Reliability and Validity of the Standardized Elevated Arm Stress Test in the diagnosis of Neurogenic Thoracic Outlet Syndrome

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ABSTRACT

Objective: We developed a standardized elevated arm stress test (sEAST) meter to standardize patients' posture and measure additional grip and fatigue parameters. In the present prospective cohort study, we aimed to determine the reliability and validity of the sEAST in the diagnosis of neurogenic thoracic outlet syndrome (NTOS).

Methods: Patients evaluated for NTOS between October 2018 and February 2020 were included and performed the sEAST. The patients were classified into a proven NTOS group or a symptomatic control group using the reporting standards for NTOS and the outcome of thoracic outlet decompression surgery. Healthy persons were recruited as an asymptomatic control group. The test–retest reliability, area under the receiver operating characteristic curve, and positive and negative predictive values were calculated for each sEAST parameter.

Results: A total of 426 patients with suspected NTOS and 147 healthy controls had performed the sEAST. The validity analysis was performed with data from 111 patients with proven NTOS, 94 symptomatic controls, and 147 asymptomatic controls. The reporting standards were inconclusive for 116 patients; 77 patients had been excluded because thoracic outlet decompression surgery had not been performed or was unsuccessful, and 28 because they had arterial or venous thoracic outlet syndrome. The area under the receiver operating characteristic curve for the proven NTOS group compared with the asymptomatic control and symptomatic control groups ranged from 0.59 to 0.77 and 0.54 to 0.63, respectively. The positive predictive value ranged from 46% to 65% and the negative predictive value from 51% to 66%. The test–retest reliability analysis for 80 patients with multiple sEAST measurements showed moderate to good (0.52-0.87) intraclass correlation coefficient values for the duration and grip strength parameters. However, the grip fatigue parameters demonstrated poor (0.46-0.16) intraclass correlation coefficient values.

Conclusions: The sEAST showed good test–retest reliability for the duration and grip strength parameters. However, the discriminative value of all sEAST parameters was low for NTOS diagnostics. The good test–retest reliability of the sEAST parameters indicates that they could be valuable outcome measures for comparison in a diagnostic care pathway. (J Vasc Surg 2022;76:821-9.)

Clinical Relevance: A recent study showed the limitations and low diagnostic value of the elevated arm stress test (EAST) in neurogenic thoracic outlet syndrome (NTOS) diagnostics and follow-up. In the present study, we developed a standardized EAST (sEAST) meter to standardize patients' posture and measure additional objective grip and fatigue parameters. With this sEAST, the test–retest reliability of the EAST as measured by the duration increased significantly. In addition, the good test–retest reliability of the additional parameters allowed for reliable comparisons of the grip and fatigue parameters and endorses further investigation to determine whether these sEAST parameters can be used to measure changes over time after treatment of NTOS.

Keywords: Elevated arm stress test; Neurogenic thoracic outlet syndrome; Pinch strength; Provocation test; Thoracic outlet syndrome; Upper extremity

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The diagnosis of neurogenic thoracic outlet syndrome (NTOS) has remained challenging and complex despite the publication of the Society for Vascular Surgery (SVS) reporting standards for NTOS. As described in the SVS reporting standards, the elevated arm stress test (EAST) is used by many clinicians in the diagnostic workup to initiate symptoms and determine the results of a scalene muscle block. However, significant differences in the sensitivity and specificity of the EAST have been reported, which had led to debate regarding the diagnostic value of the EAST.[1,2]

Recently, we determined the diagnostic value of the EAST in a NTOS cohort diagnosed and treated in accordance with the SVS reporting standards for NTOS. Significant differences in patient posture, the instructions given, and the duration of the measurements were observed in our center.[3,4] This could explains the low test–retest reliability of the EAST, which was found in previous studies, and the significant differences in the clinimetric properties of the EAST.[1-3,5-7]

The low test–retest reliability, which we ascribed to the subjective nature of the performance and interpretation of the EAST, was the basis for our development of the standardized EAST meter (SEM). The SEM standardizes posture and performance, frequency of the compressions, and measures five grip strength and four grip fatigue parameters, in addition to the conventional duration measurement. In the present study, we determined the diagnostic value using the test–retest reliability and validity of the sEAST and compared these results to the diagnostic value of the conventional EAST results.

