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Videler, A.J.; Beelen, A.; van Schaik, I.N.; Verhamme, C.; van den Berg, L.H.; Visser, M.; Nollet, F.

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# Tripod pinch strength and thumb opposition are the major determinants of manual dexterity in Charcot–Marie–Tooth disease type 1A

Annemieke J Videler,[1] Anita Beelen,[1] Ivo N van Schaik,[2] Camiel Verhamme,[2] Leonard H van den Berg,[3] Marianne de Visser,[2] Frans Nollet[1]

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[1]Department of Rehabilitation, Academic Medical Center, University of Amsterdam, Amsterdam, The Netherlands
[2]Department of Neurology and Clinical Neurophysiology, Academic Medical Center, University of Amsterdam, Amsterdam, The Netherlands
[3]Department of Neurology, Rudolf Magnus Institute of Neuroscience, University Medical Centre, Utrecht, The Netherlands

**Correspondence to**
Mrs A J Videler, Department of Rehabilitation, A01-415, Academic Medical Center, University of Amsterdam, PO Box 22660, 1100 DD Amsterdam, The Netherlands; a.j.videler@amc.uva.nl

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## ABSTRACT

**Background** Clinical features of Charcot–Marie–Tooth disease type 1A (CMT1A) include slowly progressive distal muscle weakness, atrophy and sensory loss. Upper-limb involvement results in reduced manual dexterity interfering with the execution of daily activities.
**Objective** To identify which hand function impairments are determinants of manual dexterity in CMT1A.
**Methods** In a cross-sectional, observational study, hand function (strength, mobility and sensory function) and manual dexterity (Sollerman hand function test) were evaluated in adults with CMT1A. Multiple linear regression analysis was used to determine the independent contribution of hand function variables on manual dexterity. Multifocal motor neuropathy (MMN) patients were chosen as a reference group with only motor impairments.
**Results** Forty-nine proven CMT1A patients (21 males, mean age 47±12) and 15 MMN patients (12 males, mean age 54±8) were studied. Hand strength, mobility and sensory functions were impaired in CMT1A compared with normal values. Limited manual dexterity was found in 94% of the CMT1A patients. From the investigated determinants (age, gender, grip and pinch strength, joint mobility, thumb opposition, touch, discrimination and vibration sense), tripod pinch strength, thumb opposition and, to a lesser degree, vibration sense were independently associated with manual dexterity (69% explained variance). Tripod pinch strength was also most strongly associated with manual dexterity in MMN.
**Conclusions** Tripod pinch strength and thumb opposition are major determinants of manual dexterity in CMT1A and should therefore be the focus of intervention strategies that aim to preserve or enhance manual dexterity in CMT1A.

## INTRODUCTION

Charcot–Marie–Tooth disease type 1A (CMT1A), the most frequent form of CMT, is caused by a duplication of the gene for peripheral nerve myelin protein 22 (PMP22) on chromosome 17p11.2 (MIM 118220) and characterised by slowly progressive length-dependent distal muscle weakness, atrophy and sensory loss.[1–4] Symptoms and signs are most pronounced in feet and hands. Although it is generally assumed that the hands of CMT1A patients are involved less frequently and later in the disease as compared with the lower extremities, a recent study among young children with CMT1A showed that hand weakness and dysfunction may be present from the earliest stages of the disease.[5]

In CMT1A, the intrinsic hand muscles are primarily affected resulting in a (mild) clawing position of the fingers, loss of thumb opposition, and impaired grip and pinch strengths.[1 6 7] Sensory loss commonly involves decreased sense of vibration and touch.[1] Manual dexterity, defined as the ability to move the hands easily and skilfully, and to work with hands, is of utmost importance in performing daily activities and is known to be frequently impaired in CMT1A.[8 9]

Identifying the underlying determinants is important to develop intervention strategies that can effectively maintain or improve manual dexterity in CMT1A. Loss of thumb and finger mobility, grip and pinch strengths and sensory functions may all impact manual dexterity in CMT1A and were therefore chosen as potential determinants in this study. We hypothesised that both motor and sensory impairments would contribute to the loss of manual dexterity in CMT1A and therefore compared the CMT1A results with those of patients with multifocal motor neuropathy (MMN), chosen as a reference group in which motor impairments are the only determinants of manual dexterity. MMN is a rare acquired immune-mediated disorder characterised by slowly progressive, asymmetrical, predominantly distal weakness of one or more limbs without sensory loss usually starting in the hand or forearm.[10]

In this study, we determined the impact of hand strength, joint mobility and sensory function on manual dexterity in both CMT1A and MMN patients.

