing tensile force in the upper limb nerves.

Cadavers that had been donated to the University of Newcastle Body Donor Program were considered for entry into the study (in June 2011). Cadavers were excluded from the study if they were found to have evidence of communicable disease or shoulder pathology or if they failed to meet the following range-of-motion (ROM) criteria required for testing using usual clinical methods: shoulder abduction >100 degrees, shoulder external rotation >60 degrees, shoulder internal rotation >60 degrees, elbow flexion >140 degrees, and wrist extension >30 degrees. Out of 15 cadavers examined, 5 were excluded due to inadequate joint ROM.

Sample Size and Dissection
A sample size of 10 cadavers was used in this study, which equates to 20 upper limbs. Anatomical studies published in the literature typically have sample sizes similar to that of the current study.[8,23] The ulnar, median, and radial nerves were exposed in the axilla of both upper limbs through removal of the skin and subcutaneous tissue in a 10- × 5-cm window overlying the nerves. To preserve the relationship between the nerves and surrounding tissue, care was taken to remove as little tissue as possible and still allow attachment of the 3 buckle force transducers.

Instruments
In the present study, *tension* was defined as the longitudinal force applied to a nerve in response to movement of the upper limb.[3] Ten-
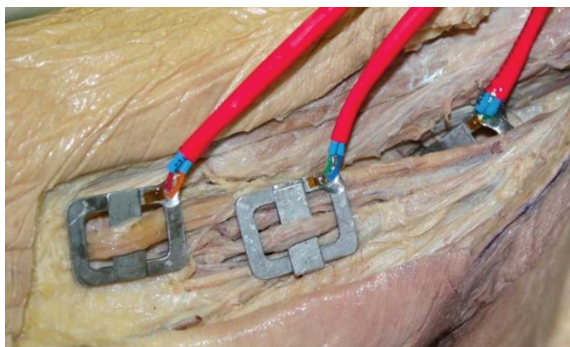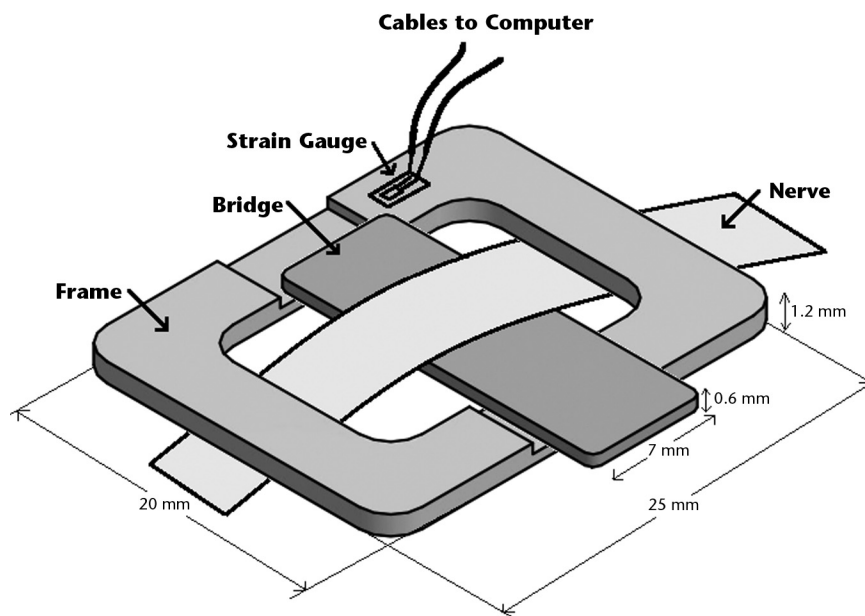

Figure 2.
The 3 buckle force transducers in situ attached (from left to right) to the median, ulnar, and radial nerves in the axilla.

sion of the ulnar, median, and radial nerves was measured (in newtons) using buckle force transducers. Similar transducers have been tested and found to be highly reliable and consistent using nonbiological tissues[30] and human peripheral nerve tissue.[8,29]

To allow for reliable comparison of the nerves during positioning, a buckle force transducer was attached to each of the radial, ulnar, and median nerves at 2, 5, and 8 cm distal to the inferior border of the latissimus dorsi tendon, respectively (Fig. 2). Changes in alignment of nerve tissue in the buckle have been shown to affect the amplitude of tension.[30] Therefore, the position of the 3 buckles was visually inspected before the commencement of each test procedure to ensure the bridges were fixed perpendicularly to each nerve.