ARTICLE HIGHLIGHTS

- **Type of Research:** A prospective, cohort study
- **Key Findings:** We performed a validity and reliability analysis of the standardized elevated arm stress test (EAST) for the duration and grip fatigue parameters for the diagnosis of neurogenic thoracic outlet syndrome (NTOS). The study included 111 NTOS patients, 94 symptomatic controls, and 147 asymptomatic controls. The results showed low validity (area under the curve, 0.54-63) compared with symptomatic controls but moderate to high test–retest reliability (intraclass correlation, 0.52-0.87).
- **Take Home Message:** Standardization of the EAST led to significant improvements in test–retest reliability. However, the discriminative value of the EAST was low for NTOS diagnostics.

METHODS

The SEM was developed in collaboration with the Applied Physics Department of Fontys Academy (Eindhoven, The Netherlands). After testing two prototypes, the SEM was implemented in September 2018 in daily clinical practice. All patients with suspected NTOS who had been referred from October 2018 to February 2020 to the thoracic outlet syndrome (TOS) clinic were asked to participate in the sEAST measurements. Patients aged >18 years who had provided written informed consent and had had suspected NTOS were included. All patients with comorbidities resulting in posture-related problems for performance of the sEAST (eg, frozen shoulder) and/or technical issues with the sEAST measurements were excluded. All included patients were evaluated in accordance with a multidisciplinary diagnostic care pathway for NTOS determined by the SVS reporting standards for TOS. A detailed description of our care pathway and diagnostic criteria has been recently reported.[8] After evaluation, the diagnosis and treatment options were considered by a multidisciplinary team consisting of a vascular surgeon, a neurologist, a physiotherapist, a radiologist, a pain anesthesiologist, and an orthopedic surgeon.

sEAST measurements. The sEAST was administered by four vascular technicians who had received formal training before the beginning of the study. First, the SEM was set to the patient's posture and the patient was instructed to clench their hand in the grip strength sensors using the firmness of a handshake. The measurement was started by the vascular technician, and the patient clenched and opened their hands at 1-second intervals, following a flashing light, with both arms in 90° of abduction and externally rotated, with the elbows flexed to 90° (Fig 1). The patient and vascular technician were unaware of the sEAST measurement results except for the duration of the sEAST in seconds because that parameter was reported for usual care and decision making. The SEM consisted of identical HD-BTA hand dynamometers (Vernier Software and Technology, Beaverton, OR), one for the left hand and one for the right, which were connected to a computer using a sensorDAQ interface (Vernier Software and Technology; Fig 1 and Supplementary Fig, online only). The sEAST parameters were measured automatically and independently for each hand and included the duration, grip strength, and grip fatigue. The definitions of all parameters are summarized in Table I. The results of the affected side were used for analysis. If both sides were affected, the results of the most affected side were used for analysis. The mean values for both hands were used for analysis of the asymptomatic control group to decrease the potential effect of a stronger dominant hand in a single side comparison with the results from those with NTOS. The results of the sEAST measurement on the first testing day were used for calculation of the diagnostic value.

Fig 1. Standardized elevated arm stress test (sEAST) measurement with the EAST meter setup.

Table I. Standardized elevated arm stress test (sEAST) meter (SEM) measurement parameters

Parameter	Description
Duration	Duration of SEM, seconds
F total	Total grip strength, N
100% Impulse	100% impulse, N × seconds
F max	Maximal grip strength, N
Average impulse	Average impulse, N × seconds
F average	Average grip strength, N
Impulse <50%	Moment in time of reaching 50% of 100% impulse, seconds (fatigue)
Decrease 50%	Decrease of impulse after reaching 50% of 100% impulse, %/second
Decrease total	Decrease of impulse during SEM, %/second
Decrease 10	Decrease of impulse during SEM without first 10 clenches, %/second

Diagnosis and group formation. The participants were divided into three groups: those with proven NTOS, symptomatic controls, and asymptomatic controls. The proven NTOS group included patients who had met the diagnostic criteria of the SVS reporting standards for NTOS and had had a positive response to thoracic outlet decompression (TOD) surgery. The results of TOD surgery were determined by combining the patient-reported outcomes using the Derkash score, disability of the arm shoulder and hand – Dutch language version (DASH-DLV) score, and cervical brachial score questionnaire (CBSQ) results. A positive response was defined as an excellent or good Derkash classification or a fair classification with improvement in the last measured DASH-DLV and CBSQ score compared with the baseline scores. A negative response was defined as a fair Derkash classification without improvement in the last measured DASH-DLV and CBSQ score compared with the baseline scores or a poor Derkash classification. Patients were included in the symptomatic control group if they had not met the SVS reporting standards and a different pathology was diagnosed. Patients were excluded from the present analysis if the findings using the SVS reporting standards were inconclusive. Finally, healthy persons were recruited to form the asymptomatic control group.

