Validity of range of motion, muscle strength, sensitivity, and Tinel sign tele-assessment in adults with traumatic brachial plexus injury

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Abstract
Background The COVID-19 pandemic and the need for social distancing created challenges for accessing and providing health services. Telemedicine enables prompt evaluation of patients with traumatic brachial plexus injury, even at a distance, without prejudice to the prognosis. The present study aimed to verify the validity of range of motion, muscle strength, sensitivity, and Tinel sign tele-assessment in adults with traumatic brachial plexus injury (TBPI).

Methods A cross-sectional study of twenty-one men and women with TBPI admitted for treatment at a Rehabilitation Hospital Network was conducted. The participants were assessed for range of motion, muscle strength, sensitivity, and Tinel sign at two moments: in-person assessment (IPA) and tele-assessment (TA).

Results The TA muscle strength tests presented significant and excellent correlations with the IPA (the intra-rater intraclass correlation coefficient, ICC ranged between 0.79 and 1.00 depending on the muscle tested). The agreement between the TA and IPA range of motion tests ranged from substantial to moderate (weighted kappa coefficient of 0.47–0.76, p < 0.05) depending on the joint, and the kappa coefficient did not indicate a statistically significant agreement in the range of motion tests of supination, wrist flexors, shoulder flexors, and shoulder external rotators. The agreement between the IPA and TA sensitivity tests of all innervations ranged from substantial to almost perfect (weighted kappa coefficient 0.61–0.83, p < 0.05) except for the C5 innervation, where the kappa coefficient did not indicate a statistically significant agreement. The IPA versus TA Tinel sign test showed a moderate agreement (weighted kappa coefficient of 0.57, p < 0.05).

Conclusions The present study demonstrated that muscle strength tele-assessment is valid in adults with TBPI and presented a strong agreement for many components of TA range of motion, sensitivity, and Tinel sign tests.

Keywords Brachial plexus · Data accuracy · Pandemics · Physical examination · Rehabilitation · Telehealth

Introduction
Traumatic brachial plexus injury (TBPI) occurs in approximately 1.2% of multi-trauma victims admitted to a large trauma hospital [25]. It can be extremely disabling; the person may experience several functional limitations ranging from difficulty in performing simple tasks, such as cutting food, to not being able to return to work in the same way as before the trauma [11, 24]. After TBPI, it is essential to monitor recovery at various time intervals. The main variables used for monitoring are muscle strength, sensitivity, and the presence of the Tinel sign. More severe cases that do not show signs of recovery may require neurosurgical treatment, which is generally performed in the first 6 months after the accident [23, 28]. However, the measurements and evaluations implemented in the physical examination must be valid, reliable, and sensitive to detect change.

Abbreviations
TBPI Traumatic brachial plexus injury
IPA In-person assessment
TA Tele-assessment
The recent coronavirus outbreak (COVID-19) is now a pandemic, and as a result, many individuals around the world are isolated for treatment and evaluation to prevent the spread of the infection [26]. In addition, isolation can make it difficult to access rehabilitation services, which are the most effective measures against declining physical and psychological conditions of those who depend on these services [27].

Telerehabilitation, like tele-exercise, is an alternative to provide rehabilitation services to individuals in remote locations and could serve as a solution to the current situation of social isolation [6]. One of the pathologies that may benefit from this intervention format is traumatic injuries of the brachial plexus (TBPI) [32].

However, the measurements and evaluations implemented in the physical examination must be valid, reliable, and sensitive to detect change. No specific studies have assessed the reliability of virtual physical examinations in patients who are victims of TBPI [1]. Thus, the present study aimed to verify the validity of muscle strength, range of motion, sensitivity, and Tinel sign tele-assessment in adults with TBPI.

Methods

Participants

Twenty-one men and women with TBPI admitted to rehabilitation were recruited for the study. Data were collected from June 2020 to April 2021. The study was approved by the institutional Ethics Committee (protocol no. 4.277.239), and all participants provided written informed consent.

The inclusion criteria were (a) diagnosis of TBPI; (b) over 18 years of age; and (c) participants with internet access with sufficient capacity for video calling.

Participants were excluded if they had a history of severe sequelae of traumatic brain injury, clinically unstable diseases (neoplastic processes, infectious or uncontrolled convulsive crises), fractures under treatment with an external fixator, or wounds that prevented evaluation.

Procedure

The assessments were carried out by two experienced professionals in brachial plexus evaluation, a physical therapist and a neurosurgeon, and lasted about 30 min depending on some aspects such as internet connection and patient collaboration.