## METHODS

### Patients

All (n=63) DNA-proven CMT1A patients between 18 and 70 years old known at the departments of Rehabilitation and Neurology at the Academic Medical Center (AMC) were invited to participate. Additionally, a convenience sample of 20 patients with MMN, diagnosed on clinical, laboratory and electrophysiological characteristics,[10] aged between 18 and 70 years old and known at the departments of Neurology at the AMC and the University Medical Centre Utrecht were asked to participate.

Patients were excluded if they had difficulty comprehending the Dutch language or with a history of comorbidity that might interfere with upper-limb function in CMT1A or MMN, including stroke, plexopathy, radiculopathy, upper limb

surgery, alcohol abuse or a psychiatric disorder. All subjects gave informed consent to the procedures, which were approved by the Medical Ethical Committees of the AMC.

### Assessments

Clinical information was obtained by one examiner (AV) in a standardised manner and included medical history taking with the general question whether patients noticed hand involvement and, if so, which symptoms they perceived, a detailed clinical assessment of the motor and sensory functions of the hand, and evaluation of manual dexterity.

Standard goniometric measurements of both the passive range of motion (PROM) and active range of motion (AROM) of the fingers joints were used and classified as impaired or normal.[11] Thumb opposition was evaluated according to the Kapandji opposition score, which defines 10 stages of opposition, with full opposition scored as stage 10.[12]

Three sensory functions were evaluated: the threshold for touch, tactile discrimination and vibration sense. The threshold for touch was determined at seven locations divided over the hand and fingers using Semmes–Weinstein monofilaments (SWM).[13] The set of monofilaments ranged from 2.38 to 6.65, which represent the values of the logarithmic transformation of the force needed to buckle the filament. The finest filament felt at each location was recorded, and the average of the seven locations on the hand was calculated. We used data of a Dutch reference population to determine the cut-off for normal threshold for touch.[14] We calculated the mean+1.96 SD with these reference data, resulting in filament 3.61 as cut-off for normal threshold for touch. Testing with monofilaments has good to excellent intra- and interobserver reliability in CMT.[15] Tactile discrimination was evaluated with static two-point discrimination (s2PD) using a Disk-Criminator at the tip of the index finger.[16] For s2PD, a distance of less than 6 mm was taken as a cut-off for normal tactile discrimination in the finger pulp.[16] The vibration threshold was assessed using a Rydel–Seiffer tuning fork at the dorsum of the distal interphalangeal joint of the index finger. The average of three repeated readings was calculated as the vibration threshold. Results can be compared with reference values and graded as normal (grade 0) or disturbed (grade 1–4). A disturbed vibration sense at the dorsum distal interphalangeal joint of the index finger is classified as grade 1; abnormal sense at the ulnar styloid process as grade 2; at the medial humerus epicondyle as grade 3; and at the acromioclavicular joint as grade 4.[17 18] Good inter- and intra-observer agreements and high responsiveness values were demonstrated for this tuning fork.[17 18]

While muscle strength is commonly measured subjectively, using the MRC scale, hand-held dynamometry is regarded as more precise, sensitive and objective.[19] Therefore, we assessed maximal isometric grip and pinch (two-point, tripod, and lateral pinch) strength using digital handgrip dynamometers (Lode Medical Technology) according to a standardised testing procedure.[20] Patients were seated on a height-adjustable chair and received verbal encouragement during strength measurements. For grip strength testing, the handle of the dynamometer was set in the second position, recommended to test maximal grip strength irrespective of age, weight or hand dimensions.[21] The mean force (in Newtons) of three trials was taken for all strength measurements. The use of hand-held dynamometry to measure hand strength has been shown to be highly reliable and valid in adults with CMT.[7 22]

To examine manual dexterity, the standardised Sollerman hand function test (SHT) was used, consisting of 20 subtests (scale 0–4) assessing unilateral and bilateral handgrip function, and reflecting the most common handgrips used during daily activities.[23] Both hands were evaluated. Subjects with normal manual dexterity should achieve a total of 80 points with their dominant hand and 77–79 points with the non-dominant hand.