The validity analysis was performed using data from the proven NTOS, symptomatic control, and asymptomatic control groups. The test–retest reliability analysis was conducted using data from the proven NTOS group and symptomatic control group with multiple sEAST measurements available. Patients were included when they had performed the first sEAST measurement at the first testing day and the second measurement before the scalene muscle test injection. A flowchart of all the groups for the validity and test–retest reliability analyses is presented in Fig 2. The medical ethical committee of Catharina Hospital approved the present study.

Statistical analysis. Descriptive statistics were used to compare the baseline characteristics. Test–retest reliability was determined using intraclass correlation coefficient (ICC) estimates and their 95% confidence intervals calculated based on a single-rating, absolute-agreement, two-way mixed effects model.[9] Only parameters with an ICC >0.50 were used to determine the validity because parameters with an ICC <0.50 have poor reliability.[9] A subgroup analysis of the ICC values was performed to compare the NTOS and non-NTOS group. Additionally, a subgroup analysis of ICC values was performed to compare patients who had performed both sEAST measurements within 30 days and those who had performed the two measurement with >30 days between them.

To determine whether the sEAST parameters could be used to distinguish among the groups (validity analysis), the area under the receiver operating characteristic (ROC) curve (AUC) was calculated for each sEAST parameter. A backward multiple linear regression of the asymptomatic control group for each sEAST parameter was performed for sex, age, and the dominant hand because these characteristics can influence grip strength.[10] An adjusted ROC curve was created if these characteristics had influenced the sEAST parameter, and a simple

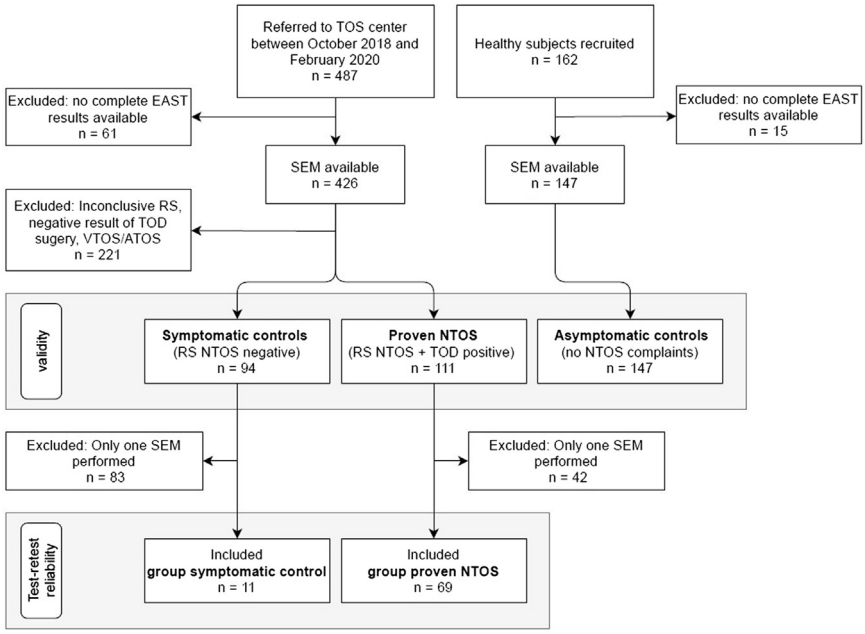

Fig 2. Flowchart showing group formation. *ATOS,* Arterial thoracic outlet syndrome; *EAST,* elevated arm stress test; *NTOS,* neurogenic thoracic outlet syndrome; *RS,* reporting standards; *SEM,* standardized elevated arm stress test meter; *TOD,* thoracic outlet decompression (surgery); *TOS,* thoracic outlet syndrome; *VTOS,* venous thoracic outlet syndrome.