They were divided into two stages, in-person assessment (IPA) and tele-assessment (TA), separated by a maximum of 4 weeks. One professional performed the TA and other professional performed the IPA.

Both assessments were performed in a standardized way.

TA positioning instructions

In TA, patients were instructed to remain standing approximately 1.5 m in front of their computer, or in the case of a cell phone or tablet, to support it on a table in front of them. In the sitting position, patients were instructed to sit with their arms resting on a table in front of the camera, which was positioned “one arm away,” equivalent to about 40 cm. For the supine position, a family member or companion was asked to hold the camera.

Muscle strength

Muscle strength was assessed by manual muscle testing according to the Medical Research Council scale [5] and Daniels’ manual of testing [13].

The upper trapezius, shoulder abductors, elbow flexors, triceps brachii, supinators, wrist extensors, wrist flexors, flexor pollicis longus, opponens pollicis, and adductor pollicis muscles were evaluated (Appendix 25).

IPA

Tests were performed as described by Daniels [13], and the manual resistance was applied by the examiner.

TA

Tests were performed as described by Daniels [13], and the manual resistance was applied by the patient following verbal instructions and with visual feedback from the examiner. The patient was instructed to push the tested segment with the contralateral hand and resist the movement. The distinction between grades 4 and 5 was made by observational analysis; grade 5 was considered when the patient failed to push the tested segment down.

Passive range of motion

Passive range of motion was assessed by visual estimation as normal or restricted according to the normality references [15, 30].

Global exploration of the shoulder (functional range), shoulder flexion, abduction and external rotation, elbow, wrist, metacarpophalangeal and interphalangeal flexion and extension, and forearm supination was assessed.
IPA

For global exploration of the movement of the shoulder, the patients were instructed to raise their arm and then the lead hand towards the contralateral scapula. This movement explored abduction and external rotation. The amplitude was considered normal when the arm was brought parallel to the ear [15].

Passive range of motion was assessed by an examiner.

TA

For global exploration of the movement of the shoulder, the patients were instructed to raise their arm with the other hand and then move the hand towards the contralateral scapula. The amplitude was considered normal when the arm was brought parallel to the ear [15].

For passive range of motion, the patients were instructed to carry out the movements with help from the other hand, following verbal instructions and with visual feedback from the examiner.

Sensitivity

Sensitivity was assessed by an adaptation of the 10 test, which is a simple touch perception test with excellent reliability (ICC = 0.87–0.91), and correlation with the Semmes–Weinstein monofilament test [29]. In this test, the patient was instructed to classify as normal, diminished, or absent the perception of the touching movement applied to the skin compared to the contralateral side. Each upper limb dermatome was tested separately.

In IPA, the test was performed by the examiner.
In TA, the touch was performed by the patient, following verbal instructions and with visual feedback from the examiner.

Tinel sign

The evaluation of the Tinel sign was obtained through percussion of the supraclavicular cervical region in the topography referring to the brachial plexus in the region posterior to the sternocleidomastoid between the anterior and middle scalenes. The presence of paresthesia radiating to the arm, forearm, or hand after percussion of the neck was considered positive. The accuracy of the Tinel test to distinguish between avulsion/pre-ganglionic and post-ganglionic lesion is described as 73.7% [17].

In IPA, percussion was performed by the examiner.
In TA, percussion was performed by the patient, following verbal instructions and with visual feedback from the examiner.

Data analysis

A sample size of 21 individuals was calculated a priori using the correlation for a bivariate normal model, considering an α of 5%, power (1-β) of 90%, and a moderate effect size (0.60) [10].

For the kappa statistic, the Donner and Eliasziw goodness-of-fit [7] approach claims that based on alpha and beta error rates of 0.05 and 0.2, respectively, when testing a statistical difference between moderate (0.40) and excellent (0.90) kappa values, sample size estimates range from 13 to 66.

The Kolmogorov–Smirnov test was used to assess the data normality assumptions. Descriptive data are presented as mean and standard deviation or median and interquartile range (25th and 75th percentiles) for the outcomes defined as parametric or nonparametric, respectively.

To assess the validation of muscle strength tests, the intraclass correlation coefficient (ICC) with the Bland–Altman plot was used to correlate the IPA with TA. The ICC was classified based on the Cicchetti standards: the level of clinical significance is poor below 0.40; fair between 0.40 and 0.59; good between 0.60 and 0.74; excellent between 0.75 and 1.00 [4]. Confidence intervals of 95% (95% CI) were used between comparisons.

