Research paper

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Median nerve versus flexor tendons: visualization of median nerve level changes in the proximal carpal tunnel during wrist movement with dynamic high-resolution ultrasound

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Keywords
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Abstract

Aim: The purpose of this prospective ultrasound study was to document dorso-palmar (vertical) displacement of the median nerve in relation to the superficial flexor tendons at the level of the carpal tunnel. Furthermore, the gliding patterns of the median nerve were characterized. The presence of vertical gliding was intended to serve as an additional bio-kinematic parameter of median nerve movement, and will be referred to as a 'level change'. **Material and methods:** In this study, a total of 32 healthy young individuals underwent dynamic high-resolution ultrasound examinations of both wrists. The neutral position, and maximum flexion and extension of the wrist had to be reached in active and passive movement. The gliding patterns were determined in relation to the superficial flexor tendons. When no vertical nerve gliding was observed, it was characterized as 'no level change'. **Results:** The presence of a level change prevailed in the healthy young cohort and was observed in 84% (27/32) of individuals during wrist flexion. The following gliding pattern was distinctively the most common: gliding of the entire nerve in between the flexor tendons in active but not in passive movement of the right and left wrists (13/27; 48%). The extent of vertical displacement was found to be associated with the gliding pattern (Kruskal–Wallis test). **Conclusions:** Movement in the carpal tunnel allows the median nerve to adapt to biomechanical stress. Dynamic ultrasound can demonstrate median nerve level changes in response to wrist movements. Furthermore, a typical gliding pattern was characterized. The presence of level change and gliding patterns were proposed as additional movement parameters during wrist flexion in healthy individuals.

Introduction

The carpal tunnel is a fibro-osseous canal at the wrist that accommodates the median nerve (MN) and the flexor tendons of the forearm. The structures running through the carpal tunnel are exposed to mechanical stress when finger or wrist movements are performed[1–2]. The feasibility of dynamic ultrasound examinations for the visualization and assessment of the median nerve has been well established[3]. However, the literature reports are rather heterogeneous both in design and outcome[4–6]. Displacement of the MN in the radio-ulnar and dorso-palmar directions in a transverse plane[4], cranio-caudal gliding in a longitudinal plane[7], deformation, and changes in area and perimeter[8] have been described as possible MN responses to mechanical stress.

The purpose of this study was to introduce MN level change, namely a dorso-palmar (vertical) gliding of the MN underneath or in between the superficial flexor tendons, as an additional parameter to describe the bio-kinematics of the MN in the carpal tunnel.

Materials and methods

Study population

The study was approved by the local institutional review board. A total of 32 healthy volunteers were recruited via public notice and by word of mouth. Prior to the examination, written informed consent was obtained from all the participants. Baseline patient data (Tab. 1) and pain questionnaires were obtained in the next step. Relevant answers in the pain questionnaire are listed among the exclusion criteria. Individuals presenting with anatomical median nerve variations, such as a bifid MN, were included in the study. All the subjects were between 20 to 30 years of age, clinically healthy, and with a body mass index (BMI) of <30. Recruitment and dynamic high-resolution ultrasound (DHRUS) examinations of both wrists (n = 64) were carried out in 2022. All the subjects could be included in the study since none of the young healthy volunteers met any predefined exclusion criteria.

Inclusion criteria:
- Age ≥18
- BMI <30
- No diabetes mellitus (anamnestic)
- Overall negative pain questionnaire
- Signed written informed consent
- Motor and mental ability to follow movement instructions
- Sufficient image quality

Exclusion criteria:
- Age <18
- BMI ≥30
- No signed written informed consent
- Inability to follow movement instructions
- Insufficient image quality due to non-device-related factors (incorrect positioning of the transducer etc.)
- Positive pain questionnaire:
  - History of or present pain/pathology of the arms, wrists, and fingers
  - History of or present nerve pathology in the upper extremities (polyneuropathy, carpal tunnel syndrome (CTS), cubital tunnel syndrome, etc.)
  - Upper limb surgery
  - History of fractures of the wrist or distal radius/ulna
- Diabetes mellitus (anamnestic)