### Statistical analysis

Data from clinical examination were analysed using descriptive statistics and compared with normal values. Published reference values of healthy subjects, stratified by age, gender and hand dominance, were recalculated in Newtons and used to determine the impact of CMT1A on hand strength (grip, two-point pinch, tripod and lateral pinch).[20] Differences between dominant and non-dominant hand function variables were analysed with the Wilcoxon signed ranks test. The scores on the Sollerman test were log-transformed (log ((80−score)+1)) to yield a normal distribution as they were skewed to the left. Associations between manual dexterity (log-transformed SHT sum score) and continuous hand function variables (thumb opposition, clawing position, the threshold for touch, two-point discrimination, grip strength, two-point pinch, tripod pinch and lateral pinch strength) were investigated using Pearson product moment correlation coefficients (r). Associations between manual dexterity and dichotomous variables (AROM, PROM, vibration sense) were investigated with point biserial correlation coefficients ($r_{pb}$). In the CMT1A group, a multiple linear regression analysis was performed to determine the independent contribution of hand function variables on manual dexterity. Variables with a univariate p value $<0.10$ were entered in a multiple stepwise linear regression analysis to obtain a set of mutually independent determinants. Considering the relatively large number of independents for the multiple regressions and a sample size of 63 CMT1A patients at most, three separate models were built for manual dexterity with determinants on joint mobility (model 1), sensory functions (model 2) and grip and pinch strength (model 3) with three or four potential determinants in each model. A final model for manual dexterity was made using the independent factors that were significant in the three regression models. Diagnostic tests were used to check for violations of the assumptions inherent in linear regression models. Given the small sample size, only univariate analyses were used in MMN. All statistical analyses were performed using the SPSS software package for Windows version 16.0 (SPSS, Chicago, Illinois). A p value of $<0.05$ was considered to be statistically significant.

## RESULTS

### Patient characteristics

From the 63 eligible CMT1A patients, 53 agreed to participate. Four patients were excluded: three with comorbidity (Dupuytren disease, recent shoulder surgery, psychiatric disorder) and one with history of alcohol abuse. Sixteen MMN patients were willing to participate. One MMN patient was excluded because of hand surgery. The final study samples comprised 49 patients with CMT1A and 15 patients with MMN (table 1). All MMN patients reported hand involvement, whereas this was the case in 38 (78%) of the CMT1A patients. All but one MMN patient perceived loss of hand strength compared with 35 (71%) of the CMT1A patients. The percentage of patients who perceived hand fatigue, pain, cramps and tremor varied between 41 and 73% in both groups. One MMN patient mentioned symptoms of sensory loss.

### Descriptive data on hand function and manual dexterity

Group values for dominant and non-dominant hand function and manual dexterity in CMT1A and MMN patients are given

**Table 1** Patient characteristics

| | | CMT1A n=49 | Multifocal motor neuropathy n=15 |
|---|---|---|---|
| Gender: male/female | n (%) | 21 (43)/28 (57) | 12 (80)/3 (20) |
| Age: years | Mean±SD | 46.8±11.7 | 54.2±8.3 |
| | Range | 21–69 | 39–66 |
| Hand dominance: right/left | n (%) | 48 (98)/1 (2) | 14 (93)/1 (7) |
| Disease duration*: years | Mean±SD | 28.5±16.9 | 16.6±6.7 |
| | Range | 0–57.8 | 5.9–30 |
| History of hand involvement: yes/no | n (%) | 38 (78)/11 (22) | 15 (100)/0 |
| Duration hand involvement†: years | Mean±SD | 10.9±12.2 | 14±6.1 |
| | Range | 0–54.8 | 3.8–23.1 |
| Perceived hand symptoms: yes/no | | | |
| Loss of strength | n (%) | 35 (71)/14 (29) | 14 (93)/1 (7) |
| Fatigue | | 21 (43)/28 (57) | 7 (47)/8 (53) |
| Sensory loss | | 28 (57)/21 (43) | 1 (6,7)/14 (93) |
| Pain, cramps | | 29 (59)/20 (41) | 8 (53)/7 (47) |
| Tremors | | 20 (41)/29 (59) | 11 (73)/4 (27) |