ROC curve was created for the remaining sEAST parameters. First, the proven NTOS group was compared with the asymptomatic control group. If an sEAST parameter had a moderate AUC (AUC >0.70), the proven NTOS group was compared with the symptomatic control group. The cutoff values for the sEAST parameters were determined using the ROC curves comparing the proven NTOS group to the symptomatic control group. If the AUC was <0.70, two optimal cutoff values for daily care practice at 70% sensitivity and 70% specificity were determined. Using these cutoff values, the true-positive (TP), true-negative (TN), false-positive (FP), and false-negative (FN) results were determined and the positive and negative predictive values (PPV and NPV, respectively) calculated.[11] The significance level was set at $P < .05$. Analysis was performed using RStudio, version 1.2.5033 (RStudio, Boston, MA).

RESULTS

A total of 487 patients suspected of having NTOS were referred to the TOS center. Of these 487 patients, 61 were excluded. Exclusion resulted from technical problems (n = 30), posture-related problems and comorbidities (n = 11), the absence of written informed consent (n = 2), and age <18 years (n = 18). After diagnostic analysis, 221 patients were excluded because of inconclusive reporting standards (n = 116), TOD surgery had not been performed (n = 33) or had been unsuccessful (n = 16), incomplete follow-up data (n = 28), or a diagnosis of arterial or venous TOS (n = 28; Fig 2). The validity analysis was conducted using 111 participants with proven NTOS, 94 symptomatic controls, and 147 asymptomatic controls (Table II). The pathology for the symptomatic control group was in the following main categories: a local shoulder problem (n = 24; 26%), tendo-myogenic complaints (n = 6; 6%), radicular syndrome (n = 15; 16%), carpal tunnel syndrome (n = 7; 8%), neuralgic amyotrophy (n = 3; 3%), clavicular abnormalities (n = 1; 1%), and upper extremity complaints not meeting NTOS criteria or another definitive diagnosis (n = 38; 40%). The percentage of women was significantly higher in the proven NTOS group (80%) than in the symptomatic control group (52%; $P < .05$) or asymptomatic control group (45%; $P < .05$). The proven NTOS group was also older (median age, 41 years) than the asymptomatic control group (median age, 31 years; $P < .05$) but not the symptomatic control group (median age, 42 years; $P = .12$). The other baseline characteristics were not significantly different between the groups. The patients with proven NTOS had had significantly ($P < .005$) lower mean scores compared with the symptomatic control group for all sEAST parameters. The asymptomatic control group had had the highest mean scores ($P < .005$) of the three groups. However, no significant differences were found for duration, impulse <50% (moment in time of reaching 50% of 100% impulse), or total grip strength between the healthy and symptomatic control groups. The test duration for the asymptomatic control group was 180 - seconds. All force and fatigue parameters for the

Table II. Patient characteristics stratified by group

Variable	Validity			Test–retest reliability	*P* value
	Proven NTOS group	Symptomatic control group	Asymptomatic control group		
Participants					<.05,[a] .273,[b] <.05[c]
Total	111	94	147	80	
Female	89	49	66	60	
Male	22	45	81	20	
Age, years	41 (34-50)	43 (34-54)	31 (21-46)	42 (35-51)	.118,[a] <.05,[b] <.05[c]
Dominant hand					.291.[a] .705,[b] <.110[c]
Right	95	85	135	66	
Left	16	9	12	14	
Affected side used for analysis					<.829,[a] NA[b,c]
Right	56	46	NA	39	
Left	55	48	NA	41	
Affected side also dominant hand					<.149,[a] NA[b,c]
Yes	62	43	NA	43	
No	49	51	NA	37	
Interval between measurements, days	NA	NA	NA	26 (15-41)	NA[a,b,c]

NA, Not applicable; *NTOS*, neurogenic thoracic outlet syndrome.
Data presented as number or median (interquartile range).
[a] *P* value of χ^2 test for proven NTOS vs symptomatic control groups.
[b] *P* value of χ^2 test for symptomatic control vs asymptomatic control groups.
[c] *P* value of χ^2 test for asymptomatic control vs proven NTOS groups.

asymptomatic group differed significantly between the dominant and nondominant hands ($P < .01$) except for impulse <50%. The women had had significantly ($P < .005$) lower mean scores compared with the men in the asymptomatic control group.