Image acquisition

All DHRUS examinations were performed at the Department of Biomedical Imaging and Image-Guided Therapy of the University Hospital Vienna using a GE Logiq E9 US imaging system. A GE ML6-15 transducer with a standardized "peripheral nerve" ultrasound preset (B-mode, frame rate: 26 frames per second, frequency: 15 MHz, gain: 44, depth: 2 cm, time-gain compensation (TGC): centered, dynamic range (compression): 60, auto optimization: 100%) was used. The gain, focus, depth, frequency, and TGC were then adapted to the individual anatomical situations. A 15 MHz probe was deliberately chosen over higher-frequency transducers, as it provides a wider field of view, allowing complete visualization of the carpal tunnel and all important anatomical structures during dynamic examination. The examinations were carried out by a medical student who received prior instruction and was supervised during the initial examinations by a radiologist specializing in peripheral nerve HRUS with eight years of professional experience (SJ). During the ultrasound examination, the participants sat opposite the examiner, with the elbow joint bent at about 90°–120° and with the forearms resting on the examination table in front of them. The hands were held in the supine position and the fingers were closed in a loose fist. The transducer was placed over the proximal carpal tunnel in a transverse plane, and the wrist was visualized down to the carpal bones. No additional pressure was applied by the examiner. Loops were acquired using the B-mode, keeping the median nerve in view at all times. The pisiform and scaphoid bones were visualized on the ultrasound monitor to ensure maximum standardization of the initial transducer position over the carpal tunnel. The bony landmarks were not kept in view at all times during loop recording. The following movement sequence was obtained for each study participant and hand both in active and passive wrist alignment, resulting in four different ultrasound loops per participant: neutral wrist position; maximum flexion; return to neutral position; maximum extension; return to neutral position (Fig. 1). During the dynamic examination of the carpal tunnel, the aim was to capture the

Tab. 1. Baseline characteristics

Age	
Median (IQR)	23 (IQR = 22–26)
Minimum	20
Maximum	30
Male (median, IQR)	25 (IQR = 22–26)
Female (median, IQR)	23 (IQR = 22–25)
Gender	
Male (*n*, %)	16 (50%)
Female (*n*, %)	16 (50%)
Handedness	
Right (*n*, %)	30 (94%)
Left (*n*, %)	2 (6%)
IQR – interquartile range	

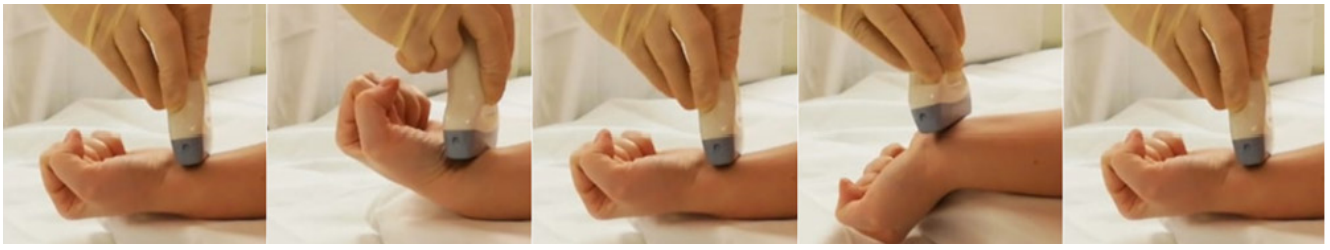

Fig. 1. *Examination scheme: wrist alignments*

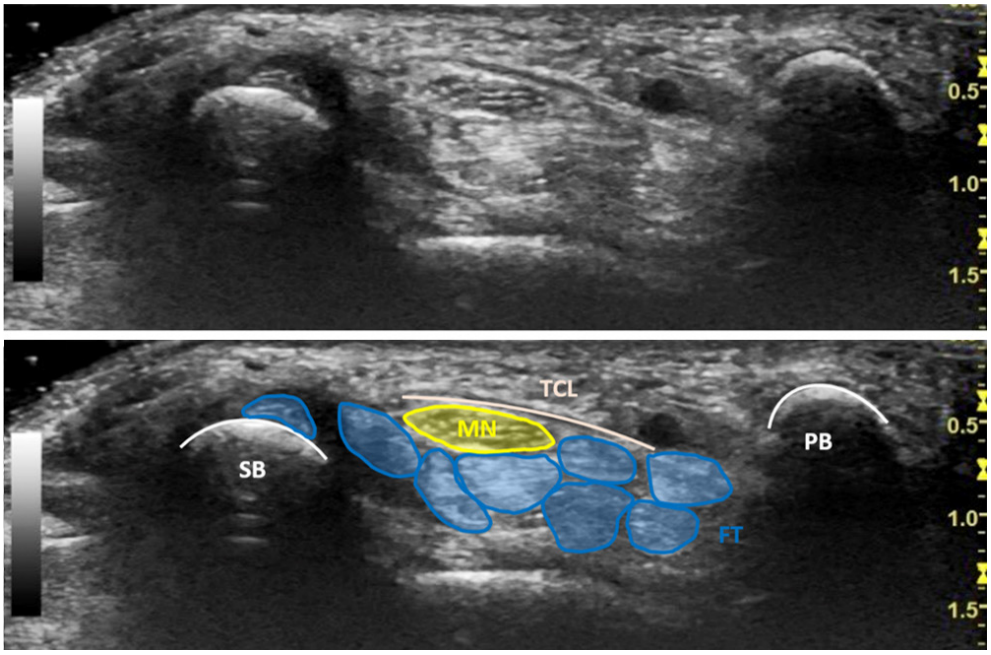

Fig. 2. *Wrist in maximum flexion: no level change of MN (pattern A). MN – median nerve; FT – flexor tendons; TCL – transverse carpal ligament; SB – scaphoid bone; PB – pisiform bone*