Two Charcot–Marie–Tooth disease type 1A (CMT1A) patients could not recall time of onset of symptoms (n=47) and one CMT1A patient could not recall the onset of hand symptoms (n=48).
*Time since onset of symptoms.
†Time since onset of hand symptoms.

in table 2. Differences between the dominant and non-dominant hand were found in CMT1A for grip strength (p=0.035), two-point discrimination (p=0.007) and for the threshold for touch (p=0.049).

Limited active range of motion presenting as a clawing position of the fingers was found in 27% of the CMT1A patients. The extent of clawing varied between involvement of all four fingers n=7(14%) and solely the fifth finger n=2 (4%). Loss of thumb opposition was found in more than half of the patients.

An impaired threshold for touch was found in 51% of the CMT1A patients. Thirteen patients (27%) scored outside the normal value range (<6 mm) for static two-point discrimination. Disturbed vibration sense was found in 20% of the patients; five (10%) with grade 1, one (2%) with grade 2 and four (8%) with grade 4.

A large variation in grip strength (range 42 to 544 N) was found (table 2). Compared with reference values of healthy subjects grouped by gender and age, maximal isometric grip and pinch (two-point, tripod, and lateral pinch) strength was lower in CMT1A patients (table 3). The mean grip strength in CMT1A reached 65% of the normal reference value. Two-point, tripod and lateral pinch strengths of CMT1A patients were reduced to approximately 50%.

Manual dexterity of the dominant hand was impaired in all but three (94%) patients with CMT1A (table 2). The most difficult Sollerman subtests were: picking up coins and putting them into a purse, opening and closing a zipper, picking up nuts and putting them on bolts, doing up buttons, putting a paper clip on an envelope and pouring water from a cup. A more detailed description of the SHT data in this study sample has been published previously.[9]

On all aspects of joint mobility and hand strength, MMN patients scored worse than CMT1A patients (table 2). Impaired sensory function was found in one MMN patient. Manual dexterity of the dominant hand was limited in 87% of the MMN patients. The average SHT sum score was substantially lower for both the dominant and non-dominant hand in MMN patients compared with CMT1A patients. The SHT subtests that caused most difficulty in MMN patients were comparable with those of

**Table 2** Group values of clinical variables of hand function and manual dexterity

| | | | | Charcot–Marie–Tooth disease type 1A n=49 | Multifocal motor neuropathy n=15 |
|---|---|---|---|---|---|
| Mobility of the fingers | Impaired active range of motion | n (%) | D | 18 (37) | 12 (80) |
| | | | ND | 13 (27) | 13 (87) |
| | Clawing of the fingers | n (%) | D | 13 (27) | 8 (53) |
| | | | ND | 11 (22) | 7 (47) |
| | Impaired passive range of motion | n (%) | D | 3 (6) | 3 (20) |
| | | | ND | 2 (4) | 2 (13) |
| | Impaired opposition | n (%) | D | 25 (51) | 11 (73) |
| | | | ND | 20 (41) | 10 (67) |
| Sensory modalities | Threshold for touch (Semmes Weinstein Monofilaments, mean of seven localisations) | Mean±SD, range | D | 3.62±0.33, 2.89–4.32 | 3.37±0.19, 3.05–3.68 |
| | | | ND | 3.57±0.32, 2.89–4.25 | 3.35±0.26, 2.83–3.74 |
| | Static two-point discrimination (mm) | Mean±SD, range | D | 5.18±2.27, 2–16 | 4.4±2.67, 2–12 |
| | | | ND | 4.76±2.80, 2–20 | 4.3±2.46, 2–12 |
| | Impaired vibration sense | n (%) | D | 10 (20) | 1 (7) |
| | | | ND | 7 (14) | 1 (7) |
| Hand strength | Grip (N) | Mean±SD, range | D | 245±122, 42–544 | 166±132, 13–458 |
| | | | ND | 237±117, 39–533 | 170±119, 5–449 |
| | Two-point pinch (N)* | Mean±SD, range | D | 31±20, 0–78 | 17±24, 0–64 |
| | | | ND | 33±19, 0–80 | 15±19, 0–56 |
| | Tripod pinch (N)* | Mean±SD, range | D | 43±28, 0–102 | 26±40, 0–105 |
| | | | ND | 44±26, 0–96 | 21±24, 0–66 |
| | Lateral pinch (N) | Mean±SD, range | D | 47±24, 6–102 | 41±32, 3–100 |
| | | | ND | 47±23, 7–112 | 38±25, 2–79 |
| Manual dexterity | Sollerman hand function test sum score | Median (P25; P75), range | D | 76 (67.5; 78), 33–80 | 48 (43; 68), 27–80 |
| | | | ND | 76 (69; 77.5), 41–80 | 50 (44; 67), 19–77 |