AUCs for the ROC curves comparing the proven NTOS group and asymptomatic control group adjusted for gender were created for the total grip strength, 100% impulse, maximal grip strength, average impulse, and average grip strength. The AUCs for these sEAST parameters ranged from 0.59 to 0.77, with the duration showing the greatest chance (77%) of correctly distinguishing patients with proven NTOS from asymptomatic controls (Fig 3). The ROC curves comparing the proven NTOS and symptomatic control groups resulted in AUCs ranging from 0.54 to 0.63. Again, duration had the highest AUC, with a 63% change of distinguishing proven NTOS patients and symptomatic controls (Fig 3). Because all ROC curves comparing participants with NTOS to symptomatic controls resulted in an AUC <0.70, the cutoff points at 70% sensitivity and 70% specificity were determined for the duration, total grip strength, 100% impulse, maximal grip strength, average impulse, and average grip strength. The cutoff for duration at 70% specificity could not be determined owing to the ceiling effect for this parameter. Using these cutoff points, the TP, FP, TN, and FN results and PPVs and NPVs were determined for each parameter. These outcomes show the low discriminative value for all sEAST parameters, with a 53% to 67% chance (PPV), depending on the parameter, that the participant will have NTOS if the participant has scored less than the lowest cutoff value. The chance that the participant will not have NTOS if the participant scored higher than the highest cutoff value (NPV) varied from 51% to 66% depending on the parameter. The PPVs and NPVs for each parameter are listed in Table III.

The test–retest reliability for the sEAST was determined using data from a subgroup of 80 patients who had undergone at least two sEAST measurements (Table II). The remaining 125 patients were excluded from the analysis because they had not performed the second sEAST measurement. A total of 49 patients had undergone both sEAST measurements within 30 days. The ICC estimates with the 95% confidence intervals are summarized in Table IV. The duration, total grip strength, average impulse, and average grip strength showed good test–retest reliability, with ICCs between 0.70 and 0.87. The 100% impulse and maximal grip strength parameters showed moderate test–retest reliability with an ICC of 0.52 and 0.69, respectively. Impulse <50%, 50% decrease (decrease of impulse after reaching 50% of 100% impulse), total decrease (decrease of impulse during SEM), and decrease 10 (decrease of impulse during SEM without first 10 clenches) showed poor test–retest reliability, with ICCs between −0.16 and 0.46. No improvement in the ICCs were found for the patients who had performed both sEAST measurements within