The design of the buckle force transducer used in this study is shown in Figure 3. A rectangular frame lies over a nerve, with a bridge that is

Figure 3.
Schematic of the buckle force transducer with a nerve segment.

passed beneath the nerve and on top of the frame. As longitudinal force is applied to the nerve, it straightens, causing the bridge to exert a force on the frame. This force is detected by a force transducer (Applied Measurement, Eastwood, New South Wales, Australia), which is attached to the longer side of the frame. The force transducer forms one limb of a Wheatstone bridge circuit such that changes in tensile force are represented as voltage. Voltage from the strain gauge was displayed continuously using LabVIEW version 10.0 (National Instruments Australia, North Ryde, New South Wales, Australia). For each measure of tension in each limb position, data were collected for 5 seconds at 100 Hz, with the mean value of these 500 data points representing the nerve tension. This procedure allowed comparison of the 3 nerves for each position. These data were converted to newtons for analysis and presentation.

Test Procedure

Each cadaver was placed supine, in the anatomical position. The cadaver was then placed diagonally across the examination table so that the axis of the glenohumeral joint lay just off the table to facilitate scapular depression and shoulder horizontal abduction. Changes in the orientation of the cervical spine, thoracic spine, and the 3 non-test limbs have been shown to alter tension of the upper limb nerves.[28] Therefore, to ensure reliable comparison among cadavers, these body segments were stabilized using sandbags and straps applied to the head, thorax, and lower limbs.

A single trial consisted of measuring tension at the starting position, at 5 test positions (Tab. 1), then again on return to the starting position. One examiner (N.M.) performed 3 trials of each test position, and an average value was calculated and used for analysis. A second examiner (J.J.M.) repeated the test procedure for ULNT3, ULNT3+H.Abd, and ULNT3+H.Abd+IR to determine interrater reliability of tension measurement for these positions. The examiner conducting the test procedure was blinded to the tension data being recorded.

For each upper limb test position, the amount of shoulder abduction and elbow flexion was standardized using conventional goniometry, which has been shown to be reliable when measured by a single assessor.[31,32] All other joints were moved to the maximum available ROM, as these movements could not be reliably measured during the test procedure.

To ensure reliable comparison between trials, a fixed protocol for the sequencing of each position was adopted (Tab. 1). The sequence of the 5 positions was not randomized between trials to allow detection of potential hysteresis across each limb. When the end point of a particular position was achieved, 5 seconds of continuous tension data for each nerve was recorded and averaged. The force transducer was zeroed at the start of the sequence but was not zeroed between test positions. This procedure allowed for comparison of tension between the initial starting (resting) position and the final resting position for the entire sequence to determine the degree of hysteresis, if any, in each nerve.

Data Analysis

Reliability. Reliability of positioning the upper limb was calculated with intraclass correlation coefficients (ICCs) using two-way mixed-effects models for absolute agreement. Incorporating data from the 3 nerves, intrarater reliability was calculated using the 3 trials performed by the first examiner for each position. Interrater reliability was calculated using the mean of the 3 trials between the first and second examiners for ULNT3, ULNT3+H.Abd, and ULNT3+H.Abd+IR. The standard error of measurement (SEM) was calculated using the formula $SD \times \sqrt{1 - r}$, where SD is the standard deviation of all values of the compared trials (3 trials for intrarater comparison and 2 trials for interrater comparison) and r is the ICC value. The smallest detectable difference at a 95% confidence level (SDD_{95}) was calculated using the formula $1.96 \times \sqrt{n} \times SEM$, where n is the number of compared trials (3 for intrarater analysis and 2 for interrater analysis).