*If a patient was not able to perform a two-point or tripod pinch, a score of 0 N was recorded.
D, dominant hand; ND, non-dominant hand.

**Table 3** Dominant hand strength: percentage of healthy reference values

| | | CMT1A n=49 | MMN n=15 |
|---|---|---|---|
| Grip strength | Mean %±SD of norm* | 65±25.4 | 36 (24.8; 50.6) |
| | Range | 9.8–111.5 | 2.7–90.7 |
| Two-point pinch strength† | Mean %±SD of norm* | 49±27.7 | 0 (0; 51.8) |
| | Range | 0–98.1 | 0–79.0 |
| Tripod pinch strength† | Mean %±SD of norm* | 47±28.5 | 0 (0; 42.1) |
| | Range | 0–102.1 | 0–96.3 |
| Lateral pinch strength | Mean %±SD of norm* | 51±22.4 | 30 (20.2; 66.7) |
| | Range | 5.8–93.3 | 2.6–87.7 |

Published reference values of healthy subjects, stratified by age, gender and hand dominance, were used to understand the impact of Charcot–Marie–Tooth disease type 1A (CMT1A) on hand strength. The dominant hand was taken for comparison.
*Median % and the 25; 75 percentile scores are given for multifocal motor neuropathy (MMN) patients, as data were skewed.
†Five CMT1A and nine MMN patients were not able to perform a two-point pinch, and six CMT1A and nine MMN patients were not able to perform a tripod pinch, which resulted in a score of 0 N.

CMT1A patients, but additionally included activities that require a strong grip such as pouring water from a jug, lifting an iron and unscrewing a lid from a jar.

### Associations between hand function and manual dexterity

Associations between hand-function impairments and manual dexterity of CMT1A and MMN patients are shown in table 4. In CMT1A, all variables of hand function were significantly associated with manual dexterity, with the strongest associations found for tripod pinch and two-point pinch strength (figure 1). In MMN, tripod pinch strength showed the strongest association with manual dexterity scores. Sensory functions were not related to manual dexterity in MMN patients. In both patient groups, manual dexterity was not related to age and gender.

In table 5, the results of the multiple linear regression analysis are given. The final model showed that in CMT1A, only tripod pinch strength (57% explained variance; online figure 2), thumb opposition (10% added explained variance) and, to a lesser degree, vibration sense (2% added explained variance) were independently associated with manual dexterity (69% explained variance).

**Table 4** Associations between hand function and manual dexterity

| | Charcot–Marie–Tooth disease type 1A (n=49) | Multifocal motor neuropathy (n=15) |
|---|---|---|
| | Log-transformed Sollerman hand function test sum scores | |
| Continuous variables | r | |
| Clawing of the fingers | 0.67** | 0.64* |
| Thumb opposition | −0.73** | −0.72** |
| Threshold for touch | 0.34* | 0.30* |
| Two-point discrimination | 0.55** | 0.31* |
| Grip strength | −0.51** | −0.89** |
| Two-point pinch strength | −0.76** | −0.89** |
| Tripod pinch strength | −0.76** | −0.95** |
| Lateral pinch strength | −0.66** | −0.94** |
| Dichotomous variables | $r_{pb}$ | |
| Limited active range of motion | 0.64** | 0.57* |
| Limited passive range of motion | 0.44** | 0.30 |
| Impaired vibration sense | 0.51** | 0.12 |

Associations between manual dexterity (log-transformed Sollerman hand function test sum score) and continuous hand function variables were investigated using Pearson product moment correlation coefficients (r). Associations between manual dexterity and dichotomous variables were investigated with point biserial correlation coefficients. The results of the dominant hand were taken for all associations.
*p<0.05; **p<0.01.