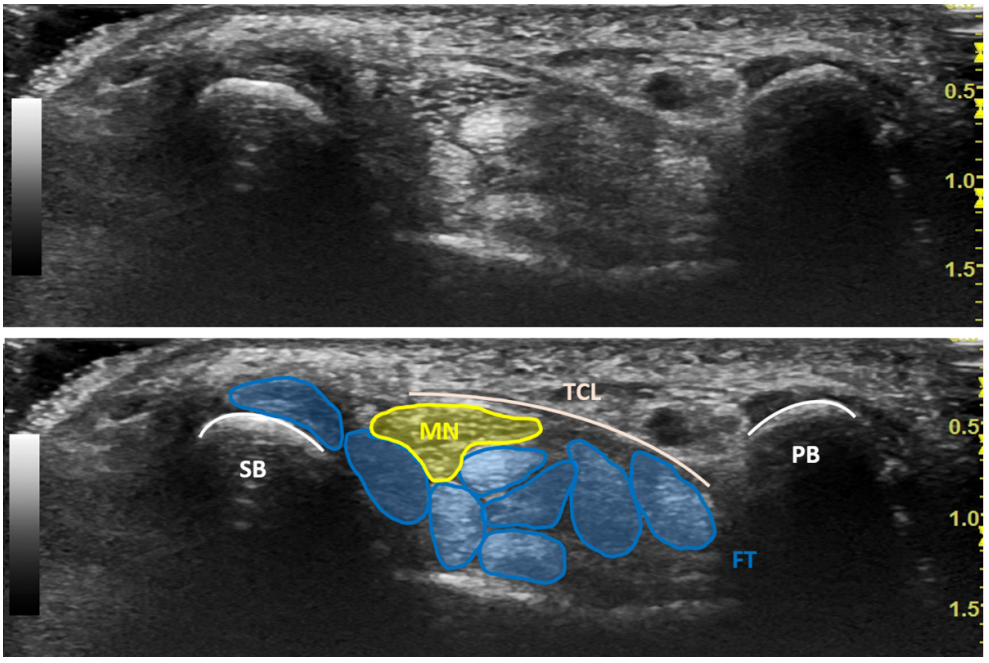

Fig. 3. *Wrist in maximum flexion: partial or mild gliding of MN parts (<1/3) onto the tendon level (pattern B). MN – median nerve; FT –flexor tendons; TCL – transverse carpal ligament; SB – scaphoid bone; PB – pisiform bone*

maximum migration and level change of the median nerve in each subject. To this end, the participants performed their individual maximum wrist flexion and extension. The images shown in Fig. 2, Fig. 3, Fig. 4, Fig. 5, and Fig. 6 below were extracted from the recorded examination loops, providing a realistic representation of the image acquisition process. It is important to note that these images have a different quality compared to separately taken still images. After a quality check of all the loops for measurement purposes conducted by the senior investigators, all measurements were obtained using a DICOM viewer.

Data handling and storage

The obtained data were stored at the Department of Biomedical Imaging and Image-Guided Therapy of the University Hospital Vienna. The randomization of the study cohort was performed by consecutively numbering the subjects before the examination, which made it impossible to assign any recordings to the respective individuals during data interpretation.