Hysteresis. Paired sample t tests were used to compare nerve tension for each nerve between the initial starting (resting) position at the start of all trials and the final resting position at the end of all trials performed by the first examiner. This comparison determined the possible effect of hysteresis on each of the 3 nerves.

Effect of limb position on tension. The effect of limb position on tension was calculated using the mean of 3 trials performed by the first examiner for each position. Data were checked for normality prior to analyses. Descriptive statistics were used to calculate average tension for the radial, median, and ulnar nerves for each of the 5 test positions. A repeated-measures analysis of variance (ANOVA) was used to determine the effects of limb position and nerve on the measured tension. A significant position × nerve interaction indicated a significant effect of position and nerve on tension. Bonferroni post hoc tests determined if tension of the ulnar nerve was significantly different among limb positions. Further comparisons using Bonferroni post hoc tests determined whether there was a difference in tension among the 3 upper limb nerves for each limb position.

Table 2.
Intrarater and Interrater Reliability, SEM, and SDD$_{95}$ of Tension Measurements for the 5 Neurodynamic Test Positions for the Ulnar Nerve[a]

Position	Intrarater Reliability				Interrater Reliability			
	ICC	95% CI	SEM	SDD$_{95}$	ICC	95% CI	SEM	SDD$_{95}$
ULNT3	.92	.88, .95	1.20	4.07	.90	.83, .94	1.20	3.34
ULNT3+IR	.95	.92, .97	1.04	3.54				
ULNT3+Sup	.91	.86, .94	0.89	3.03				
ULNT3+H.Abd	.94	.91, .96	1.41	4.78	.96	.93, .97	1.09	3.03
ULNT3+H.Abd+IR	.95	.93, .97	1.21	4.09	.92	.87, .95	1.21	4.17

[a] ULNT3=ulnar nerve upper limb neurodynamic test (scapular depression, abduction and external rotation, elbow flexion, forearm pronation, and wrist and finger extension) as described by Butler[10]; ULNT3+IR=ULNT3 with internal rotation; ULNT3+Sup=ULNT3 with forearm supination; ULNT3+H.Abd=ULNT3 with horizontal abduction; ULNT3+H.Abd+IR=ULNT3 with horizontal abduction and internal rotation; ICC=intraclass correlation coefficient; 95% CI=95% confidence interval; SEM=standard error of measurement; SDD$_{95}$=smallest detectable difference at 95% CI. The second examiner did not record data for ULNT3+IR and ULNT3+Sup.

Role of the Funding Source

Results
Reliability
Intrarater and interrater reliability were excellent for all positions calculated (Tab. 2). Excellence was defined as ICC >.75.[33] The SEM values across all tested limb positions were ≤1.41 N, and the SDD$_{95}$ values were ≤4.78 N (Tab. 2).

Hysteresis
No significant differences in mean resting tension were observed between the initial starting (resting) position and the final resting position for each of the 3 nerves. The mean starting tension measured over 10 seconds of continuous recording at 100 Hz and the mean ending tension were −0.21 N (SD=0.48) and 0.02 N (SD=0.60), respectively, for the ulnar nerve (P value for the difference=.12); 0.02 N (SD=0.53) and −0.22 N (SD=0.57), respectively, for the median nerve (P=.16); and −0.11 N (SD=0.58) and 0.01 N (SD=0.94), respectively, for the radial nerve (P=.62). These very similar values for tension at the beginning and end of the sequence of limb positioning trials indicate that hysteresis did not occur.

Greatest Ulnar Nerve Tension
Descriptive data are displayed in Table 3 for the 3 nerves in each of the 5 test positions. The ULNT3+H. Abd and ULNT3+H.Abd+IR positions produced significantly greater tension of the ulnar nerve compared with the ULNT3 position (P≤.01, Tab. 3). The largest mean tension of the ulnar nerve occurred in the ULNT3+H.Abd position. The ULNT3+Sup position produced the least amount of tension of the ulnar nerve, significantly less tension than in the ULNT3 position (P<.01, Tab. 3).