To assess the validation of the passive range of motion and the sensitivity test and the Tinel sign evaluation, the Cohen kappa test was used to correlate the IPA with the TA. The kappa test is a measure of agreement for variables that can be categorized. The scale for determining the level of agreement of kappa values according to Landis and Koch [18] states 0 = poor; 0.01–0.2 = slight; 0.21–0.4 = fair; 0.41–0.6 = moderate; 0.61–0.8 = substantial; and 0.81–1 = almost perfect.

The IBM SPSS Statistics package (version 22.0; SPSS Inc., Armonk, NY, USA) and G*Power Statistical Power Analyses software (version 3.1.9.2; Universität Kiel, Germany) were used. Statistical significance was set at 5% (P ≤ 0.05; two-tailed).

Results

There were no dropouts from the study. A total of 21 individuals with TBPI (1 woman and 20 men) were recruited with a median and interquartile range (25th and 75th percentiles)
of 29.3 (23.5–35.5) years. The complete demographic and clinical data of the participants are presented in Table 1.

**TA muscle strength tests**

The TA muscle strength tests presented significant and excellent correlations with the IPA muscle strength tests: upper trapezius (ICC = 0.79; 95% CI [0.47, 0.92]); shoulder abductors (ICC = 0.87; 95% CI [0.69, 0.95]); elbow flexors (ICC = 1.00; 95% CI [1.00, 1.00]); triceps brachii (ICC = 0.99; 95% CI [0.98, 1.00]); supinators (ICC = 0.91; 95% CI [0.78, 0.97]); wrist extensors (ICC = 0.99; 95% CI [0.98, 1.00]); wrist flexors (ICC = 0.99; 95% CI [0.98, 1.00]); flexor pollicis longus (ICC = 0.99; 95% CI [0.97, 1.00]); adductor pollicis (ICC = 0.96; 95% CI [0.98, 1.00]); and opponens pollicis (ICC = 0.96; 95% CI [0.90, 0.98]) (Table 2).

The Bland and Altman analysis showed differences between the TA and IPA muscle strength tests, and the intervals around the differences (±1.96 S.D.), were −0.3 and 4.3 (trapezius); 0.1 and 1.9 (shoulder abductors); 0.0 and 0.0 (elbow flexors); −0.1 and 1.9 (triceps brachii); 0.0 and 3.4 (supinators); 0.0 and 1.5 (wrist extensors); 0.0 and 1.5 (wrist flexors); 0.0 and 2.0 (flexor pollicis longus); 0.1 and 3.8 (adductor pollicis); and 0.1 and 3.8 (opponens pollicis), respectively. Two points were outside these limits (Table 2, Fig. 1).

**TA range of motion tests**

The TA versus IPA range of motion tests of the functional range, wrist extension, metacarpophalangeal flexion/extension, and interphalangeal flexion/extension showed substantial agreement (weighted kappa coefficient of 0.63–0.76, p < 0.05), with agreements ranging between 84 and 95%. The TA versus IPA range of motion tests of the elbow and shoulder abduction showed 80% agreement and moderate agreement (weighted kappa coefficient of 0.47–0.55, p < 0.05) depending on the joint tested. Kappa coefficient did not indicate a statistically significant agreement in the range of motion tests of supination, wrist flexion, shoulder flexion, and shoulder external rotation (Table 3).

**TA sensitivity tests**

The IPA versus TA sensitivity tests of all innervations showed agreements ranging between 84 and 90% and substantial to almost perfect agreement (weighted kappa coefficient of 0.61–0.83, p < 0.05) except for the C5 innervation for which the kappa coefficient did not indicate a statistically significant agreement (Table 3).

**TA Tinel sign test**

The IPA versus TA Tinel sign test showed 78% agreement and moderate agreement (weighted kappa coefficient of 0.57, p < 0.05) (Table 3).