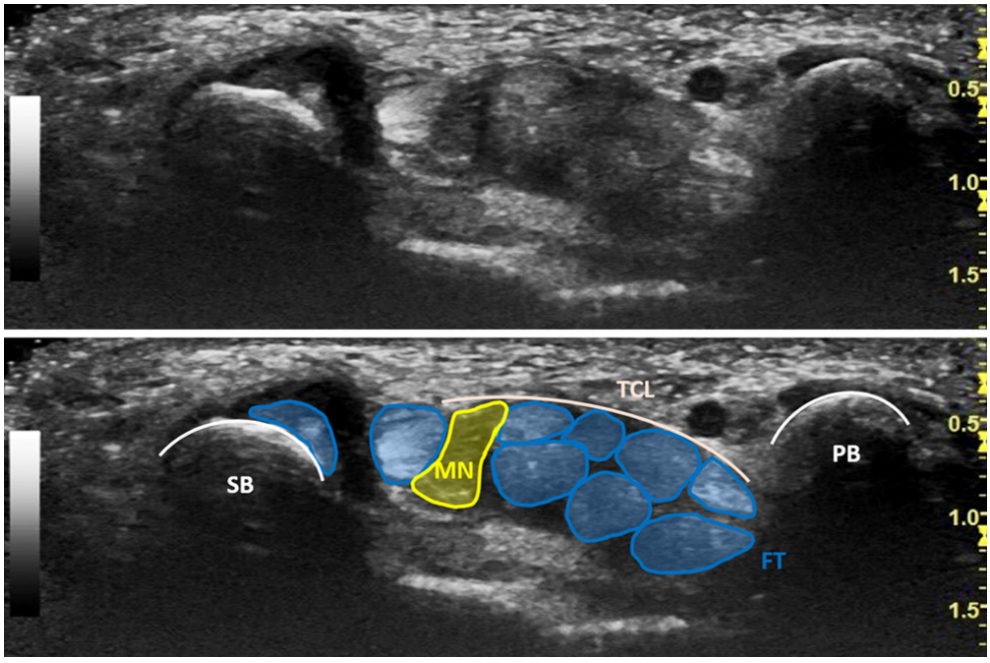

Fig. 4. *Wrist in maximum flexion: significant or total gliding (>2/3) of the MN cross-section onto the tendon level (pattern C). MN – median nerve; FT –flexor tendons; TCL – transverse carpal ligament; SB – scaphoid bone; PB – pisiform bone*

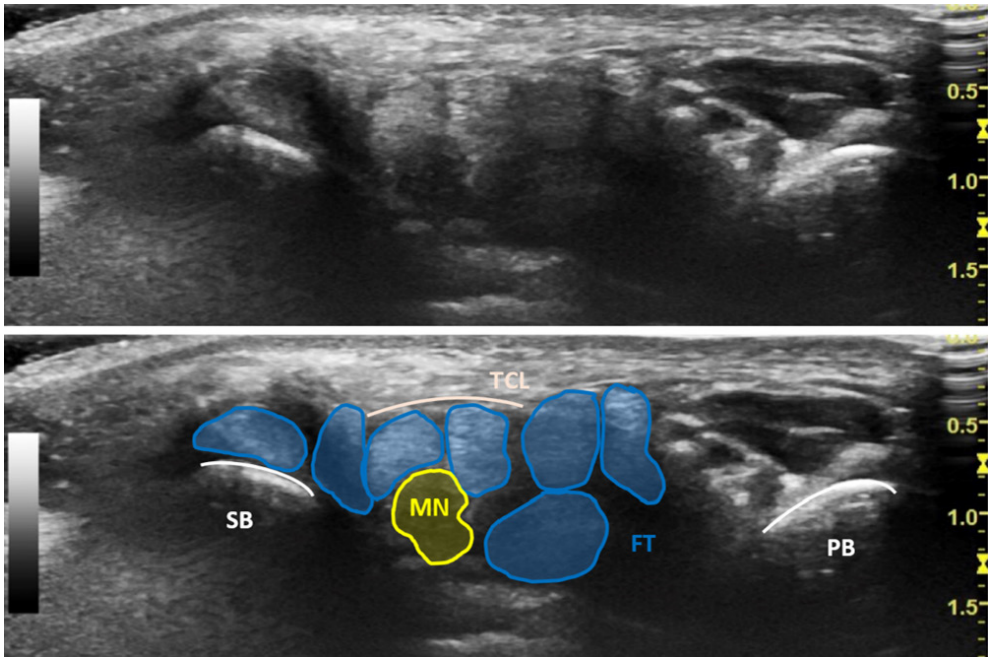

Fig. 5. *Wrist in maximum flexion: gliding of the MN below the flexor tendons (pattern D). MN – median nerve; FT –flexor tendons; TCL – transverse carpal ligament; SB – scaphoid bone; PB – pisiform bone*

Image analysis

The analysis took place two and four weeks after all ultrasound examinations were completed to evaluate intra-observer variability. The loops were reviewed by the medical student and the HRUS specialist in separate sessions. The loops were screened for the presence of MN level changes in relation to the flexor tendons. Each level change was qualitatively subclassified into one of four different gliding patterns:

- Pattern A: no level change (MN remaining superficial to the flexor tendons during wrist flexion) (Fig. 2)
- Pattern B: mild or partial gliding of MN onto the tendon level (<1/3 of the MN cross-sectional area (CSA)) (Fig. 3)
- Pattern C: significant or total translocation onto the tendon level (>1/3 of the MN CSA) (Fig. 4)
- Pattern D: gliding of the MN underneath the superficial tendons (Fig. 5)