Greatest Difference in Tension Among the Ulnar, Median, and Radial Nerves
All positions resulted in significantly greater tension of the ulnar nerve compared with the median and radian nerves (P<.01, Tab. 3). The ULNT3+H.Abd position showed the greatest difference in tension between the ulnar and median nerves (mean difference=11.87 N; 95% confidence interval [95% CI]=9.80, 13.92; P<.01) and the ulnar and radial nerves (mean difference=8.47 N; 95% CI=6.41, 10.53; P<.01) (Tab. 3). The ULNT3+Sup position resulted in the lowest mean difference between the ulnar and median nerves (mean difference=5.25 N; 95% CI=3.73, 6.77; P<.01) and the ulnar and radial nerves (mean difference=3.10 N; 95% CI=1.58, 4.61; P<.01).

Discussion
The currently accepted ULNT3 with the addition of shoulder horizontal abduction (ULNT+H.Abd) and this position with the substitution of shoulder internal rotation for external rotation (ULNT3+H.Abd+IR) resulted in the greatest tension of the ulnar nerve and the greatest difference in tension between the ulnar nerve and the other 2 major nerves of the upper limb: median and radial. These positions constitute biomechanically plausible ULNTs for the ulnar nerve based on the development of tensile force within the nervous system. Their application clinically may contribute to more accurate interpretation of symptom reproduction during testing, which may improve the clinical detection of neuropathic pain related to the ulnar nerve.

Greatest Ulnar Nerve Tension
The position generating the greatest tension of the ulnar nerve was determined by measuring the magnitude of tension of the ulnar nerve when it

Table 3.
Tension (in Newtons) of the Ulnar, Median, and Radial Nerves and Mean Differences in Tension Among the Nerves for Each of the 5 Test Positions[a]

Position	Ulnar Nerve	Median Nerve	Radial Nerve	Ulnar Nerve–Median Nerve	Ulnar Nerve–Radial Nerve	Radial Nerve–Median Nerve
ULNT3	8.71 (3.12) [7.25, 10.17]	0.40 (1.01) [−0.07, 0.87]	3.48 (2.26) [2.42, 4.53]	8.31 [6.52, 10.11][c]	5.24 [3.44, 7.03][c]	3.08 [1.28, 4.87][c]
ULNT3+IR	10.00 (3.54) [8.33, 11.65]	0.42 (0.78) [0.55, 0.78]	3.53 (1.57) [2.80, 4.26]	9.57 [7.80, 11.35][c]	6.46 [4.68, 8.24][c]	3.11 [1.34, 4.89][c]
ULNT3+Sup	6.14 (2.42) [5.01, 7.27][b]	0.89 (1.34) [0.26, 1.52]	3.04 (1.92) [2.15, 3.94]	5.25 [3.73, 6.77][c]	3.10 [1.58, 4.61][c]	2.15 [0.64, 3.67][c]
ULNT3+H.Abd	12.62 (3.96) [10.76, 14.47][b]	0.75 (0.90) [0.33, 1.17]	4.14 (2.10) [3.16, 5.13]	11.87 [9.80, 13.92][c]	8.47 [6.41, 10.53][c]	3.39 [1.33, 5.45][c]
ULNT3+H.Abd+IR	11.86 (4.07) [9.96, 13.77][b]	1.08 (0.93) [0.65, 1.52]	4.97 (2.87) [3.63, 6.31]	10.78 [8.50, 13.06][c]	6.90 [4.62, 9.18][c]	3.89 [1.61, 6.16][c]

[a] Measurements are expressed as mean (SD) [95% confidence interval]. ULNT3=ulnar nerve upper limb neurodynamic test (scapular depression, abduction and external rotation, elbow flexion, forearm pronation, and wrist and finger extension) as described by Butler[9]; ULNT3+IR=ULNT3 with internal rotation; ULNT3+Sup=ULNT3 with forearm supination; ULNT3+H.Abd=ULNT3 with horizontal abduction; ULNT3+H.Abd+IR=ULNT3 with horizontal abduction and internal rotation.
[b] Significantly different mean tension (P≤.01) in this position than in ULNT3.
[c] Significantly different tension (P<.05) between 2 nerves (eg, ulnar and median) for a given position (eg, ULNT3).