**Discussion**

The purpose of this study was to verify the validity of muscle strength, range of motion, sensitivity, and Tinel sign tele-assessment in adults with TBPI. The TA muscle

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### Table 1: Participants demographic data. Age was expressed as median and quartiles (25%; 75%). Time since injury and age at injury were presented as mean (standard deviation). Level injury and etiology were expressed in absolute values (frequency)

| Relation women to men | 1:20 |
|-----------------------|------|
| Age (years)           | 29.3 (23.5–35.5) |
| Time since injury (months) | 9.9 (±5.5) |
| Age at injury (years)  | 21.6 (±11.8) |
| Level injury (n)      |       |
| C5                    | 2 (9.5%) |
| C5–C6                 | 6 (28.6%) |
| C5–C7                 | 2 (9.5%) |
| C5–C8                 | 1 (4.8%) |
| C5–T1                 | 10 (47.6%) |
| Etiology (n)          |       |
| Crush                 | 1 (4.8%) |
| Falls                 | 2 (9.4%) |
| Motorcycle accident   | 17 (81.0%) |
| Running over          | 1 (4.8%) |

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### Table 2: Intraclass correlation coefficient (ICC) comparing in-person assessment and tele-assessment. The interval confidence was set on 95% (95% CI)

| Strength          | MD  | Δ     | ICC (95% CI)    |
|-------------------|-----|-------|-----------------|
| Upper trapezius   | −0.3| 4.3   | 0.79* (0.47–0.92) |
| Shoulder abductors| 0.1 | 1.9   | 0.87* (0.69–0.95) |
| Elbow flexors     | 0.0 | 0.0   | 1.00* (1.00–1.00) |
| Triceps brachii   | −0.1| 1.9   | 0.99* (0.97–1.00) |
| Supinators        | 0.0 | 3.4   | 0.91* (0.78–0.97) |
| Wrist extensors   | 0.0 | 1.5   | 0.99* (0.98–1.00) |
| Wrist flexors     | 0.0 | 1.5   | 0.99* (0.98–1.00) |
| Flexor pollicis longus | 0.0 | 2.0   | 0.99* (0.97–1.00) |
| Adductor pollicis | 0.1 | 3.8   | 0.96* (0.98–1.00) |
| Opponens pollicis | 0.1 | 3.8   | 0.96* (0.90–0.98) |

IPA, in-person assessment; MD, mean difference; TA, tele-assessment *Significant difference (p ≤ 0.05)
strength tests demonstrated excellent correlations with the IPA, indicating that strength tele-assessment is an alternative for clinical measurement in the new telerehabilitation approach.

Muscle strength was assessed by manual muscle testing, which presents a diagnostic accuracy of 78% and has excellent reliability for trained examiners [3, 9]. The present study found significant and excellent correlations between TA and IPA for muscle strength tests, and most results did not present differences between TA and IPA. Mani et al., in their systematic review, described good-to-excellent agreement when examining studies measuring static muscle strength by applying patient self-resistance in musculoskeletal disorders [21]. Despite the reliable results, the assessment of muscle strength through the TA was a challenge, especially in the distinction between grades 0 and 1 and grades 4 and 5, as the examiners lacked physical contact with the patients.
Passive range of motion was assessed by visual estimation, which has good reliability, similar to goniometry [12]. The present study presented moderate-to-substantial agreement, and the agreement ranged between 80 and 95% for TA versus IPA range of motion for all movements evaluated except for forearm supination and shoulder flexion and external rotation. We did not find references comparing visual estimation between TA and IPA or evaluating the reliability of visual estimation in TA. Using goniometric measurements, general studies described a good-to-excellent agreement between TA and IPA [21]. Another study about visual estimation in IPA described fair to good reliability for the visual estimation and goniometry for shoulder abduction [12]. Lower levels of accuracy [22] were described for the hand and wrist. The results of the present study differed for shoulder flexion and external rotation and elbow measures. Previous studies described fair to good reliability for the visual estimation and goniometry of the shoulder in IPA [12] and excellent agreement for elbow visual estimation and goniometry in IPA [2].

Many factors could explain the lack of agreement in the range of motion tests of supination, shoulder flexion, and shoulder external rotation and the lower estimated elbow range of motion. Measures were categorized differently, such as normal or restricted in the current study and in degrees in the other studies. Technological factors such as bandwidth limitations, low camera resolution, and bad lighting may have made it difficult to guide and visualize all movements [21]. Variations in the positioning of the patient or the camera, such as not positioning exactly to the side or in front of the camera, or even the tilt angle of the camera could give false visualization of a mobility restriction as well as variation in the patient’s pressure at the end of the movement. Lastly, supination and shoulder external rotation are complex movements to perform.

In future studies, other technologies can be considered besides goniometry, including the use of clinometers in smartphones, accelerometers, gyroscopes, camera-based motion software, and inertial sensor monitoring units [16].