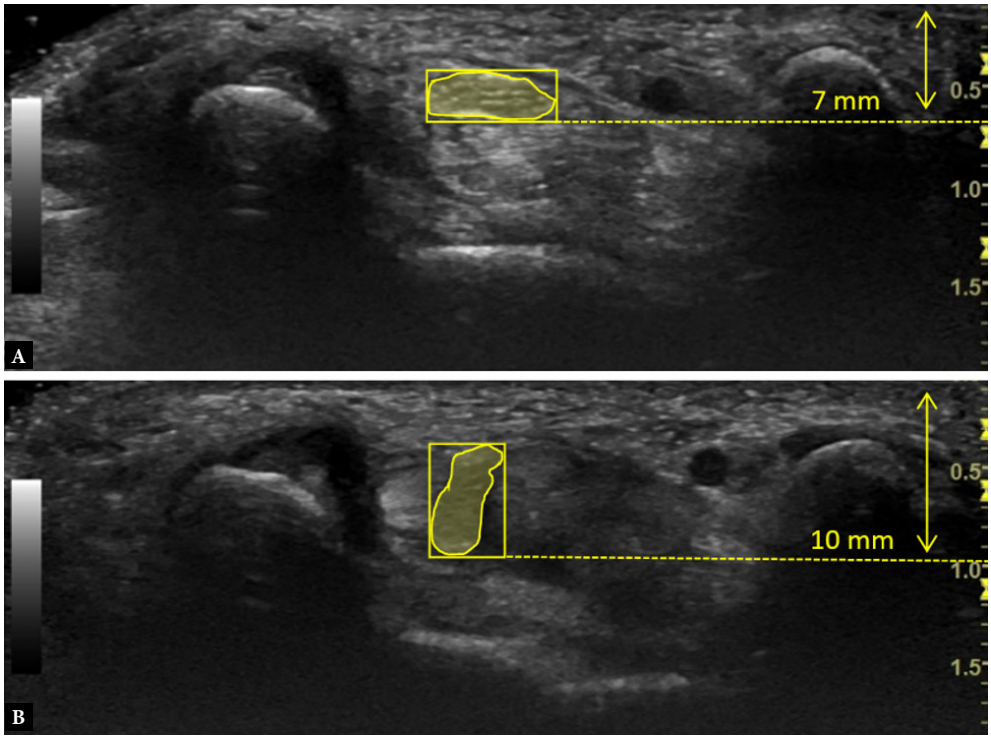

Fig. 6. *Median nerve: measurement of vertical displacement.* **A.** *neutral wrist position;* **B.** *maximum flexion*

Different combinations of gliding patterns A–D within the same subject or hand were also reported. In Fig. 7, they are referred to as E* and F*. In subjects with a bifid MN, each nerve bundle displacement was evaluated individually. In cases with MN translocation (patterns B, C, and D), absolute vertical displacement of the MN from neutral wrist alignment to maximum wrist flexion was measured (Fig. 6). The vertical displacement was measured in millimeters from the palmar surface of the wrist to the most dorsal point of the MN in each subject. The most dorsal point of the MN was determined by placing the smallest possible box around the nerve. The point that touched the bottom of the box was used (Fig. 6).

Statistical analysis

Spearman's correlations were used to correlate absolute vertical displacements. Fisher's exact test was performed to compare the frequencies. Mann–Whitney U test, Wilcoxon signed-rank test, and Kruskal–Wallis test were used to compare metric data. Since the data were not normally distributed, medians and interquartile ranges were calculated. Bar charts were used for the visual representation of the results. P-values <0.05 were considered statistically significant. Cohen's kappa coefficient was calculated for intra- and inter-observer variability. IBM SPSS Statistics 29 was used for statistical analysis.

Results

MN level changes were evident only during flexion, but not during extension of the wrist (active and/or passive). MN level changes occurred in 84% (27/32) of the subjects. In 16% (5/32), no MN level change could be observed. When reaching the neutral wrist posture (baseline position), the MN returned to a position above the flexor

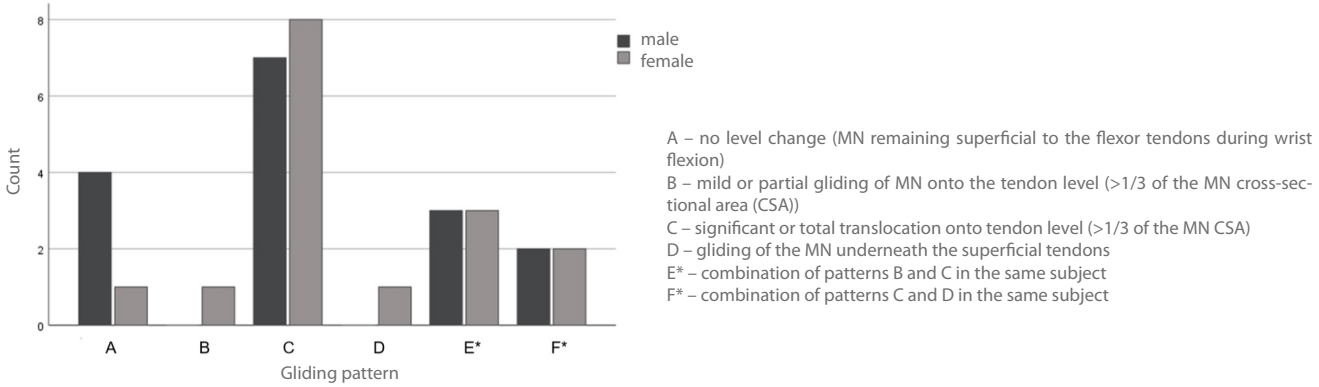

Fig. 7. *Median nerve: gliding patterns during movement from neutral wrist position to maximum flexion in individual subjects* (n = *32)*