## DISCUSSION

The main finding of this study is that tripod pinch strength and thumb opposition are the major determinants of impaired manual dexterity in CMT1A. Together with impaired vibration sense, they explained 69% of the total variance in manual dexterity scores. Inclusion of the MMN patients corroborated that motor impairment is the main determinant of decreased manual dexterity in CMT1A.

The sensory impairments appeared to have some but limited consequences for manual dexterity. Among the sensory variables, only vibration sense was independently associated with manual dexterity. In the literature, impaired sensory functions of the hand are reported in 14–64% of the CMT patients, but results are difficult to compare due to different measurement methods and cut-off values.[1 2 15 24–27]

Tripod pinch strength was the most discriminatory factor explaining manual dexterity in both groups. Several explanations can be given. First, this grip pattern in particular may become affected in CMT1A and MMN patients as a result of the weak intrinsic thenar muscles. Second, a tripod pinch grip is one of the most frequently used grip patterns in daily activities.[23 28] Finally, the manual dexterity subtests that were the most difficult to perform almost all required pinch grips such as the tripod pinch. The 9% explained variance, added by loss of thumb opposition in CMT1A, is more difficult to understand, as the thumb is positioned and stabilised by the same thenar muscles used during pinch grip. One explanation may be that some patients could not perform the required tripod grip for the dynamometer. In these patients, tripod pinch strength was recorded as 0 N, but a differentiation in opposition score could still be given. With the multivariable model, a large percentage of the variance in manual dexterity could be explained in CMT1A. However, other non-investigated factors such as loss of proprioception and coordination may have contributed to manual dexterity.

Hand function and manual dexterity were impaired in the majority of this large group of CMT1A patients. Previously, we showed that impaired manual dexterity was associated with

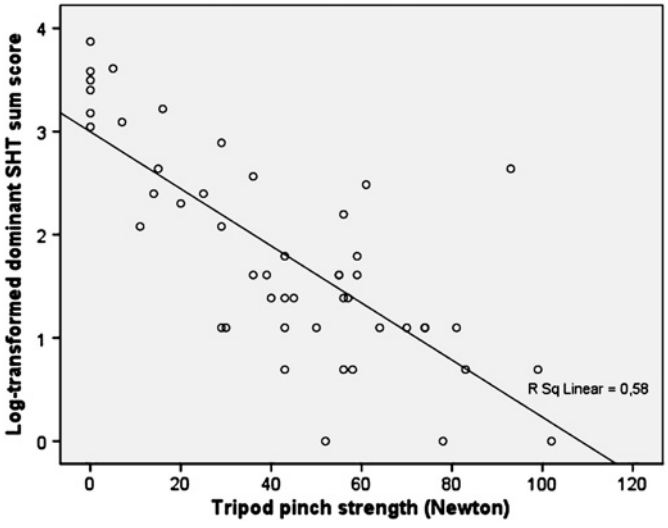


**Figure 1** Scatter plot of bivariate association between tripod pinch strength and log-transformed Sollerman hand function test (SHT) sum score of the dominant hand in Charcot–Marie–Tooth disease type 1A (CMT1A).

**Table 5** Stepwise regression models to determine the independent contribution of hand function variables on manual dexterity in Charcot–Marie–Tooth disease type 1A