The IPA versus TA Tinel sign test showed 78% agreement and moderate agreement. The present study demonstrated equivalent results to those described for IPA, with the accuracy of the Tinel test described as 73.7% [29].

Sensitivity was assessed by an adaptation of the ten test, which is a simple touch perception test, with excellent reliability (ICC = 0.87–0.91) and correlation with the Semmes–Weinstein monofilaments test [15]. The present study presented substantial to almost perfect agreement, ranging between 84 and 90% for IPA versus TA sensitivity tests for all innervations except for the C5 innervation. Other studies describe sensory testing performed by TA as challenging and difficult [19, 33]. In the current study, we observed that it was difficult for some patients to define whether what they were feeling was hypoesthesia, anesthesia, or even hyperesthesia. Further studies that compare different methods of evaluating the C5 innervation are suggested to prove this hypothesis.

### Study limitations

One of the limitations of this study was related to the convenience sample. However, the population studied was representative of the general population with TBPI [8, 14]. Another consideration is that the evaluators were not blind to clinical information. Also, no random order of tests was utilized, which could influence the results [20, 31].

Considerations about the tests are discussed below.

### Clinical implication

In patients with traumatic brachial plexus injury, tele-assessment could represent an important tool to guide treatment. For example:

- At this moment, we believe that in some cases, we do not indicate surgery using only the tele-assessment, as in patients that recovered all the movements of the

| Table 3 | Kappa coefficient (K) comparing in-person assessment and tele-assessment of range of motion, sensibility, and Tinel sign |
|---------|--------------------------------------------------------------------------------------------------|
|         | Range of motion | Sensibility | Tinel |
|         |               | % | K   | %     | K     |
| Functional range | 84 | 0.70* | 65 | 0.19 | 78 | 0.57* |
| Elbow flexion/extension | 80 | 0.47* | 90 | 0.83* | 84 | 0.61* |
| Supination | 70 | 0.29 | 90 | 0.82* | 70 | 0.29 |
| Wrist flexion | 95 | 0.50 | 85 | 0.74* | 80 | 0.55* |
| Wrist extension | 90 | 0.76* | 85 | 0.63* | 90 | 0.76* |
| Metacarpophalangeal flexion/extension | 85 | 0.63* | 95 | 0.64* | 70 | 0.29 |
| Interphalangeal flexion/extension | 95 | 0.64* | 70 | 0.29 | 80 | 0.55* |
| Shoulder flexion | 70 | 0.29 | 80 | 0.55* | 70 | 0.29 |
| Shoulder abduction | 80 | 0.55* | 80 | 0.55* | 70 | 0.29 |
| Shoulder external rotation | 70 | 0.29 | 80 | 0.55* | 70 | 0.29 |
| Sensibility | C5 innervation | 65 | 0.19 | 65 | 0.19 | 84 | 0.61* |
|            | C6 innervation | 90 | 0.83* | 90 | 0.83* | 84 | 0.61* |
|            | C7 innervation | 90 | 0.82* | 90 | 0.82* | 84 | 0.61* |
|            | C8 innervation | 85 | 0.74* | 85 | 0.74* | 70 | 0.29 |
|            | T1 innervation | 84 | 0.61* | 84 | 0.61* | 70 | 0.29 |
| Sensibility | C5 innervation | 65 | 0.19 | 65 | 0.19 | 84 | 0.61* |
|            | C6 innervation | 90 | 0.83* | 90 | 0.83* | 84 | 0.61* |
|            | C7 innervation | 90 | 0.82* | 90 | 0.82* | 84 | 0.61* |
|            | C8 innervation | 85 | 0.74* | 85 | 0.74* | 70 | 0.29 |
|            | T1 innervation | 84 | 0.61* | 84 | 0.61* | 70 | 0.29 |

IPA, in-person assessment; TA, tele-assessment

* Significant difference (p ≤ 0.05)

%: percentage agreement
affected upper limb. The opposite is also true: there are situations where we can have a good estimate of the need for surgery, as in patients with 6 months of trauma and that have a flail arm. However, it must be emphasized that in all the situations, we advise an in-person evaluation to confirm surgery to help decide the surgical approach. Tele-assessment may help the surgeon to indicate surgery and estimate the ideal surgical approach.