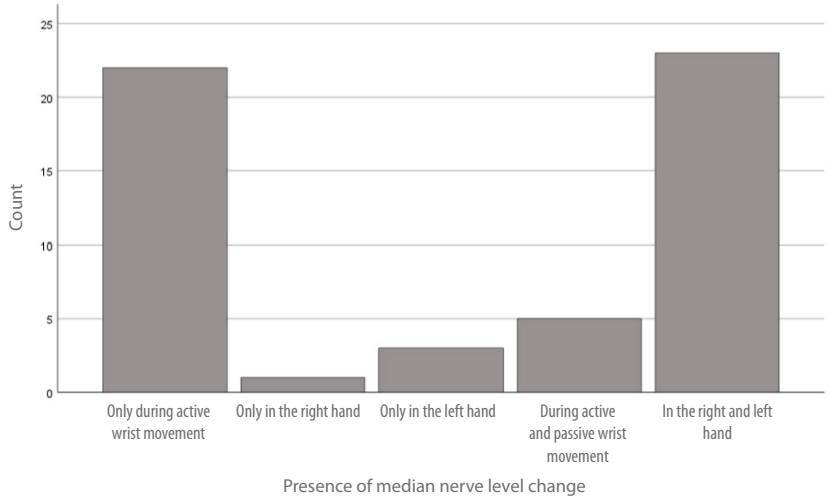

Fig. 8. *Median nerve: presence of level change in individual subjects* (n = *32)*

tendons in all cases. In most individuals, gliding of the entire nerve cross-section onto the tendon level (25/27; 93%) (pattern C) was observed (Fig. 7). There was no significant difference between men and women in the distribution of the gliding patterns of the MN (Fisher's exact test; p >0.05) (Fig. 7). The following gliding pattern was distinctive as the most common: gliding of the entire nerve in between the flexor tendons (pattern C) in active but not in passive movement (13/27; 48%) of the right and left wrists. In all individuals with a bilateral bifid MN (3/32; 9%; two women, one man), both nerve bundles followed this exact pattern as well.

A gender-based comparison revealed a similar prevalence of MN level change. MN level change occurred in 12 men (12/16; 75%) and in 15 women (15/16; 94%) (Fisher's exact test; p >0.05).

Gliding of the MN in both hands (23/27; 85%) occurred significantly more often (Fisher's exact test; p <0.001) than MN gliding in only one hand (4/27; 15%). One-sided nerve gliding was observed in the right hand in one case, and gliding only in the left hand occurred in three cases (Fig. 8). All cases of one-sided nerve gliding were evident in right-handed individuals and always occurred during active wrist alignment.

A level change could be observed more often during active flexion (27/27; 100%) than during passive flexion of the wrist (6/27; 22%) (Fisher's exact test; p <0.001) (Fig. 8). A level change during active as well as passive wrist alignment in the right as well as the left hand was noted in three subjects (3/27; 11%).

The median absolute vertical displacement of the MN was 4 mm (IQR = 3–5 mm; min. 1 mm; max. 8 mm).

There was no significant difference in the absolute vertical displacement of the MN between men (4 mm; IQR = 3–4 mm) and women (4 mm; IQR = 3–5 mm) (Mann–Whitney U test; Z = –9.36; p >0.05).

The extent of vertical displacement was dependent on whether gliding appeared in only one (2 mm; IQR = 2–3 mm) or in both hands (4 mm; IQR = 3–5 mm) (Mann–Whitney U test; Z = –2.5; p = 0.012). There was a significant positive correlation of the vertical MN displacement between the two hands in the same subject (Spearman; R = 0.638; p <0.001). The extent of vertical displacement in the right hand (4 mm; IQR = 2–4 mm) was slightly different from the extent of vertical displacement in the left hand (4 mm; IQR = 4–5 mm) within the same subjects of the mostly right-handed study population (Wilcoxon signed-rank test; p = 0.013).

The extent of vertical displacement did not differ significantly between active (5 mm; IQR = 4–6 mm) and passive (4 mm; IQR = 3–6 mm) wrist movements in the same subject (Wilcoxon signed-rank test; p >0.05) or between subjects (active: 4 mm; IQR = 3–5 mm and passive: 4 mm; IQR = 3–6 mm) (Mann–Whitney U test; p >0.05). Therefore, the frequency of occurrence, but not the extent of gliding, differed for active and passive movement of the wrist. There was a significant difference in the vertical displacement between cases with gliding pattern B (2 mm; IQR = 2–4 mm), pattern C (4 mm; IQR = 3–4 mm) and pattern D (6 mm; IQR = 6–7 mm) (Kruskal–Wallis test; p = 0.022 (B/C); p <0.001 (B/D, C/D). Further detailed information regarding both hands (n = 64) cumulatively is listed in Tab. 2, Tab. 3, and Tab. 4.