| | | Model summary and coefficients | | | |
|---|---|---|---|---|---|
| **Entry order** | **Predictors** | **B** | **SE (b)** | **p Value** | **Change in $R^2$** |
| Model 1: joint mobility | Thumb opposition | −0.169 | 0.045 | 0.000 | 0.53 |
| Active range of motion, passive range of motion, clawing of fingers, thumb opposition | Clawing of fingers | 0.205 | 0.096 | 0.038 | 0.03 |
| Model 2: sensory functions | Two-point discrimination | 0.200 | 0.051 | 0.000 | 0.29 |
| Threshold for touch, two-point discrimination, vibration sense | Vibration sense | 0.971 | 0.285 | 0.001 | 0.13 |
| Model 3: strength | Tripod pinch strength | −0.028 | 0.003 | 0.000 | 0.57 |
| Grip strength, two-point, tripod, lateral pinch strength | | | | | |
| Final model | Tripod pinch strength | −0.018 | 0.004 | 0.000 | 0.57 |
| Thumb opposition, clawing of fingers, two-point discrimination, vibration sense, tripod pinch strength | Thumb opposition | −0.107 | 0.036 | 0.005 | 0.10 |
| | Vibration sense | **0.481** | 0.227 | 0.040 | 0.02 |

Charcot–Marie–Tooth disease type 1A: n=49. The independent contributions of joint mobility, sensory functions and hand strength on manual dexterity (log-transformed Sollerman hand function test sum scores) is given. Analysis of residuals did not show violations of necessary assumptions in multiple regression in terms of linearity, equality of variance, independence of error and normality.

limitations in upper-limb-related activities and restricted participation in CMT1A.[29 30] Hand involvement was present in 78% of our patients, which is more frequent than other CMT studies reporting upper-limb involvement in one-half to two-thirds.[1 27] This may be explained by the fact that our study addresses various aspects of hand function. Loss of thumb opposition and impaired threshold for touch were present in more than half of the patients and disturbed discrimination and vibration sense in approximately a quarter of the patients. Disturbed discrimination and vibration sense in approximately a quarter. Grip and pinch strength in CMT1A reached 65% and 50% of the normal reference value. Although 27% of the CMT1A patients presented with clawing of the fingers, restricted passive range of motion was found in only 6%. Apparently, in most CMT1A patients, there is little contracture of the fingers, and thus preventive measures are generally not needed.

Recently, potential differences between dominant and non-dominant hand strength in CMT have been discussed, and contradictory findings have been reported.[31–33] In a cohort of 106 CMT patients, the dominant hand was found to be weaker than the non-dominant hand and ascribed to overwork weakness.[31] In contrast, we found a significant difference between dominant and non-dominant grip strength in favour of the dominant hand which refutes the overwork hypothesis.

Manual dexterity was limited more often and more severely in patients with MMN compared with CMT1A. Activities that were difficult to perform for MMN patients were comparable with those of CMT1A patients, but limited dexterity in MMN was also due to impaired grip strength. Tripod pinch strength also appeared to be the most explaining factor of manual dexterity in MMN. Hand function and manual dexterity have not yet been studied in MMN; therefore, our findings cannot be compared with those of others.

This study evaluated hand function and manual dexterity in a large sample of CMT1A patients. Some selection bias may have occurred. Patients with advanced upper limb involvement could have been more willing to participate than those with less impairment. Nonetheless, a high percentage of the known CMT1A patients at our departments participated, and upper-limb involvement of the participating patients ranged from unaffected to severely affected.

In the absence of Dutch norm values for grip and pinch strength, we used normative data from the USA collected with a comparable but non-digital hand-held dynamometer (Jamar).[20] Applying normative data internationally is not ideal. However, we do believe that the values used are currently the most appropriate because they were obtained from a large study sample, a broad range of socio-economic and occupational groups were included, and the same standardised testing procedure and data analysis was applied (subject position, handle setting, patient instructions, mean of three trials).

Preservation of upper-limb functioning of CMT1A patients is a major issue, but there is no evidence about effective interventions. This study shows that tripod pinch strength and thumb opposition should be the focus of intervention strategies that aim to preserve or enhance manual dexterity in CMT1A. Surgical interventions such as tendon transfer procedures may restore thumb opposition and tripod pinch strength, but literature on this subject is limited.[34 35] Orthotic management, assistive devices and exercise programmes have only been described for the lower limbs.[36–39] The results of this study justify the need for therapeutic and surgical intervention studies aimed at improving hand function, manual dexterity and ultimately daily life functioning of patients with CMT1A.

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**Competing interests** None.

**Patient consent** Obtained.

**Ethics approval** Ethics approval was provided by the Medical Ethics Committee of the Academic Medical Center, Amsterdam, The Netherlands.

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