- Tele-assessment may help to establish a topographic diagnosis and infer the severity and prognosis of the injury.
- Tele-assessment allows for the observation of joint limitations, which occur frequently, and guidance for passive mobilization.
- Some variables influence tele-assessment, such as when a patient is seriously ill and still in a hospital. While we did not go through this situation, but if we observe that for various reasons, such as the patient’s clinical condition, cooperation, and ability to collaborate with the online consultation, or problems with the internet, a face-to-face consultation will be necessary for a better evaluation.

Furthermore, in the postoperative period, it is possible to observe if there is recovery to guide rehabilitation.

There is also the possibility of evaluating other aspects, such as the response to drug treatment for neuropathic pain and conducted rehabilitation, providing a continuous review and adequation of exercises, mood swings, and coping; education on citizens’ rights and community resources; and facilitation of activities of daily living.

Finally, in countries with continental dimensions, it is possible to reduce face-to-face consultations, maintaining the quality of care and leading to a lower cost of treatment for patients and the government.

Perspectives

The COVID-19 pandemic and the need for social distancing has created challenges in health care access. Telemedicine has played a significant role in the delivery of medical services and is likely to be of continued importance and used even after the current pandemic.

Overall, the present study showed a strong agreement for many components of TA range of motion, sensitivity, and Tinel sign tests. However, the established differences in the range of motion (supination, wrist flexors, shoulder flexors, and external rotators) and sensitivity (C5 innervation) between TA and IPA should be considered. The authors suggest further studies to acquire more precise data of TA range of motion (supination, wrist flexors, shoulder flexors, and external rotators) and sensitivity (C5 innervation).

Since our study, we continued to use tele-assessment for many patients, mostly for those who live far away from our hospital, and we intend to improve it.

Conclusions

The present study demonstrated that muscle strength tele-assessment is valid in adults with TBPI and presented strong agreement for many components of TA range of motion, sensitivity, and Tinel sign tests. However, the authors suggest emphasizing the criteria used for TA in range of motion (supination, wrist flexors, shoulder flexors, and external rotators) and sensitivity (C5 innervation), as these TA showed limitations. These findings support the importance of remote assessment in the context of the pandemic or post-pandemic, allowing us to direct the treatment of patients early or on time.

Appendix I

Upper trapezius

The patient was guided to elevate their shoulders in a standing position.

In IPA, the examiner remained behind the patient and gave resistance in a downward direction.

In TA, manual resistance was applied by the patient, following verbal instructions and with visual feedback from the examiner. The distinction between grades 4 and 5 was made by observational analysis; grade 5 was considered when the patient failed to push the tested segment down.

Shoulder abductors

The patient was guided to lift their arm out to the side to shoulder level in a standing position.

If the patient abducted the arm to 90°

In IPA, the examiner remained behind the patient and gave resistance in a downward direction, to grades between 4 and 5.

In TA, manual resistance was applied by the patient, following verbal instructions and with visual feedback from the examiner. The distinction between grades 4 and 5 was made by observational analysis; grade 5 was considered when the patient failed to push the tested segment down.

If the patient was not able to abduct the arm to 90°

In both situations, the examiner looked for reduction in subluxation for grade 1 and continued testing in the supine position to test grade 2, asking the patient to abduct the arm to 90°.
Elbow flexors

The patient was guided to bend their elbow in a standing position.

If the patient completed the available range

In IPA, the examiner remained in front of the patient and gave resistance in a downward direction, to grades between 4 and 5. In TA, manual resistance was applied by the patient, following verbal instructions and with visual feedback from the examiner. The distinction between grades 4 and 5 was made by observational analysis; grade 5 was considered when the patient failed to push the tested segment down.

If the patient was not able to complete the available range

The exam continued to test grades 0 to 2. In IPA, with the arm abducted to 90° and supported by an examiner, the patient was guided to bend their elbow for grade 2. If no movement was observed, the examiner palpated for contractile response to evaluate grade 1. In TA, the arm was supported by the patient for grade 2 testing. To evaluate grade 1, the examiner looked for contraction and asked the patient to palpate or perceive a contractile response.

Elbow extensors

The patient was guided to extend their elbow in a standing position.

If the patient completed the available range

In IPA, the examiner gave resistance in a downward direction, to grades between 4 and 5. In case of suspected compensation, the test was also performed in the supine position. In TA, with the arm at the side and elbow flexed to 90°, manual resistance was applied by the patient in an upward direction, following verbal instructions and with visual feedback from the examiner. The distinction between grades 4 and 5 was made by observational analysis; grade 5 was considered when the patient failed to push the tested segment up.