was placed in various upper limb positions. The ULNT3+H.Abd position (Fig. 1 [A and B]) generated the largest mean tension of the ulnar nerve. This tension was significantly higher than that produced in any other of the tested positions. The ULNT3+H.Abd position produced 45% more tension of the ulnar nerve compared with ULNT3 alone. In terms of tensile force, this upper limb position may be the most likely to detect neuropathic pain arising from the ulnar nerve and the position least likely to produce a false-negative test. However, in the clinical context, placing the shoulder toward end-range abduction and external rotation may not be tolerated by some patients due to the stress that this position places on nonneural tissue of the anterior shoulder.[22,34] In such instances, the ULNT3+H.Abd+IR position (Fig. 1 [C and D]) may be a more suitable test, as it utilizes shoulder internal rotation rather than external rotation, potentially decreasing stress on the anterior shoulder while producing significantly greater tension of the ulnar nerve compared with ULNT3 alone. Similarly, patients with shoulder pain arising from causes such as subacromial impingement syndrome may not tolerate end-range horizontal abduction and internal rotation. Therefore, the use of either ULNT3 variation should be balanced against the potential sensitivity of local nonneural shoulder structures.

Greatest Difference in Tension Among the Ulnar, Median, and Radial Nerves

The position that generated the greatest difference in tension among the 3 nerves of the upper limb was determined by comparing the tension among the ulnar, median, and radial nerves for each tested upper limb position. That is, the greater the difference in tension between the ulnar nerve and the other 2 nerves

(median and radial), the greater the capacity of that limb position for detecting ulnar nerve tension without inducing tension in the other upper limb nerves. Although in all test positions there were statistical differences in tension among the 3 upper limb nerves, the ULNT3+H.Abd position produced the greatest difference in tension between the ulnar nerve and the other 2 nerves. In terms of tensile force, this upper limb position may be the most likely to differentiate neuropathic pain arising from the 3 major nerves of the arm and the position least likely to produce a false-positive test. However, patients with pre-existing shoulder pathology or highly irritable symptoms may not tolerate the addition of horizontal abduction to an abducted and externally rotated shoulder.[2,22,34] In such patients, the ULNT3+H.Abd+IR position may be used as an alternative to the ULNT3+H.Abd position, as it also displayed comparatively large differences among the 3 upper limb nerves.

Inclusion of Forearm Pronation
The currently accepted ULNT3 includes forearm pronation rather than supination, as anatomical observations suggest that the ulnar nerve would have to traverse farther during pronation, theoretically increasing its tension.[9] However, there were no identified studies comparing tension of the nerve in these 2 variations of the ULNT3. The present study revealed that the ULNT3 test position generated significantly greater tension of the ulnar nerve compared with the ULNT3+Sup position. Similarly, Wright et al,[23] when measuring strain at the elbow and wrist in 5 fresh frozen transthoracic specimens, found that a composite position (ie, 110° of shoulder abduction, elbow flexion, forearm pronation, radial deviation, and wrist and finger extension) produced the greatest strain of the ulnar nerve at

the elbow and wrist. This finding lends support to the inclusion of pronation rather than supination as a component of an ulnar nerve bias ULNT. However, Wright et al[23] did not compare this position with one including supination.