The results showed good inter-observer agreement (κ = 0,82; p <0.001). Intra-observer agreement (κ = 0.82 and κ = 0.87; p <0.001) indicated consistent evaluations by individual raters. Cohen's kappa

Tab. 2. Gliding patterns in active and passive wrist flexion of both hands cumulatively (n = 64)

Wrist movement	Pattern A	Pattern B	Pattern C	Pattern D
Active flexion	12/64 8 men / 4 women	7/64 2 men / 5 women	39/64 21 men / 18 women	6/64 1 man / 5 women
Passive flexion	55/64 29 men / 26 women	1/64 1 man / 0 women	5/64 1 man / 4 women	3/64 1 man / 2 women
A – no level change (MN remaining superficial to the flexor tendons during wrist flexion) B – mild or partial gliding of MN onto the tendon level (>1/3 of the MN cross-sectional area (CSA)) C – significant or total translocation onto tendon level (>1/3 of the MN CSA) D – gliding of the MN underneath the superficial tendons				

Tab. 3. Distribution of gliding patterns in active wrist flexion between the right and left hands in 32 individuals (n = 32)

Left/Right	Pattern A	Pattern B	Pattern C	Pattern D
Pattern A	4/32 3 men / 1 woman	1/32 0 men / 1 woman	2/32 2 men / 0 women	0
Pattern B	1/32 0 men / 1 woman	0	3/32 0 men / 3 women	0
Pattern C	0	2/32 2 men / 0 women	15/32 8 men / 7 women	1/32 0 men / 1 woman
Pattern D	0	0	1/32 1 man / 0 women	2/32 0 men / 2 women

A – no level change (MN remaining superficial to the flexor tendons during wrist flexion)
B – mild or partial gliding of MN onto the tendon level (>1/3 of the MN cross-sectional area (CSA))
C – significant or total translocation onto tendon level (>1/3 of the MN CSA)
D – gliding of the MN underneath the superficial tendons

Tab. 4. Distribution of gliding patterns in passive wrist flexion between the right and left hands in 32 individuals (n = 32)

Left/Right	Pattern A	Pattern B	Pattern C	Pattern D
Pattern A	26/32 14 men / 12 women	1/32 1 man / 0 women	1/32 0 men / 1 woman	0
Pattern B	0	0	0	0
Pattern C	1/32 0 men / 1 woman	0	1/32 0 men / 1 woman	0
Pattern D	0	0	1/32 1 man / 0 women	1/32 0 men / 1 woman

A – no level change (MN remaining superficial to the flexor tendons during wrist flexion)
B – mild or partial gliding of MN onto the tendon level (>1/3 of the MN cross-sectional area (CSA))
C – significant or total translocation onto tendon level (>1/3 of the MN CSA)
D – gliding of the MN underneath the superficial tendons

coefficient was used. None of the evaluators had to exclude any study participants because of insufficient image quality.

Discussion

Most of the young healthy volunteers showed MN level changes in both hands during the maximum wrist flexion. The finding aligns with previous research suggesting that the presence of loose connective tissue surrounding the MN in the carpal tunnel of healthy individuals leads to greater dorso-palmar movement ability, especially during wrist flexion[9] than in patients with CTS. During the translocation in between and underneath the flexor tendons, the MN shows highly flexible adaptation (deformation) in healthy individuals, as depicted exemplarily in Fig. 4. In contrast, inflammation, hypertrophy[11], and progressive fibrosis[12]the most common findings are fibrosis of the subsynovial connective tissue (SSCT of the connective tissue surrounding the MN in conditions such as carpal tunnel syndrome (CTS) can restrict MN deformation during wrist movement, as illustrated by Wang *et al.*[10] and, therefore, might affect the MN level change as well. Further studies exploring level changes in conditions such as CTS may provide additional insights into MN bio-kinematics in affected wrists.