If the patient was not able to complete the available range

In IPA, with arm horizontally abducted to 90° and supported by the examiner, the patient was guided to straighten their elbow for grade 2. If no movement was observed, the examiner palpated for contractile response to evaluate grade 1. In TA, the arm was supported by the patient for grade 2 testing. To evaluate grade 1, the examiner looked for contraction and asked the patient to palpate or perceive a contractile response.

Forearm supinators

In a sitting position, arm at the side and elbow flexed to 90°, the patient was guided to supinate the forearm until the palm faced the ceiling.

If the patient completed the available range

In IPA, the examiner stood in front of the patient and supported the elbow.

In TA, their arm was resting on a table.

If the patient was not able to complete the available range

In both situations, the exam continued with the shoulder flexed around 45° and elbow flexed to 90° to grade 2. In IPA, palpation for a contractile response, to grade 1, was performed.

Author’s hints: We do not recommend palpation in TA because it is difficult to distinguish between supinators and wrist and hand muscles. It is important to guide patients to keep their wrist and fingers relaxed to avoid substitution by the extensors.

Wrist flexors

In a sitting position, arm at the side and elbow flexed to 90°, forearm supinated, the patient was guided to flex the wrist, keeping the fingers and thumb relaxed.

If the patient completed the available range

In IPA, the examiner stood in front of the patient and supported the forearm.

In TA, the forearm was resting on the table and the wrist off the table. Help from a family member or companion was requested to keep the forearm in supination.

If the patient was not able to complete the available range

In IPA, the examiner gave resistance in the direction of wrist extension, to grades between 4 and 5.
In TA, manual resistance was applied by the patient in the direction of wrist extension, following verbal instructions and with visual feedback from the examiner. The distinction between grades 4 and 5 was made by observational analysis; grade 5 was considered when the patient failed to extend the wrist.

**If the patient was not able to complete the available range**

In both situations, the exam continued with the forearm in a neutral position.
In IPA, if no movement was observed, the examiner palpated for contractile response to evaluate grade 1.
In TA, the forearm was supported by the patient for grade 2 testing. To evaluate grade 1, the examiner looked for contraction and asked the patient to palpate or to perceive a contractile response.

**Wrist extensors**

In a sitting position, arm at the side and elbow flexed to 90°, forearm pronated, the patient was guided to extend the wrist keeping the fingers and thumb relaxed.
In IPA, the examiner stood in front of the patient and supported the forearm.
In TA, the forearm was resting on the table and the wrist off the table.

**If the patient completed the available range**

In IPA, the examiner gave resistance in the direction of wrist flexion, to grades between 4 and 5.
In TA, manual resistance was applied by the patient in the direction of wrist flexion, following verbal instructions and with visual feedback from the examiner. The distinction between grades 4 and 5 was made by observational analysis; grade 5 was considered when the patient failed to flex the wrist.

**If the patient was not able to complete the available range**

In IPA, the forearm was supported in a neutral position by the examiner for grade 2 testing. To evaluate grade 1, the examiner palpated for a contractile response.
In TA, their hand was resting on the table.

**Flexor pollicis longus**

In a sitting position, arm at the side with the elbow flexed to 90°, forearm and wrist in a neutral position, and thumb lying relaxed and adjacent to the second metacarpal. The patient was guided to flex the interphalangeal joint of the thumb.
In IPA, the examiner stood in front of the patient and stabilized the metacarpophalangeal joint.
In TA, the forearm was resting on the table and the patient stabilized the metacarpophalangeal joint.

**If the patient completed the available range**

In IPA, the examiner gave resistance in the direction of thumb extension, to grades between 4 and 5.
In TA, manual resistance was applied by the patient, following verbal instructions and with visual feedback from the examiner. The distinction between grades 4 and 5 was made by observational analysis; grade 5 was considered when the patient failed to extend the interphalangeal joint of the thumb. Help from a family member or companion was requested to keep the thumb stabilized and provide the resistance.

**If the patient was not able to complete the available range**

Muscle was graded as 2, if some movement was perceived, 1 or 0.
If no movement was perceived, to evaluate grades between 0 and 1:
In IPA, the examiner palpated for contractile response to evaluate grade 1.
In TA, the examiner looked for contraction and asked the patient to palpate or to perceive a contractile response.

**Adductor pollicis**

In a sitting position, arm at the side with the elbow flexed to 90°, forearm in pronation and thumb relaxed in abduction position. The patient was guided to adduct the thumb without flexion of the interphalangeal joint of the thumb.
In IPA, the examiner stood in front of the patient and stabilized the metacarpophalangeal joints of the four joints of the ulnar side.
In TA, their hand was resting on the table.