The present study also revealed that both the ULNT3 and ULNT3+Sup positions created a statistically significant difference in tension among all 3 major nerves of the upper limb. This result is in contrast to the findings of Kleinrensink et al,[8] who demonstrated that the ULNT3+Sup position failed to significantly increase tension of the ulnar nerve relative to the other 2 major nerves of the upper limb. The disparity between these findings may be due to the amount of tissue removed in each study, as it has been shown that the tissue surrounding a nerve affects tension development.[35] Alternatively, it may be due to the discrepancy in elbow flexion range (ie, 140° in the present study compared with 120° in the study by Kleinrensink et al[8]), as elbow flexion causes the greatest tension of the ulnar nerve.[9,23,36] Although the current study demonstrated the ULNT3+Sup position resulted in significantly greater tension of the ulnar nerve compared with the median and radial nerves, this position produced the lowest mean difference in tension among all 3 nerves. Therefore, the findings of the present study suggest the use of forearm pronation is preferred over supination for increasing tension in the ulnar nerve, which supports the inclusion of pronation as a component of the currently used ULNT3.

Clinical Implications
The ability of a ULNT to selectively increase tension of its intended nerve provides a foundation for its plausibility to detect peripheral neuropathic pain. A ULNT should be able to reproduce a patient's symp-

toms in the sensory distribution of its intended nerve. In addition, the use of a structural differentiation maneuver should change these symptoms. This is the process used clinically to confirm the presence of neuropathic pain arising from a peripheral nerve. It has been demonstrated that the median nerve bias ULNT is biomechanically plausible[8] and that the use of this test clinically reproduces sensory responses in the distribution of the median nerve in people who are asymptomatic.[2,37]

The present study suggests that the ULNT3 with forearm pronation is biomechanically plausible based on development of tension in the upper limb nerves, and its use clinically has been shown to reproduce symptoms in the distribution of the ulnar nerve.[9,16,38] However, Martínez et al[17] demonstrated that the application of the ULNT3 in individuals who were asymptomatic produced sensory responses in 21 different areas of the upper limb, neck, and face. Although sensory responses occurred predominantly in the medial forearm (the distribution of the ulnar nerve), they also were reported with similar frequency in the lateral forearm and hand (the distribution of the radial and median nerves). In addition, the present study demonstrated the ULNT3+H.Abd and ULNT3+H.Abd+IR positions (Fig. 1) resulted in greater tension of the ulnar nerve and a greater difference in tension among the 3 major nerves of the arm. Therefore, these positions may be more likely to elicit symptoms in the distribution of the ulnar nerve without evoking symptoms from the median or radial nerve. Importantly, this finding may enhance the ability of the clinician to accurately detect neuropathic pain related to the ulnar nerve.

Limitations
Tension of adjacent nonneural tissue (eg, the subclavian artery) has been

documented in cadaveric studies during ULNTs.[39–41] Therefore, as the current study did not measure tension of nonneural tissue, conclusions regarding the biomechanical plausibility of ulnar nerve neurodynamic testing are only related to comparisons made among the 3 nerves. However, due to the unique course of the ulnar nerve in the upper limb, it is unlikely that the combination of movements that comprise an ulnar nerve ULNT will result in greater tension of nonneural tissue compared with the ulnar nerve, as the majority of this tissue is either monoarticular or biarticular.

Future Research

Clinical evaluation is needed to verify the utility of the ULNT3+H.Abd and ULNT3+H.Abd+IR positions in light of the multiple variables that may affect the clinical interpretation of a neurodynamic test. Normative data for joint ROM and symptom response to the proposed positions need to be established in patients who are asymptomatic. Furthermore, the ability of this test to detect ulnar nerve pathology in patients who are symptomatic should be compared with alternate diagnostic methods to determine the clinical utility of these test positions.

In conclusion, we propose a biomechanically plausible test to detect neuropathic pain related to the ulnar nerve. The test consists of the currently described ULNT3 (scapular depression, shoulder abduction and internal rotation, elbow flexion, forearm pronation, and wrist and finger extension) with the addition of horizontal abduction. In clinical situations where the nonneural tissues of the anterior shoulder complex will not tolerate the combination of abduction, external rotation, and horizontal abduction, performing the ULNT3 with internal rotation instead of external rotation may be a biomechanically plausible alterna-

tive for detecting peripheral neuropathic pain related to the ulnar nerve. However, as multiple variables may affect the clinical interpretation of these tests, further investigation is needed to determine whether these results translate to clinical practice.

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