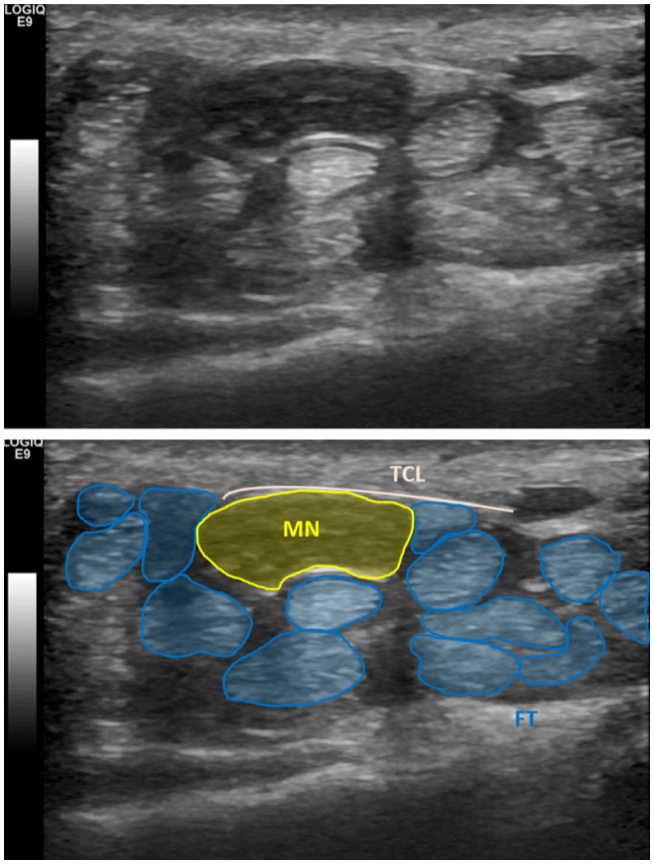

Fig. 9. *Wrist in maximum flexion: MN in CTS patient. MN – median nerve; FT – flexor tendons; TCL – transverse carpal ligament. Note for comparability: an 18 MHz linear transducer was used here, whereas a 15 MHz linear transducer was used in the other cases*

In this study, we found that level changes of the MN occurred predominantly during active rather than passive wrist flexion. This is an interesting aspect of the study, as it seems to be contrary to one of our previous research papers[12] looking at the changes in the cross-sectional area (CSA) of the MN during active and passive wrist movements. Our prior research work showed a similar CSA increase of the MN in the proximal carpal tunnel in healthy volunteers during wrist flexion regardless of the active/passive alignment. Due to the similarly increased CSA and associated space requirements of the MN in the carpal tunnel, we originally expected comparable gliding patterns in the active and passive wrist alignment, creating a sufficient space within the carpal tunnel for the MN.

Furthermore, we predominantly observed a specific gliding pattern (pattern C), during active wrist movement but not during passive wrist movement, where the entire nerve cross-section glides onto the tendon level. This was observed in both hands. The evidence of a predominant gliding pattern (pattern of level change) in healthy individuals aligns with previous research efforts with the objective of finding typical MN displacements in healthy individuals and CTS patients in

various settings and movement protocols, such as Liong *et al.*[13]. Figure 9 exemplarily illustrates a CTS patient's wrist and might serve as a point of departure for future research. Comparative studies are required to investigate the potential applicability of MN level change at the wrist as a future diagnostic criterion in everyday clinical practice for distinguishing between the healthy and affected median nerves, such as those in CTS patients, using DHRUS. The limitations of this study include a relatively small and homogeneous (young, healthy, and mostly right-handed) study cohort. Therefore, the generalizability of the results must be considered with caution, and comparisons between right-handed and left-handed subjects as well as across different age groups need to be done. However, because of the young study cohort, this study may provide a starting point for longitudinal observations to evaluate the evolution of nerve gliding behavior with increasing age and determine the possible onset of pathology.

We did not use a device to keep the transducer in the same position, as done by Nanno *et al.*[14]. Since the MN runs a long distance in the forearm, it would not seem reasonable to observe a nerve level change over only a very particular and short distance. A possible limitation of the present study is that, in contrast to some previous studies[15], no fixed landmarks were used for the measurement of vertical MN displacement, which may have introduced some measurement error[16].

Conclusions

In conclusion, this study provides evidence for a consistent pattern of MN level change in relation to the flexor tendons in young and healthy individuals. This finding adds to the current understanding of the bio-kinematics of the MN in the carpal tunnel and may have implications for the diagnostic criteria in clinical practice. Further research needs to be done to determine whether similar gliding patterns in relation to the flexor tendons can also be observed in pathological conditions such as CTS. While this study provides valuable insights into the normal level changes of the median nerve in healthy individuals, it might also serve as a foundation for future studies comparing these findings to affected wrists, including those with CTS. Long-term observations and comparisons will be crucial in enhancing our understanding of the pathophysiology and diagnostic potential of level changes in various wrist conditions.

Conflict of interest

All authors declare no conflicts of interest. No funding was received for this study.

Author contributions

Original concept of study: SAJ. Writing of manuscript: SAJ, LL. Analysis and interpretation of data: SAJ, LL. Final approval of manuscript: SAJ, GK, ED, VM, ŽS, GB. Collection, recording and/or compilation of data: LL. Critical review of manuscript: SAJ, GK, ED, VM, ŽS, GB.

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