**If the patient completed the available range**

In IPA, the examiner gave resistance in the direction of thumb abduction, to grades between 4 and 5.
In TA, manual resistance was applied by the patient in the direction of thumb abduction, following verbal instructions and with visual feedback from the examiner. The distinction between grades 4 and 5 was made by observational analysis; grade 5 was considered when the patient failed to abduct the thumb.
If the patient was not able to complete the available range

The muscle was graded as 2 if movement was observed.

To distinguish between grades 1 and 0:
In IPA, the examiner palpated for contractile response to evaluate grade 1.
In TA, the examiner looked for contraction and asked the patient to palpate or to perceive a contractile response.

Opponens pollicis

In a sitting position, arm at the side with the elbow flexed to 90°, forearm supination to a neutral position, and thumb lying relaxed and adjacent to the second metacarpal. The patient was guided to oppose the thumb to the distal phalanx of the little finger.
In IPA, the examiner stood in front of the patient and positioned the little finger in opposition. In TA, the forearm was resting on the table and the patient positioned the little finger in opposition. Help from a family member or companion was requested to keep the forearm in supination and the position of the little finger or give resistance.

If the patient completed the available range

In IPA, the examiner applied resistance in the direction of extension and abduction, to grades between 4 and 5.
In TA, manual resistance was applied by the patient, following verbal instructions and with visual feedback from the examiner. The distinction between grades 4 and 5 was made by observational analysis; grade 5 was considered when the patient failed to extend and abduct the thumb.

If the patient was not able to complete the available range

The muscle was graded as 2, if movement was observed.

To distinguish between grades 1 and 0, palpation for a contractile response was performed only in IPA.
Author’s hints: We do not recommend palpation in TA because it is difficult to distinguish between flexor pollicis longus.

Declarations

Ethics approval All procedures performed in studies involving human participants were in accordance with the ethical standards and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards (Ethics Committee protocol no. 4.277.239).

Informed consent Informed consent was obtained from all individual participants included in the study.

Conflict of interest The authors declare no competing interests.

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The COVID-19 global pandemic has placed unprecedented strain on all aspects of the health care system and has indelibly changed the way we practice medicine. During the initial peak especially (but also with subsequent surges), difficulties in resource allocation restricted operating room utilization to life-threatening emergency surgeries. This led to the delay in treatment of many patients with brachial plexus and peripheral nerve injuries who were deemed urgent but non-emergent. For patients with profound axonal loss and limited recovery potential, surgical reconstruction is generally recommended within 6 months. Patients treated beyond this window can experience irreversible loss of function, suboptimal functional recovery, and worsening of neuropathic pain.

However, with challenges come opportunities, and the COVID-19 pandemic has also catalyzed the rapid advancement of telemedicine and a re-evaluation of the delivery of surgical care. This article by Gushikem et al. provides an excellent proof of concept pilot study on the implementation of virtual care in the evaluation of brachial plexus injury (BPI) patients. They demonstrated the validity of telemedicine assessments of range of motion, sensation, and the Tinel sign with strong agreement and correlation in in-person physical examination. Telemedicine was also successfully implemented in objective and standardized pre-operative assessments of patients with facial nerve paralysis. A recent study by Grandizio et al. comparing the telemedicine and in-person administration of the CTS-6 instrument for carpal tunnel syndrome show similar high agreement. The in-person evaluation did not change management in any of the patients who were indicated for surgery via telemedicine visit.

While the treatment of BPI patients can be complex and multi-faceted, telemedicine assessments provide the ability to triage patients according to their observed improvement or lack thereof, help infer the severity and prognosis of injury, and aid in the decision of operative timing. The current pre-operative COVID-19 testing requirement also provides the opportune time for an in-person examination and discussion with the surgical team to finalize the treatment plan.

As we all look forward to life beyond COVID-19, it is important not only to recognize the need to include telemedicine into our peripheral nerve practices but also to make plans to implement it into our surgical evaluation and postoperative care—i.e., to expand our reach and address unequal access to health care. This will need to be matched with the development of infrastructure for internet access in rural and geographically isolated communities, as well as methods of telecommunication for patients lacking technical fluency. The advance of telemedicine was spurred by necessity and has quickly become an important tool in our daily practice. A practical and best practices multidisciplinary approach for the orthopedic and neurologic pain physical examination.

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