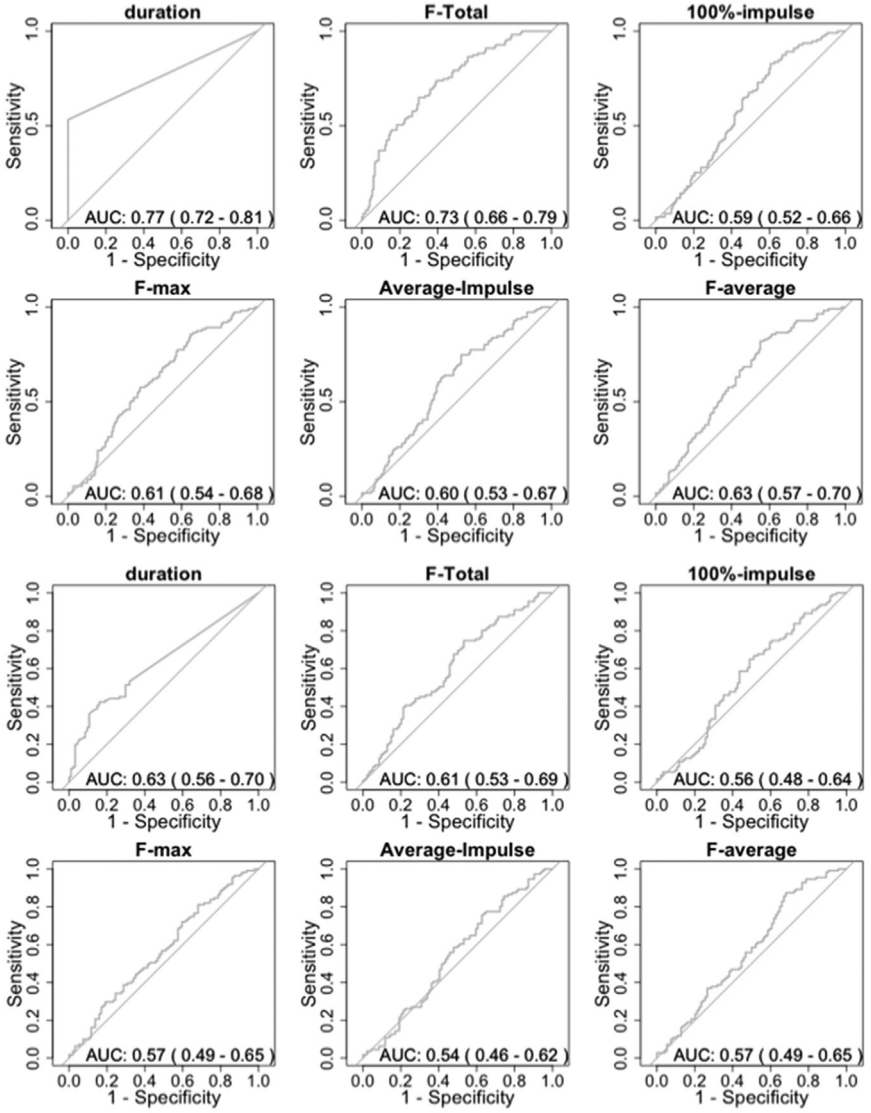

Fig 3. Receiver operating characteristic (ROC) curves and area under the curve (AUC) with 95% confidence intervals for each standardized elevated arm stress test (sEAST) measurement parameter for proven neurogenic thoracic outlet syndrome (NTOS) group compared with asymptomatic and symptomatic control groups. *F-average,* Average grip strength; *F-max,* maximal grip strength; *F-Total,* total grip strength.

30 days compared with those who had performed both measurements with >30 days between them.

DISCUSSION

In the present study, we showed that a standardized approach to posture, performance, and the outcome measures for the EAST is pivotal to performing reliable measurements. Using the SEM for the sEAST measurement, good test–retest reliability was found for duration, with a mean ICC of 0.87. Moderate to good test–retest reliability was found for six additional grip strength sEAST parameters. In contrast, the sEAST parameters that measure fatigue had very poor reliability. This could be explained by the significant variations between the single clench measurements for most patients. Because the calculation for all these fatigue parameters depends on differences between individual impulses, the outcomes for the fatigue parameters will also differ, leading to low test–retest reliability values. Thus, we would advocate for the use of a combination of the duration measurement and grip strength parameters as the primary outcome measures for the sEAST. With these parameters, the sEAST showed improved test–retest reliability compared with the conventional EAST and provided additional reliable outcome measures for comparison and follow-up.

Good test–retest reliability for a diagnostic test is essential for both diagnostic and follow-up purposes. However,

Table III. Cutoff values stratified by gender for each standardized elevated arm stress test (sEAST) measurement parameter and corresponding positive predictive value (PPV) and negative predictive value (NPV) comparing proven neurogenic thoracic outlet syndrome (NTOS) and symptomatic control groups

Parameter	Cutoff value		TP, no.	FP, no.	TN, no.	FN, no.	PPV, %	NPV, %
	Women	Men						
Duration, seconds								
70% Sensitivity	169.5	169.5	57	28	66	54	67	55
70% Specificity	NA	NA	NA	NA	NA	NA	NA	NA
F total, N								
70% Sensitivity	10,319.95	45,419.96	32	17	77	79	65	49
70% Specificity	48,137.65	83,237.66	94	66	28	17	59	62
100% Impulse, N × seconds								
70% Sensitivity	30.6	87.8	32	26	68	79	55	46
70% specificity	73.4	130.6	87	67	27	24	56	53
F max, N								
70% Sensitivity	79.7	179.0	33	21	73	78	61	48
70% Specificity	168.3	267.5	90	66	28	21	58	57
Average impulse, N × seconds								
70% Sensitivity	27.1	74.4	33	29	65	78	53	45
70% Specificity	60.5	107.8	86	68	26	25	56	51
F average, N								
70% Sensitivity	33.0	79.1	33	23	71	78	59	48
70% Specificity	69.1	115.2	97	67	27	14	59	66

FN, False negative (result); *F average,* average grip strength; *F max,* maximal grip strength; *FP,* false positive (result); *F total,* total grip strength; *NA,* not applicable; *NPV,* negative predictive value; *PPV,* positive predictive value; *TN,* true negative (result); *TP,* true positive (result).

differences in the posture of a patient can potentially alter the outcome of the conventional EAST because the angle between both arms and the chest is thought to influence the EAST results owing to the variable compressive effects on the subclavian artery, subclavian vein, and brachial plexus.[12,13] Moreover, the potential interrater variability was minimized by using a standardized approach to patient posture, an automated measurement method, and a standardized protocol for the explanation of the test. This could explain the significant differences in test–retest reliability between the conventional EAST duration (ICC, 0.65) described previously and the sEAST duration (ICC, 0.87) in the present study.[3] The differences between multiple conventional EAST measurements for the diagnosis and follow-up of patients with NTOS should, therefore, be reconsidered. However, if performed with the SEM, the good test–retest reliability of the sEAST further supports the use of the sEAST duration measurement as an objective parameter for follow-up.

The conventional EAST has a prominent role in the SVS reporting standards; however, the diagnostic value of the conventional EAST has been debated.[1,2,14] The results of the 3-minute sEAST measurement in the present study have demonstrated that the parameters can poorly distinguish participants with proven NTOS from symptomatic controls. In line with these results, a low discriminative value for duration using the conventional EAST was found in previous studies.[3] Considering the low discriminative value of both the conventional EAST and the sEAST duration measurement, the diagnosis should not be determined by a positive result from the EAST alone. The EAST should, therefore, be used as a supportive test in a diagnostic care pathway, rather than a standalone diagnostic test. At present, none of the diagnostic tests or imaging techniques have been proved to be sufficient in confirming or excluding the NTOS diagnosis with an acceptable amount of certainty. Therefore, we consider the results of multidisciplinary evaluations, patient history, a physical evaluation that includes a neurologic examination, radiography of the thoracic aperture, use of a diagnostic scalene muscle block, and additional imaging studies to exclude other diagnoses are required for the diagnosis. NTOS can be diagnosed by a combination of these outcomes as defined in the criteria from the SVS reporting standards for TOS. This diagnostic approach resulted in good outcomes for most of the treated NTOS patients.[8] Within this care pathway, the sEAST can be used as a quick screening method for upper extremity complaints during the initial evaluation. More importantly, it provides a reliable outcome measure to compare the results before and after a scalene muscle block. Consequently, the increase in test–retest reliability for the sEAST has improved its

Table IV. Intraclass correlation coefficient (ICC) estimates with 95% confidence intervals for standardized elevated arm stress test (sEAST) parameters

Parameter	Total
Duration	0.87 (0.81-0.92)
Impulse <50%	0.47 (0.28-0.62)
F total	0.79 (0.68-0.86)
100% Impulse	0.52 (0.34-0.66)
F max	0.69 (0.56-0.79)
Average impulse	0.70 (0.57-0.80)
F average	0.77 (0.66-0.85)
Decrease 50%	0.05 (−0.17 to 0.27)
Decrease total	−0.16 (−0.36 to 0.06)
Decrease 10	0.19 (−0.02 to 0.39)

Decrease 10, Decrease of impulse during standardized elevated arm stress test meter without first 10 clenches; Decrease 50%, decrease of impulse after reaching 50% of 100% impulse; Decrease total, decrease of impulse during standardized elevated arm stress test meter; F average, average grip strength; F max, maximal grip strength; F total, total grip strength; Impulse 50%, moment in time of reaching 50% of 100% impulse (fatigue).

potential as a supportive measurement method in the diagnostic care pathway of NTOS.

In addition to the diagnostic possibilities, the sEAST parameters with good ICCs can potentially be used to measure functional improvement in NTOS patients after surgical treatment. In accordance with the SVS reporting standards, the outcome of TOD surgery should be determined using the TOS disability scale, CBSQ score, and DASH score.[14] Additionally, we used the 12-item short-form quality of life survey and Derkash score to assess quality of life, patient-reported outcomes, and return to daily activities.[8] However, changes in the outcomes for these questionnaires could potentially be influenced by other factors (eg, dominant hand, mental state) and not TOD surgery alone.[6,15] Outcome measures that can evaluate functional improvement after TOD surgery independently of these factors would, therefore, be of additional value in determining the outcomes of surgery. Accordingly, future research should focus on the responsivity of the SEM measurement and the value of the sEAST parameters in determining the degree of disability and improvement in functional outcome after TOD surgery.

The present study had some limitations. First, group formation was determined by "proven NTOS" and "symptomatic controls." However, no confirmative test to diagnose NTOS is available, which could potentially have led to mistakes in classifying the patients into the specific groups. Also, the diagnostic value of diagnosing NTOS after completing a care pathway using the SVS reporting standards is unknown. Despite all this, we believe that the SVS reporting standards for TOS combined with a good result after TOD surgery are the most reliable criteria for distinguishing NTOS patients from symptomatic controls. Because of the strict selection criteria, the potential for a selection bias was present in the determination of the diagnostic value of the sEAST, which could have led to an overestimation of the effect. Considering that the diagnostic value of the sEAST used alone was poor, wider selection criteria would not be expected to lead to other conclusions. Second, we used the duration for the validity calculations. However, the duration was also used in daily care practice as a provocation test and to determine the result of the scalene injection test. Subsequently, the duration could have affected the grouping of the patients. This could have led to an overestimation of the AUC and PPVs and NPVs for the duration. However, the patient groups were determined using all the diagnostic criteria from the reporting standards and the outcome of TOD surgery. Thus, the influence of duration on the complete diagnostic care pathway is considered limited. Third, the SEM is not commercially available, making implementation of the SEM difficult. Although the SEM can be reproduced by others, clinicians can also improve and standardize their conventional EAST protocol within the scope of the sEAST, as used in the present study. Standardization of the conventional EAST protocol could also improve test–retest reliability of the conventional EAST.

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AUTHOR CONTRIBUTIONS

Conception and design: NP, BdB, NV, MvS, RT, BvN, JT
Analysis and interpretation: NP, BdB, SH, BvN
Data collection: NP, BdB, JG
Writing the article: NP, BdB
Critical revision of the article: JG, NV, SH, MvS, RT, BvN, JT
Final approval of the article: NP, BdB, JG, NV, SH, MvS, RT, BvN, JT
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NP and BdB contributed equally to this article and share co-first authorship

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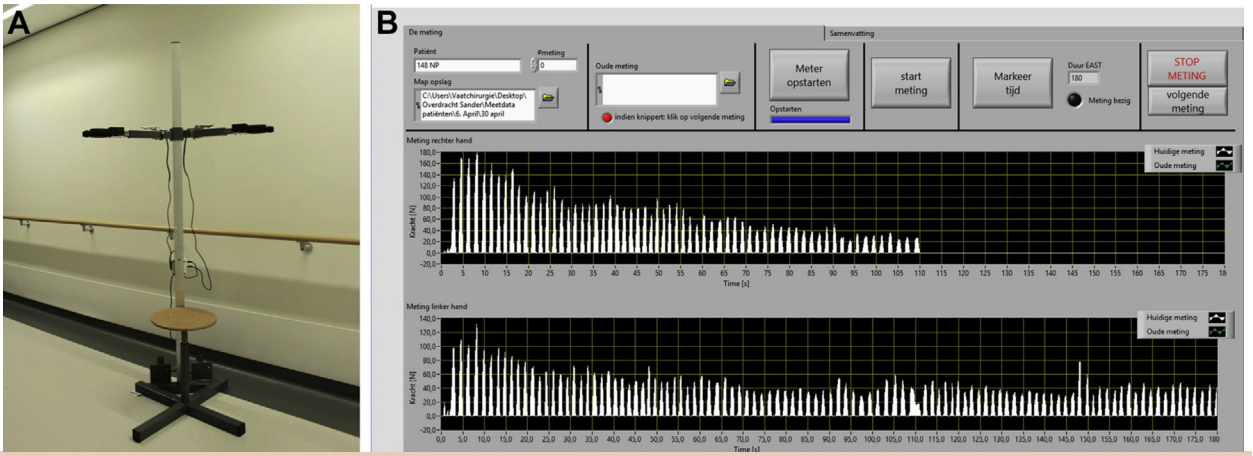

Supplementary Fig (online only). A, Build concept of the elevated arm stress test (EAST) meter. **B,** Software for the standardized EAST (sEAST) meter (SEM; in Dutch).